Corporate Average Fuel Economy Standards
Model Years 2024–2026

Draft Supplemental Environmental Impact Statement

August 2021

Docket No. NHTSA-2021-0054

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

Draft Supplemental Environmental Impact Statement for Model Year 2024–2026 Corporate Average Fuel Economy Standards

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 Supplemental Environmental Impact Statement (Draft SEIS) analyzes the environmental impacts of fuel economy standards and reasonable alternative standards for model year (MY) 2024–2026 passenger cars and light trucks. NHTSA has proposed these 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 SEIS 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 motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy," as required by 49 United States Code (U.S.C.) § 32902(f).

Public Comment Period

EPA will publish a Notice of Availability of this Draft SEIS 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 https://www.nhtsa.gov/laws-regulations/corporate-average-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-2021-0054. 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-2021-0054. Comments may also be submitted by fax to (202) 493-2251. Any announcements about public hearings will be made available at https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy and in a *Federal Register* notice.

NHTSA will simultaneously issue the Final SEIS and Record of Decision, pursuant to 49 U.S.C. § 304a(b) and U.S. Department of Transportation *Final Guidance on the Use of Combined Final Environmental Impact Statements/Records of Decision and Errata Sheets in National Environmental Policy Act Reviews* (https://www.transportation.gov/transportation-policy/permittingcenter/guidance-use-combined-feisrod-and-errata-sheets-nepa-reviews) unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.

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Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
$\mu g/m^3$	micrograms per cubic meter
ABS	auto body sheet
AC	air conditioning
ACC	Advanced Clean Car
AEF	average emission factor
AEO	Annual Energy Outlook
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AHS	American Housing Survey
AMOC	Atlantic Meridional Overturning Circulation
ANL	Argonne National Laboratory
AOGCM	atmospheric-ocean general circulation model
ASTM	American Society for Testing and Materials
BEV	battery electric vehicle
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	CO_2 System Calculations
Diesel HAD	2002 Diesel Health Assessment Document
DNA	deoxyribonucleic acid
DOE	U.S. Department of Energy
DOT	U. S. Department of Transportation
DPM	diesel particulate matter
E85	flex fuel
E/GDP	energy-gross domestic product
eGRID	EPA Emissions & Generation Resource Integrated Database
EIA	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
ESA	Endangered Species Act
EV	electric vehicle
FCV	fuel cell electric vehicle
FHWA	Federal Highway Administration
FRIA	Final Regulatory Impact Analysis
g CO_2e/MJ	grams of carbon dioxide equivalent per megajoule of energy
g CO_2e/MMBtu	grams of carbon dioxide equivalent per million British thermal units
g/mi	gallons per mile
GCAM	Global Climate Change Assessment Model
GCM	general circulation model
GCRP	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
GSL	general service lamp
Gt	gigatons
GWP	global warming potential
HD	heavy-duty
HEV	hybrid-electric vehicle
HFCs	hydrofluorocarbons
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
km^2	kilometers squared
kt	kilotonne
kWh	kilowatt-hour

LABs	lead-acid batteries
LCA	life-cycle assessment
LFP	LiFePO4
LMO	LiMn2O4
LPG	liquefied petroleum gas
MAGICC	Model for the Assessment of Greenhouse-Gas Induced Climate Change
MEF	marginal emission factor
mg/m^3	milligrams per cubic meter of air
mm	millimeters
MMbtu	million British thermal units
$MMTCO_2$	million metric tons of carbon dioxide
$MMTCO_2e$	million metric tons of carbon dioxide equivalent
MOVES	Motor Vehicle Emission 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
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NCA	National Climate Assessment
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
NMC	LiNi0.4Mn0.4Co0.2O2
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSPS	New Source Performance Standards
objECTS	Object-Oriented Energy, Climate, and Technology Systems
ODS	Ozone-Depleting Substance
PEV	plug-in electric vehicle

pH	potential of hydrogen
PHEV	plug-in hybrid electric vehicle
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
Preferred Alternative	Alternative 2
PRIA	Preliminary Regulatory Impact Analysis
quads	quadrillion Btu
RCP	Representative Concentration Pathway
RF	radiative forcing
RFS2	Renewable Fuel Standard 2
RGGI	Regional Greenhouse Gas Initiative
RIA	Regulatory Impact Analysis
SAFE	Safer Affordable Fuel-Efficient
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	oxides of sulfur
SPR	Strategic Petroleum Reserve
TS&D	transportation, storage, and distribution
TSD	Technical Support Document
TTI	travel time index
TWBs	Tailor-welded blanks
UNFCCC	United Nations Framework Convention on Climate Change and the annual Conference of the Parties
U.S.C.	U.S. Code
UV	ultraviolet
VMT	vehicle miles traveled
VOCs	volatile organic compounds
VRFBs	Vanadium redox flow batteries
WG1	Working Group 1
WRI	World Resources Institute

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.
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.
flex fuel or E85	An ethanol-gasoline fuel blend containing 51 to 83 percent ethanol fuel, depending on geography and season. (Source: https://www.fueleconomy.gov/feg/ethanol.shtml)
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 including 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.

Term	Definition
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.
heat rate	The amount of energy (BTUs) used to generate one kilowatt-hour of electricity
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.
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.
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).

Term	Definition
passenger cars and light trucks	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. Also referred to as *light-duty vehicles*.
particulate matter (PM)	Discrete particles that include dust, dirt, soot, smoke, and liquid droplets directly emitted into the air.
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 supplemental environmental impact statement (SEIS) 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) 2024 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.[1]

This SEIS compares the potential environmental impacts of four alternatives for setting fuel economy standards for MY 2024–2026 passenger cars and light trucks (three action alternatives and the No Action Alternative). This SEIS 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.

In 2018, NHTSA issued a notice of proposed rulemaking (NPRM) in which the agency proposed revising the MY 2021 light-duty fuel economy standards and issuing new fuel economy standards for MYs 2022–2026.[2] In the 2020 SAFE Vehicles Final Rule, NHTSA amended fuel economy standards for MY 2021 and

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[1] Because this SEIS is a continuation of a NEPA process that began before the effective date of a 2020 Council on Environmental Quality (CEQ) rule that amended the NEPA implementing regulations (September 14, 2020), NHTSA will apply the NEPA implementing regulations that were in effect prior to that date.

[2] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks; Notice of Proposed Rulemaking, 83 FR 42986 (Aug. 24, 2018) (hereinafter “SAFE Vehicles NPRM”).

established standards for MYs 2022–2026 that would increase in stringency at 1.5 percent per year from 2020 levels. Concurrent with the SAFE Vehicles Final Rule, NHTSA issued a Final EIS on March 31, 2020.[3]

On January 20, 2021, President Biden issued Executive Order (EO) 13990, *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*,[4] which directed NHTSA to consider publishing for notice and comment a proposed rule suspending, revising, or rescinding the SAFE Vehicles Final Rule by July 2021. Pursuant to EO 13990, NHTSA is proposing to amend the CAFE standards for MY 2024–2026 passenger cars and light trucks in an NPRM.

To inform its development of the CAFE standards for MYs 2024–2026, NHTSA prepared this SEIS, pursuant to NEPA,[5] to evaluate the potential environmental impacts of a reasonable range of alternatives the agency is considering. 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).[6] In revising the CAFE standards established in the SAFE Vehicles Final Rule, NHTSA is proposing to make substantial changes to the proposed action examined in the SAFE Vehicles Rule Final EIS and, as such, prepared this SEIS to inform its amendment of MY 2024–2026 CAFE standards.[7] Because this SEIS is a continuation of a NEPA process that began before the effective date of a 2020 CEQ rule that amended the NEPA implementing regulations,[8] NHTSA will continue to apply the NEPA implementing regulations that were in effect prior to that date.[9] This SEIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of alternatives, including a No Action Alternative and a Preferred Alternative, and discusses impacts in proportion to their significance. NHTSA is issuing this Draft SEIS concurrently with the NPRM.

Purpose and Need for the Action

In accordance with EPCA, as amended by EISA, and EO 13990, the purpose of NHTSA's rulemaking is to amend fuel economy standards for MY 2024–2026 passenger cars and light trucks to reflect "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year." When determining the maximum feasible levels that manufacturers can achieve in each model year, EPCA requires that 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

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[3] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021–2026 Passenger Cars and Light Trucks Final Environmental Impact Statement (March 2020) (hereinafter "SAFE Vehicles Rule Final EIS"). Available at: https://www.nhtsa.gov/corporate-average-fuel-economy/safe.

[4] Executive Order 13990, Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis, 86 FR 7037 (Jan. 25, 2021).

[5] 42 U.S.C. §§ 4321–4347.

[6] 42 U.S.C. § 4332.

[7] *See* 40 CFR § 1502.9(c)(1)(i) (2019).

[8] Update to the Regulations Implementing the Procedural Provisions of the National Environmental Policy Act; Final Rule, 85 FR 43304 (Jul. 15, 2020).

[9] 40 CFR § 1506.13 (2020) (specifying that the new NEPA implementing regulations apply to any NEPA process begun after September 14, 2020).

addition, when determining the maximum feasible levels, the agency considers relevant safety and environmental factors.

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."

Proposed Action and Alternatives

NHTSA's 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 CAFE standards and alternatives under NEPA. NHTSA is establishing CAFE standards for MY 2024–2026 passenger cars and light trucks.

NHTSA has analyzed a range of action alternatives with fuel economy stringencies that increase annually, on average, 6 to 10 percent from MY 2024–2026 for passenger cars and for light trucks (depending on alternative). 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. This proposal is different than the conclusion that NHTSA reached in the 2020 SAFE Vehicles Final Rule because NHTSA has reconsidered how to balance relevant statutory considerations. As discussed further in the preamble to the proposed rule, the proposal responds to the President's direction in EO 13990, and also responds to the agency's statutory mandate to improve energy conservation to insulate our nation's economy against external factors and reduce environmental degradation associated with petroleum consumption.

The No Action Alternative (also referred to as Alternative 0 in tables and figures) assumes that the MY 2021–2026 CAFE standards established in the SAFE Vehicles Final Rule remain unchanged. In addition, the No Action Alternative assumes that the MY 2026 SAFE Vehicles Final Rule standards continue to apply for MY 2027 and beyond. 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 three action alternatives, Alternatives 1 through 3, which would require average annual increases in fuel economy ranging from 6 percent for passenger cars and light trucks (Alternative 1) to 10 percent for passenger cars and light trucks (Alternative 3) from MY 2024–2026. These action alternatives are as follows:

- **Alternative 1.** Alternative 1 would require a 10.5 percent increase for MY 2024 over MY 2023 and a 3.26 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2025–2026.
- **Alternative 2**. Alternative 2 (Preferred Alternative/Proposed Action) would require an 8.0 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2024–2026.
- **Alternative 3.** Alternative 3 would require a 10.0 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2024–2026.

For purposes of 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.

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
Projected required mpg				
MY 2024	38.1	41.8	40.7	41.6
MY 2025	38.8	43.3	44.3	46.2
MY 2026	39.4	44.7	48.1	51.3

Notes:
mpg = miles per gallon; MY = model year

The range under consideration in the alternatives encompasses 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 SEIS 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 6 to 10 percent. 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 greenhouse gas (GHG) emissions.

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 SEIS, 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 Appendix A, *U.S. Passenger Car and Light Truck Results Reported Separately*. Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies,* 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, noise, environmental justice, and safety impacts on human health.

The impacts on energy use, air quality, and climate include *direct*, *indirect*, and *cumulative impacts.*[10] 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

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[10] 40 CFR § 1508.8 (2019).

absence of any regulatory action as discussed above. The No Action Alternative for this SEIS assumes that the MY 2021–2026 CAFE standards established in the SAFE Vehicles Final Rule remain unchanged. All alternatives assume the MY 2026 standards would continue indefinitely. Because EPCA, as amended by EISA, requires NHTSA to set CAFE standards for each model year, environmental impacts would also depend on future standards established by NHTSA but cannot be quantified at this time.

Energy

NHTSA's final 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 2020, petroleum supplied 91 percent of transportation energy demand, and in 2050, petroleum is expected to supply 86 percent of transportation energy demand. Transportation accounts for the largest share of total U.S. petroleum consumption. In 2020, the transportation sector accounted for 78.9 percent of total U.S. petroleum consumption. In 2050, transportation is expected to account for 76.9 percent of total U.S. petroleum consumption.[11]

With transportation expected to account for 76.9 percent of total petroleum consumption, U.S. net petroleum imports in 2050 are expected to result primarily from fuel consumption by light-duty and heavy-duty vehicles. The United States became a net energy exporter in 2019 for the first time in 67 years 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 SEIS 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 2024–2026 or later vehicles. This table reports total 2020 to 2050 fuel consumption in gasoline gallon equivalents (GGE) for diesel, gasoline, electricity, hydrogen, and biofuel for cars and light trucks.

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

Gasoline is expected to account for 96 percent of energy consumption by passenger cars and light trucks in 2050.

Table S-2. Fuel Consumption and Decrease 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
Fuel Consumption				
Cars	1,396	1,339	1,295	1,259
Light trucks	2,114	2,070	2,049	2,023
All light-duty vehicles	3,510	3,409	3,344	3,282
Decrease in Fuel Consumption Compared to the No Action Alternative				
Cars		-56	-101	-136
Light trucks		-44	-65	-91
All light-duty vehicles		-100	-166	-227

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 3,510 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the Proposed Action and alternatives is projected to range from 3,409 billion GGE under Alternative 1 to 3,282 billion GGE under Alternative 3. All of the action alternatives would decrease fuel consumption compared to the No Action Alternative, with fuel consumption decreases that range from 100 billion GGE under Alternative 1 to 227 billion GGE under Alternative 3.

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, the U.S. Environmental Protection Agency (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 in the atmosphere 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 emitting 17.2 million tons[12] per year of CO (25 percent of total U.S. emissions), 90,000 tons per year (1 percent) of PM2.5 emissions, and 216,000 tons per year (1 percent) of PM10 emissions. 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. 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 1.4 million tons per year (8 percent of total nationwide emissions) of VOCs and 2.4 million tons per year (29 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 0.5 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

This SEIS provides findings for air quality impacts for 2025, 2035, and 2050. In general, emissions of criteria air pollutants decrease across all alternatives in later years (i.e., 2035 and 2050), with some exceptions. The changes in emissions are small in relation to total criteria pollutant emissions levels during this period and, overall, the health outcomes due to changes in criteria pollutant emissions through 2050 are projected to be beneficial. The directions and magnitudes of the changes in total

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[12] These tons are U.S. tons (2,000 pounds).

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 (which also reflect the assumption of increased adoption of plug-in electric vehicles [PEVs] after 2035), the relative proportions of gasoline, diesel, and other fuels in total fuel consumption changes, and changes in vehicle miles traveled from the rebound effect. Other CAFE Model inputs and assumptions, which are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and at length in the proposed rule preamble, Technical Support Document, and Preliminary Regulatory Impact Analysis (PRIA) issued concurrently with this Draft SEIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates. It is important to stress that changes in these assumptions would alter the air pollution estimates. For example, if NHTSA has overestimated the rebound effect, then emissions would be lower; if NHTSA has underestimated the rebound effect, then emissions would be higher. These are estimates and should be viewed as such. In addition, the action alternatives would result in decreased incidence of PM2.5-related adverse health impacts in most years and alternatives due to the emissions decreases. Decreases in adverse health outcomes include decreased 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 all criteria pollutants in 2025, emissions increase under the action alternatives compared to the No Action Alternative. The emission increases generally get larger from Alternative 1 through Alternative 3 (the most stringent alternative in terms of required miles per gallon). These increases are quite small—all less than 1 percent—and could be affected by the assumptions in the model.
- In 2025, across all criteria pollutants and action alternatives, the smallest increase in emissions is 0.01 percent and occurs for VOCs under Alternative 2; the largest increase is 0.6 percent and occurs for SO_2 under Alternative 3.
- In 2035 and 2050, emissions of CO, NO_X, PM2.5, and VOCs generally decrease under the action alternatives compared to the No Action Alternative, except for CO in 2035 under Alternative 1 (0.07 percent increase) and NO_X in 2035 under Alternative 3 (0.5 percent increase), with the more stringent alternatives having the largest decreases, except for NO_X and PM2.5 in 2035 (emissions decrease less or increase with more stringent alternatives) and NO_X in 2050 (emissions increase under Alternative 3 relative to Alternative 2). SO_2 emissions generally increase under the action alternatives compared to the No Action Alternative (except in 2035 under Alternative 1), with the more stringent alternatives having the largest increases.
- In 2035 and 2050, across all criteria pollutants and action alternatives, the smallest decrease in emissions is 0.03 percent and occurs for NO_X under Alternative 2; the largest decrease is 11.9 percent and occurs for VOCs under Alternative 3. The smallest increase in emissions is 0.07 percent and occurs for CO under Alternative 1; the largest increase is 4.8 percent and occurs for SO_2 under Alternative 3.

Toxic Air Pollutants

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

- Under each action alternative in 2025 compared to the No Action Alternative, increases in emissions would occur for all toxic air pollutants by up to 0.5 percent, except for DPM, for which emissions would decrease by as much as 0.5 percent. For 2025, the largest relative increases in emissions would occur for benzene and 1,3-butadiene, for which emissions would increase by up to 0.5 percent. Percentage increases in emissions of acetaldehyde, acrolein, and formaldehyde would be lower.
- Under each action alternative in 2035 and 2050 compared to the No Action Alternative, decreases in emissions would occur for all toxic air pollutants, except for acetaldehyde, acrolein, and 1,3-butadiene in 2035 under Alternative 1 where emissions would increase by 0.2, 0.01, and 0.1 percent, respectively, with the more stringent alternatives having the largest decreases, except for benzene (emissions increase in 2035 under Alternative 3 relative to Alternative 2). The largest relative decreases in emissions would occur for formaldehyde, for which emissions would decrease by as much as 10.3 percent. Percentage decreases in emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and DPM would be less.

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.

- In 2025, Alternative 3 would result in small increases in adverse health impacts (mortality, acute bronchitis, respiratory emergency room visits, and other health effects) nationwide compared to the No Action Alternative as a result of increases in emissions of NO_X, PM2.5, and SO_2. Alternative 2 also would result in increased adverse health impacts from mortality and non-fatal heart attacks due to increases in NO_X, PM2.5, and SO_2 emissions, while Alternative 1 would result in decreased adverse health impacts. The more stringent alternatives are associated with the largest increases in adverse health impacts, or the smallest decreases in impacts, relative to the No Action Alternative. This increase results from projected increases in emissions of PM2.5, NO_X, and SO_2 under all action alternatives, which is in turn attributable to shifts in modeled technology adoption from the baseline and to where the rebound effect would not be offset by upstream emissions reductions due to decreases in fuel usage.
- In 2035 and 2050, all action alternatives would result in decreased adverse health impacts nationwide compared to the No Action Alternative as a result of general decreases in emissions of NO_X, PM2.5, and DPM. The decreases in adverse health impacts get larger from Alternative 1 to Alternative 3.

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

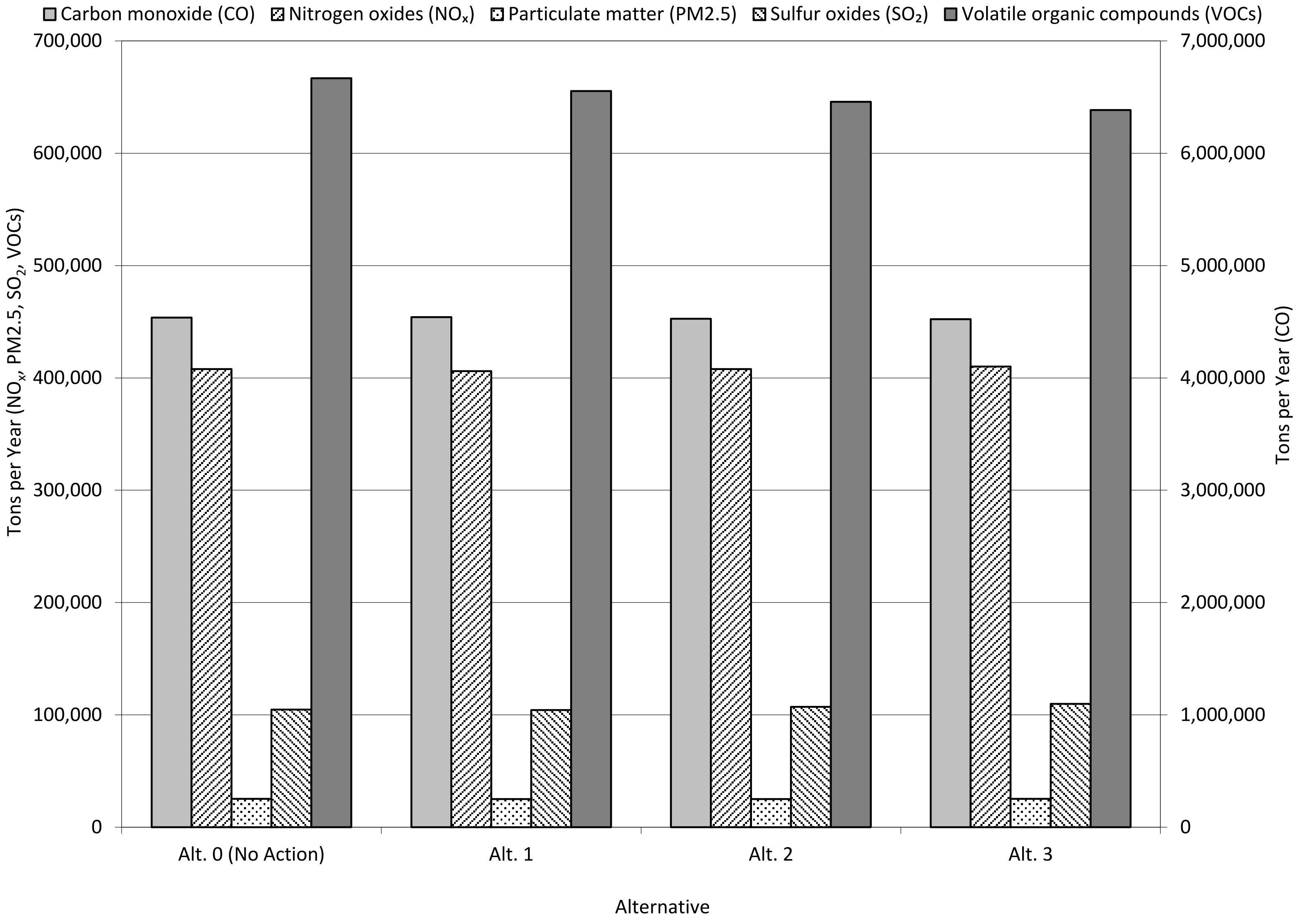
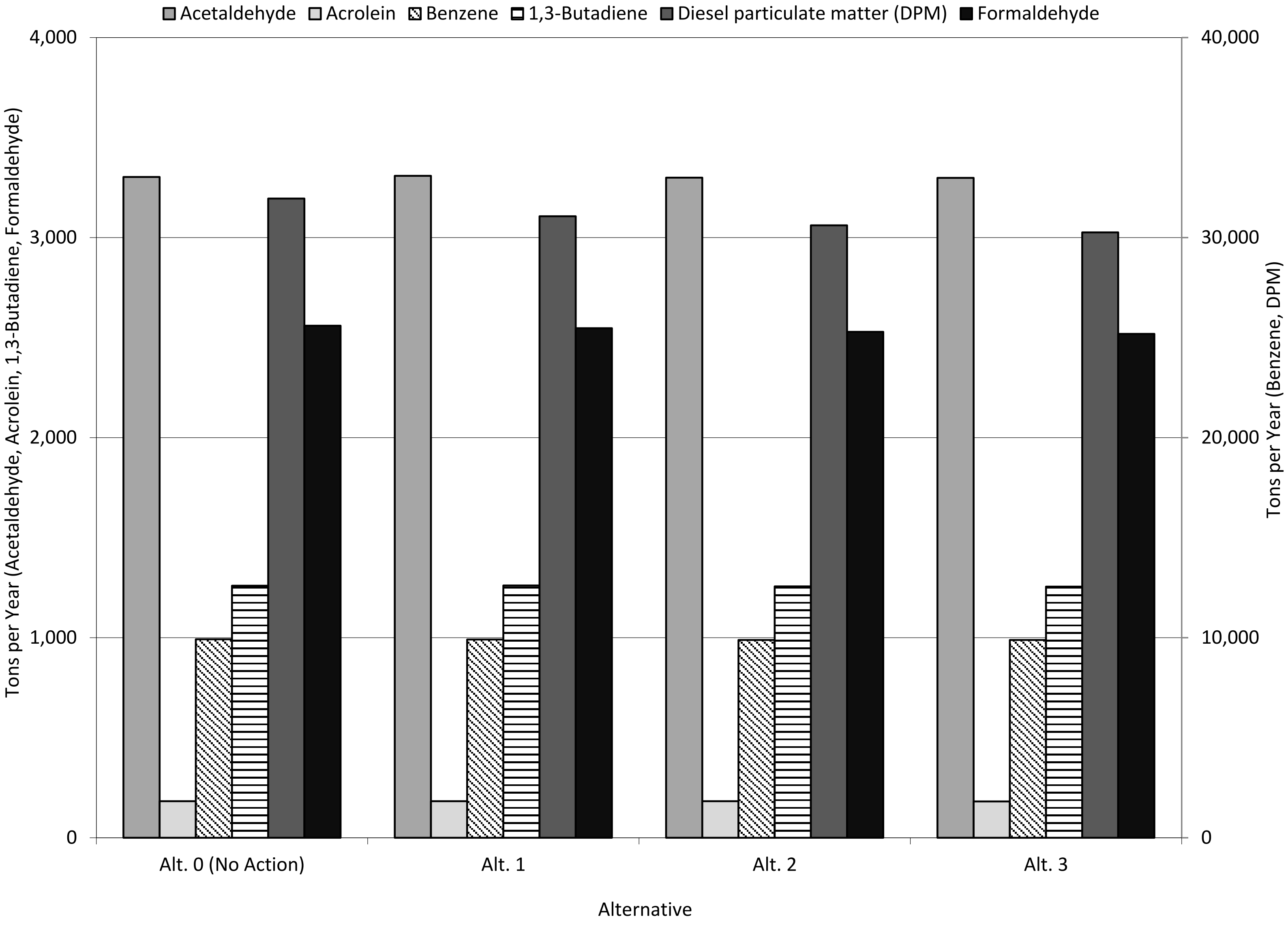


Figure S-2. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2035 by Alternative



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 SEIS, 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 carbon dioxide (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) by absorbing 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 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 degrees Celsius (°C) (1.6 degrees Fahrenheit [°F]) (U.S. Global Change Research Program [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 inch) 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 48.4 percent from approximately 278 parts per million (ppm) in 1750 (before the Industrial Revolution) (IPCC 2013a) to approximately 412 ppm in 2020 (NOAA 2021). 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).

IPCC, GCRP, and other leading groups focused on global climate change have independently concluded that human activity is the main driver for recent observed climatic changes (IPCC 2013a; GCRP 2017). Other observed changes include melting glaciers, diminishing snow cover, shrinking sea ice, ocean acidification, increasing atmospheric water vapor content, changing precipitation intensities, shifting seasons, and many more (GCRP 2017).

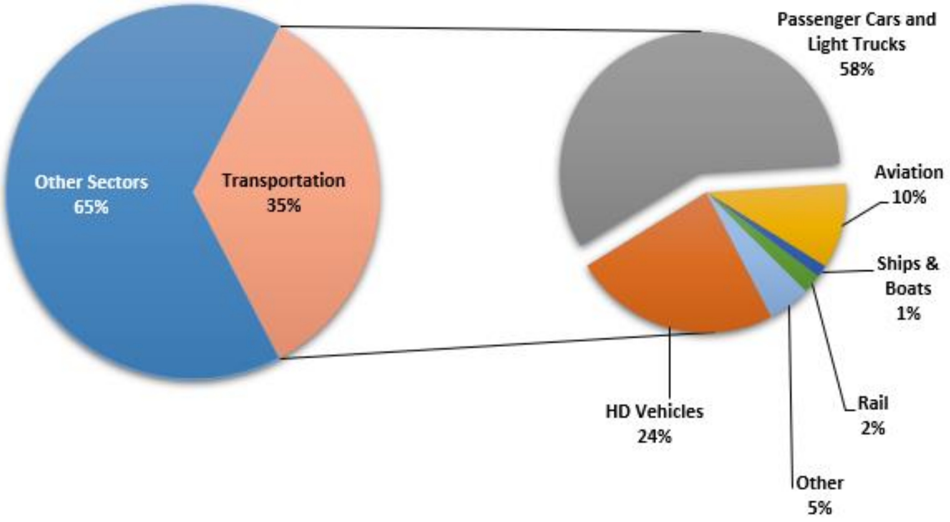
This SEIS draws primarily on panel-reviewed synthesis and assessment reports from IPCC and GCRP, supplemented with past reports from the U.S. Climate Change Science Program (CCSP), the National Research Council, and the Arctic Council.

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 (World Resources Institute [WRI] 2021). 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 WRI's Climate Watch, emissions from the United States account for approximately 14 percent of total global CO_2 emissions.[13] EPA's National Greenhouse Gas Inventory for 1990 to 2019 indicates that, in 2019, the U.S. transportation sector contributed about 35 percent of total U.S. CO_2 emissions, with passenger cars and light trucks accounting for 58 percent of total U.S. CO_2 emissions from transportation. Therefore, approximately 21 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 2018).[14] 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, 2019



Source: EPA 2021a
HD = heavy duty

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[13] The estimate for CO_2 emissions from fossil fuel combustion and industry excludes emissions and sinks from land use change and forestry (WRI 2021).

[14] Ibid.

Key Findings for Climate

The Proposed Action and alternatives would decrease U.S. passenger car and light truck fuel consumption and CO_2 emissions compared with the No Action Alternative, resulting in reductions in the anticipated increases in global CO_2 concentrations, temperature, precipitation, sea level, and ocean acidification that would otherwise occur. They would also, to a small degree, reduce the impacts and risks of climate change.

Estimates of GHG emissions and decreases 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 small in relation to global emissions trajectories. Although these effects are small, they occur on a global scale and are long lasting; therefore, in aggregate, they can have large consequences for health and welfare and can make an important contribution to reducing the risks associated with climate change.

Direct and Indirect Impacts

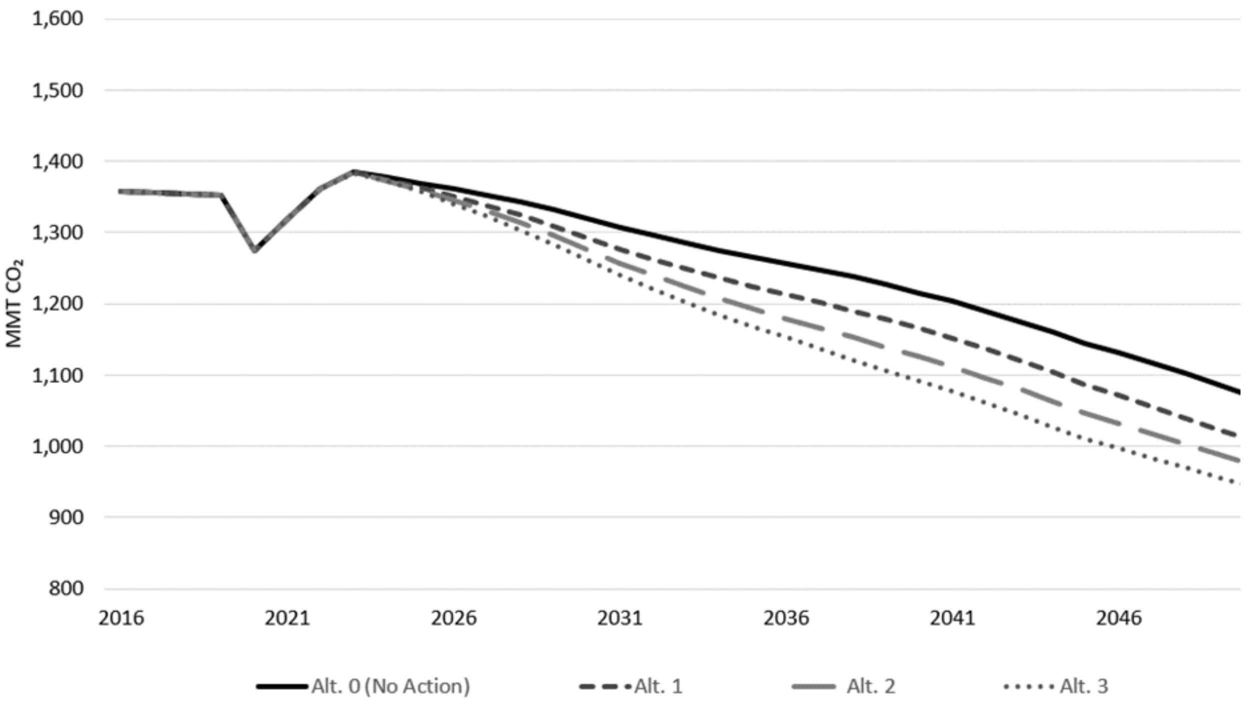
Greenhouse Gas Emissions

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 89,600 million metric tons of carbon dioxide ($MMTCO_2$) from 2021 through 2100 under the No Action Alternative. Alternative 1 would decrease these emissions by 5 percent through 2100. The Preferred Alternative would decrease these emissions by 7 percent through 2100. Alternative 3 would decrease these emissions by 10 percent through 2100. Emissions would be highest under the No Action Alternative, and emission reductions would increase from Alternative 1 to Alternative 3. All CO_2 emissions estimates associated with the Proposed Action and alternatives include upstream emissions.
- Compared with total projected CO_2 emissions of 984 $MMTCO_2$ from all passenger cars and light trucks under the No Action Alternative in the year 2100, the Proposed Action and alternatives are expected to decrease CO_2 emissions from passenger cars and light trucks in the year 2100 from 6 percent under Alternative 1 to 12 percent under Alternative 3. Under the Preferred Alternative, the 2100 total projected CO_2 emissions for all passenger cars and light trucks are 897 $MMTCO_2$, reflecting a 9 percent decrease.
- 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 reduce global CO_2 by 0.08 percent under Alternative 1, 0.13 percent under the Preferred Alternative, and 0.17 percent under Alternative 3 by 2100.
- The emission reductions in 2025 compared with emissions under the No Action Alternative are approximately equivalent to the annual emissions from 1,284,000 vehicles under Alternative 1, 1,631,000 vehicles under the Preferred Alternative, and 2,248,000 vehicles under Alternative 3. (A

total of 253,949,000 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

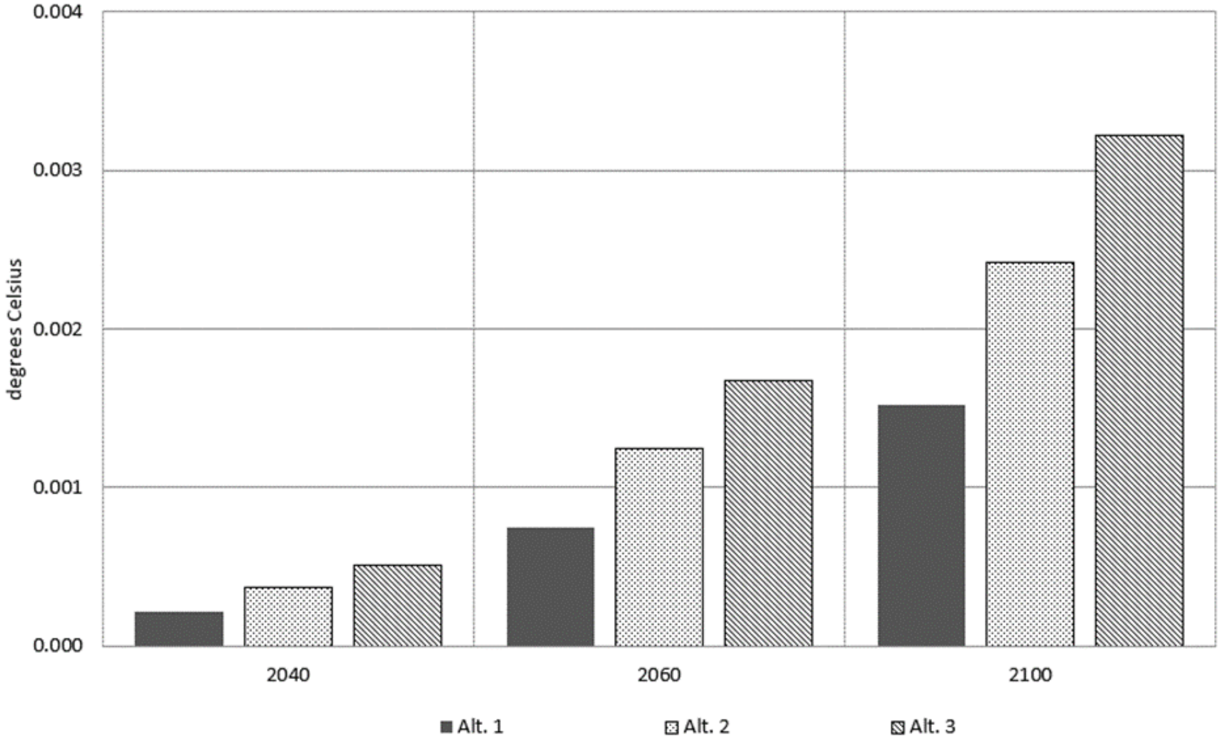
Carbon Dioxide Concentration, Global Mean Surface Temperature, Sea Level, Precipitation, and Ocean pH

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 comprehensive global actions to mitigate GHG emissions).

- Estimated CO$_2$ concentrations in the atmosphere for 2100 would range from 788.33 ppm under Alternative 3 to approximately 789.11 ppm under the No Action Alternative, indicating a maximum atmospheric CO$_2$ decrease of approximately 0.77 ppm compared to the No Action Alternative. Atmospheric CO$_2$ concentration under Alternative 1 would decrease by 0.37 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 most stringent alternative (Alternative 3) would decrease this projected temperature rise by 0.003°C (0.006°F), while implementing Alternative 1 would decrease projected temperature rise by 0.002°C (0.003°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 high of 76.28 centimeters (30.03 inches) under the No Action Alternative to a low of 76.22 centimeters (30.01 inches) under Alternative 3. Alternative 3 would result in a decrease in sea-level rise equal to 0.06 centimeter (0.03 inch) by 2100 compared with the level projected under the No Action Alternative. Alternative 1 would result in a decrease of 0.03 centimeter (0.01 inch) compared with the No Action Alternative.
- Global mean precipitation is anticipated to increase by 5.85 percent by 2100 under the No Action Alternative. Under the action alternatives, this increase in precipitation would be reduced by 0.00 to 0.01 percent.
- Ocean pH in 2100 is anticipated to be 8.2180 under Alternative 3, about 0.0004 more than the No Action Alternative. Under Alternative 1, ocean pH in 2100 would be 8.2178, or 0.0002 more than the No Action Alternative.

Figure S-5. Reductions 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 trends in electric vehicle sales and use. For climate, the analysis reflects actions in global climate change policy to reduce GHG emissions. The cumulative impacts analysis for climate also includes qualitative discussions of the cumulative impacts of climate change on key natural and human resources and the nonclimate effects of CO_2.

Energy

Changes in passenger travel, oil and gas exploration, and the electric grid mix may affect U.S. energy use over the long term. In addition to U.S. energy policy, manufacturer investments in PEV technologies and manufacturing in response to government mandates (including foreign PEV quotas) may affect market trends and energy use.

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, yielding a moderate level of global GHG reductions from the baseline global emissions scenario used in the direct and indirect analysis. The analysis of cumulative impacts also extends to include not only the immediate effects of GHG emissions on the climate system (atmospheric 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, coastal ecosystems).

Greenhouse Gas Emissions

The following cumulative impacts related to GHG emissions are anticipated.

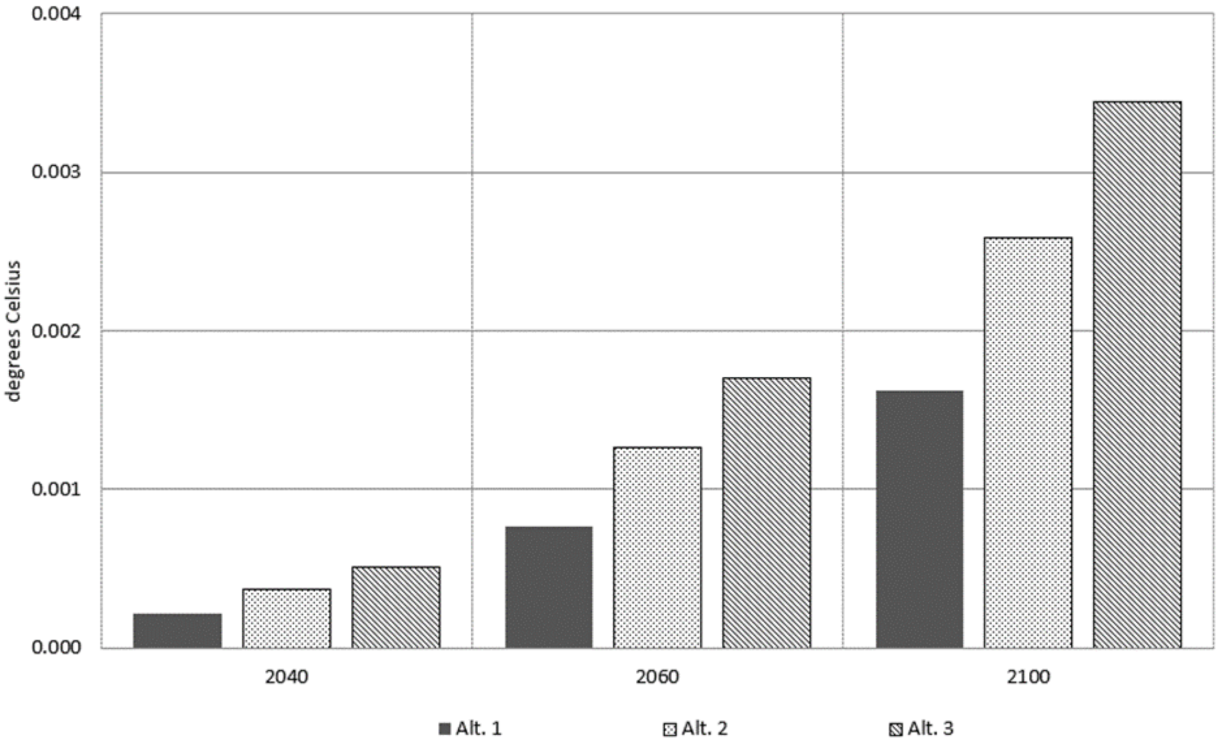
- Projections of total emissions reductions from 2021 to 2100 under the Proposed Action and alternatives and other reasonably foreseeable future actions compared with the No Action Alternative range from 4,100 $MMTCO_2$ (under Alternative 1) to 8,600 $MMTCO_2$ (under Alternative 3). The Proposed Action and alternatives would decrease total vehicle emissions by between 5 percent (under Alternative 1) and 10 percent (under Alternative 3) by 2100.
- 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 decrease global CO_2 emissions between 0.10 (Alternative 1) and 0.21 (Alternative 3) percent by 2100.

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 high of 687.29 ppm under the No Action Alternative to a low of 686.55 ppm under Alternative 3, the lowest CO_2 emissions alternative. This is a decrease of 0.74 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 0.002°C (0.003°F) under Alternative 1 to a high of 0.003°C (0.006°F) under Alternative 3. Figure S-6 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 reduced by 0.00 to 0.01 percent.
- Projected sea-level rise in 2100 ranges from a high of 70.22 centimeters (27.65 inches) under the No Action Alternative to a low of 70.15 centimeters (27.68 inches) under Alternative 3, indicating a maximum increase of sea-level rise of 0.07 centimeter (0.03 inch) by 2100. Sea-level rise under Alternative 1 would be 70.19 centimeters (27.66 inches), a 0.03-centimeter (0.01-inch) increase compared to the No Action Alternative.
- Ocean pH in 2100 is anticipated to be 8.2727 under Alternative 3, about 0.004 more than the No Action Alternative. Under Alternative 1, ocean pH in 2100 would be 8.2725, or 0.0002 more than the No Action Alternative.

Figure S-6. Reductions 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 would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. The magnitude of the changes in climate effects that would be produced by the most stringent action alternative (Alternative 3) by the year 2100 is roughly a 0.7 ppm lower concentration of CO_2, three thousandths of a degree increase in temperature rise, a small percentage change in the rate of precipitation increase, a 0.07 centimeter (0.03 inches) decrease in sea-level rise, and an increase of 0.0004 in ocean pH. Although the projected reductions in CO_2 and climate effects are small compared with total projected future climate change, they are quantifiable, directionally consistent, and would represent an important contribution to reducing the 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 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, CCSP, the National Research Council, and the Arctic Council, among others. While the action alternatives would decrease growth in GHG emissions and reduce the impact of climate change across resources relative to the No Action Alternative, they would not prevent climate change and associated impacts. Long-term climate change impacts identified in the scientific literature are briefly summarized below, and vary regionally, including in scope, intensity, and directionality (particularly for precipitation). While it is difficult to attribute any particular impact to emissions resulting from this ruling, impacts are likely to be beneficially affected to some degree by reduced emissions from the action alternatives.

- Impacts on freshwater resources could include changes in rainfall and streamflow patterns, warming temperatures and reduced snowpack, changes in water availability paired with increasing water demand for irrigation and other needs, and decreased water quality from increased algal blooms. Inland 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 inundation, 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 and agriculture, including yields, food processing, storage, and transportation, could affect food prices, socioeconomic conditions, 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), air quality, and safety. The impacts could be greater for vulnerable populations such as lower-income populations, historically underserved populations, some communities of color and tribal and Indigenous communities, 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, those experiencing discrimination, historically underserved populations, some communities of color and tribal and Indigenous communities, and low-income populations are especially vulnerable and may experience disproportionate health impacts.
- 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. Compound events consist of two or more extreme weather events occurring simultaneously or in sequence when underlying conditions associated with an initial event amplify subsequent events and, in turn, lead to more extreme impacts. To the extent the action alternatives would result in reductions in projected increases in global CO_2 concentrations, this rulemaking would contribute to reducing the risk of compound events.

CHAPTER 1 PURPOSE AND NEED FOR THE 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.[4]

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,[5] MY 2012–2016 passenger cars and light trucks,[6] MY 2017 and beyond passenger cars and light trucks,[7] and MY 2021–2026 passenger cars and light trucks.[8] NHTSA also established, pursuant to EISA, fuel efficiency standards for medium- and heavy-duty vehicles for MYs 2014–2018 (HD Fuel Efficiency Improvement Program Phase 1)[9] and MYs 2018–2027 (Phase 2).[10] Because reducing fuel use also reduces greenhouse gas (GHG) emissions from

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[1] Public Law (Pub. L.) No. 94-163, 89 Stat. 871 (Dec. 22, 1975). EPCA was enacted for purposes that include conserving energy supplies through energy conservation programs and improving the energy efficiency of motor vehicles.

[2] The Secretary of Transportation has delegated the responsibility for implementing the CAFE program to NHTSA (49 Code of Federal Regulations (CFR) § 1.95(a)). Accordingly, the Secretary, 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] Passenger cars and light trucks that meet these criteria are also referred to as light-duty vehicles. The terms *passenger car, light truck,* and *medium-duty passenger vehicle* are defined in 49 CFR Part 523.

[5] 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]).

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

[7] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule, 77 FR 62624 (Oct. 15, 2012).

[8] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks; Final Rule, 85 FR 24174 (Apr. 30, 2020) (hereinafter "SAFE Vehicles Final Rule").

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

[10] 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).

motor vehicles, NHTSA has issued its light-duty fuel economy and medium- and heavy-duty fuel efficiency standards in close coordination with the U.S. Environmental Protection Agency (EPA).[11]

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.

Consistent with NHTSA's statutory obligation to conduct a *de novo* rulemaking to establish final CAFE standards for MYs 2022–2025, NHTSA issued a notice of proposed rulemaking (NPRM) in 2018 in which the agency proposed revising the MY 2021 light-duty fuel economy standards and issuing new fuel economy standards for MYs 2022–2026.[12] In the 2020 SAFE Vehicles Final Rule, NHTSA amended fuel economy standards for MY 2021 and established standards for MYs 2022–2026 that would increase in stringency by 1.5 percent per year from 2020 levels. Concurrent with the SAFE Vehicles Final Rule, NHTSA issued a Final EIS on March 31, 2020.[13]

On January 20, 2021, President Biden issued Executive Order (EO) 13990, *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*,[14] which directed NHTSA to consider publishing for notice and comment a proposed rule suspending, revising, or rescinding the SAFE Vehicles Final Rule by July 2021. Pursuant to EO 13990, NHTSA is proposing to amend the CAFE standards for MY 2024–2026 passenger cars and light trucks in an NPRM being issued concurrent with this Draft Supplemental Environmental Impact Statement (SEIS). As described in that notice, NHTSA is proposing to retain the existing CAFE standards for MYs 2021–2023 in light of EPCA's requirement that amendments that make an average fuel economy standard more stringent be prescribed at least 18 months before the beginning of the model year to which the amendment applies.[15]

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[11] Although the agencies' programs and standards are closely coordinated, they are separate. 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 the responsibility to measure passenger car and passenger car fleet fuel economy pursuant to EPCA (49 U.S.C. § 32904(c)).

[12] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks; Notice of Proposed Rulemaking, 83 FR 42986 (Aug. 24, 2018) (hereinafter "SAFE Vehicles NPRM").

[13] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021–2026 Passenger Cars and Light Trucks Final Environmental Impact Statement (March 2020) (hereinafter "SAFE Vehicles Rule Final EIS"). Available at: https://www.nhtsa.gov/corporate-average-fuel-economy/safe.

[14] Executive Order 13990, Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis, 86 FR 7037 (Jan. 25, 2021).

[15] 49 U.S.C. § 32902(g)(2).

To inform its development of the CAFE standards for MYs 2024–2026 and pursuant to the National Environmental Policy Act (NEPA),[16] NHTSA prepared this SEIS to evaluate the potential environmental impacts of a reasonable range of alternatives the agency is considering. NEPA directs that federal agencies proposing "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action (including alternatives to the proposed action).[17] In revising the CAFE standards established in the SAFE Vehicles Final Rule, NHTSA is proposing to make substantial changes to the proposed action examined in the SAFE Vehicles Rule Final EIS and, as such, prepared this SEIS to inform its amendment of MY 2024–2026 CAFE standards.[18] Because this SEIS is a continuation of a NEPA process that began before the effective date of a 2020 Council on Environmental Quality (CEQ) rule that amended the NEPA implementing regulations,[19] NHTSA will continue to apply the NEPA implementing regulations that were in effect prior to that date.[20]

This SEIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of alternatives, including a No Action Alternative and a Preferred Alternative, pursuant to the CEQ NEPA implementing regulations in effect prior to September 14, 2020, DOT Order 5610.1C, and NHTSA regulations.[21] This SEIS analyzes direct, indirect, and cumulative impacts, and discusses impacts in proportion to their significance. As this SEIS is a continuation of a NEPA process that began with the issuance of a Notice of Intent to Prepare an EIS in July 2017, and included publication of a Draft EIS and Final EIS, NHTSA is also informed by the public comments it received and which are available for review in the docket.[22]

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

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[16] 42 U.S.C. §§ 4321–4347.

[17] 42 U.S.C. § 4332.

[18] *See* 40 CFR § 1502.9(c)(1)(i) (2019).

[19] Update to the Regulations Implementing the Procedural Provisions of the National Environmental Policy Act; Final Rule, 85 FR 43304 (Jul. 15, 2020).

[20] 40 CFR § 1506.13 (2020) (specifying that the new NEPA implementing regulations apply to any NEPA process begun after September 14, 2020).

[21] The CEQ NEPA implementing regulations are codified at 40 CFR Parts 1500–1508 (and the pre-2020 regulations were codified in the same parts); DOT Order 5610.1C, 44 FR 56420 (Oct. 1, 1979), as amended, is available at https://www.transportation.gov/office-policy/transportation-policy/procedures-considering-environmental-impacts-dot-order-56101c; and NHTSA's NEPA implementing regulations are codified at 49 CFR Part 520. All references to CEQ NEPA implementing regulations (except those denoted with "(2020)") are to those that were in effect when this NEPA process began (i.e., with NHTSA's publication of a notice of intent to prepare an EIS for new CAFE standards for MY 2022–2025 passenger cars and light trucks on July 26, 2017). Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 34740 (Jul. 26, 2017). A copy of those regulations is available at https://www.govinfo.gov/content/pkg/CFR-2019-title40-vol37/pdf/CFR-2019-title40-vol37.pdf#page=474. Citations to the CEQ NEPA implementing regulations that include "(2020)" as part of the citation refer to the revised NEPA regulations that were issued in July 2020.

[22] Comments on the agency's Notice of Intent to Prepare an EIS, Draft EIS, and Final EIS are available in Docket Number NHTSA-2017-0069, which can be accessed at https://www.regulations.gov/. Because NHTSA received a significant number of comments on these prior documents, the agency is opening a new docket for this SEIS to reduce confusion. However, the agency has considered the comments received in the prior docket as part of the preparation of this SEIS.

intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis.[23] In accordance with EPCA/EISA and EO 13990, the purpose of the rulemaking is to amend CAFE standards for MY 2024–2026 passenger cars and light trucks to reflect "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year."[24] 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."[25] 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.[26]

NHTSA has interpreted the four EPCA statutory factors as follows:[27]

- *Technological feasibility* refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established.
- *Economic practicability* refers to whether a standard is one within the financial capability of the industry, but not so stringent as to lead to adverse economic consequences, such as significant job losses or the unreasonable elimination of consumer choice.
- *The effect of other motor vehicle standards of the Government on fuel economy* involves analysis of the effects of compliance with emission, safety, noise, or damageability standards on fuel economy capability and thus 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.[28] Standards must be "based on one or more vehicle attributes related to fuel economy" and "express[ed]…in the form of a mathematical function."[29]

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[23] *See* 40 CFR § 1502.13 (2019).

[24] 49 U.S.C. § 32902(a).

[25] 49 U.S.C. §§ 32902(a), 32902(f). *See also Ctr. for Biological Diversity v. NHTSA,* 538 F.3d 1172, 1195 (9th Cir. 2008) ("The EPCA clearly requires the agency to consider these four factors, but it gives NHTSA discretion to decide how to balance the statutory factors—as long as NHTSA's balancing does not undermine the fundamental purpose of the EPCA: energy conservation."); *Ctr. for Auto Safety v. NHTSA,* 793 F.2d 1322, 1340 (D.C. Cir. 1986) ("It is axiomatic that Congress intended energy conservation to be a long term effort that would continue through temporary improvements in energy availability. Thus, it would clearly be impermissible for NHTSA to rely on consumer demand to such an extent that it ignored the overarching goal of fuel conservation.") (footnote omitted).

[26] *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.").

[27] *See* SAFE Vehicles Final Rule, *supra* note 8 at 24213–24216.

[28] 49 U.S.C. § 32902(a), (b)(2)(B).

[29] 49 U.S.C. § 32902(b)(3)(A).

1.3 Corporate Average Fuel Economy Rulemaking Process

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.

NHTSA is announcing a proposed rule to amend CAFE standards for light-duty vehicles for MYs 2024–2026. In addition, in conjunction with NHTSA's Proposed Action, EPA is proposing to amend its carbon dioxide (CO_2) emissions standards under Section 202(a) of the Clean Air Act (CAA) for MYs 2023–2026. This SEIS informs NHTSA and the public during the development of the standards as part of the rulemaking process. Section 1.3.1, *Proposed Action*, details the different components of NHTSA's Proposed Action. Section 1.3.2, *Greenhouse Gas Standards for Light-Duty Vehicles (U.S. Environmental Protection Agency)*, summarizes EPA's coordinated CO_2 emissions standards.

1.3.1 Proposed Action

For this SEIS, NHTSA's action is to amend the MY 2024–2026 fuel economy standards for passenger cars and light trucks, in accordance with EPCA, as amended by EISA. In the SAFE Vehicles Final Rule, NHTSA set final CAFE standards for MY 2021–2026 passenger cars and light trucks. As part of the current rulemaking, NHTSA is considering a range of alternatives for amending CAFE standards for MYs 2024–2026, or three model years. The Proposed Action, also known as the Preferred Alternative, and alternatives considered in this SEIS are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*.[30]

1.3.1.1 Level of the Standards

NHTSA is promulgating standards for passenger cars and light trucks under the agency's statutory authority. All the alternatives under consideration by NHTSA would amend CAFE standards for MYs 2024–2026. All action alternatives would be more stringent than the No Action Alternative. Under NHTSA's action alternatives, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would be 40.7 to 41.8 mpg in MY 2024 and 44.7 to 51.3 mpg in MY 2026. This compares to estimated average required fuel economy levels of 38.1 mpg and 39.4 mpg in MY 2024 and MY 2026, respectively, under the No Action Alternative. Under NHTSA's Proposed Action, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would be 40.7 mpg in MY 2024, 44.3 mpg in MY 2025, and 48.1 mpg 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. While NHTSA estimates the future composition of the fleet based on current market forecasts of future sales to compute the estimated average required fuel economy levels under each regulatory alternative, any estimates of future sales

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[30] NHTSA uses the terms *Proposed Action* and *Preferred Alternative* interchangeably in this SEIS. Unless otherwise specified, these terms refer to the proposed CAFE standards in the proposed rule issued concurrently with this Draft SEIS, not to the CAFE standards established in the SAFE Vehicles Final Rule. The Proposed Action/Preferred Alternative is described in greater detail in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*.

are subject to considerable uncertainty. Therefore, the average future required fuel economy under each regulatory alternative is also subject to considerable uncertainty.

1.3.1.2 Form of the Standards

Since the reformed CAFE program for light trucks for MYs 2008–2011,[31] NHTSA has set standards based on an attribute: vehicle footprint. NHTSA has extended this approach to passenger cars in the CAFE rule for MY 2011, as required by EISA.[32] NHTSA and EPA also used an attribute standard for the joint rules establishing coordinated standards for MY 2012–2016 and MY 2017–2025 passenger cars and light trucks.[33] In this rulemaking for MYs 2024–2026, NHTSA again proposes attribute-based standards based on vehicle footprint for passenger cars and light trucks.

Under an attribute-based standard, each vehicle model has a fuel economy performance target, the level of which depends on the vehicle’s attribute. As in previous CAFE rulemakings, 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 III.B of the NPRM preamble.

Under the proposed rule, each manufacturer will 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) will be subject to lower fuel economy targets than smaller vehicles. This is because, typically, smaller vehicles are more capable of achieving higher levels of fuel economy 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[34] average (for CAFE, harmonic average[35]) 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.

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

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

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

[34] Production for sale in the United States.

[35] 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.

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.[36] 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.

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

1.3.1.3 Program Flexibilities for Achieving Compliance

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

- 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 full-size pickup trucks with strong hybrid technologies and full-size pickup trucks that overperform their compliance targets by greater than a specified amount.

Additional flexibilities are discussed in NHTSA's proposal. Some of these flexibilities will be available to manufacturers in aiding compliance under both NHTSA and EPA standards, but some flexibilities, such as additional incentives for alternative fueled vehicles, will 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.

1.3.1.4 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 CO_2 emissions standards programs. In the SAFE Vehicles Final Rule, NHTSA and EPA made minor modifications to these provisions, as they would apply for model years beyond MY 2020. These changes are described in Section IX of the SAFE Vehicles Final Rule preamble. NHTSA's current compliance and enforcement program and proposed changes are described in Section VII of the proposed rule preamble.

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[36] 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).

NHTSA makes its ultimate determination of a manufacturer's CAFE compliance obligation based on official reported and verified CAFE data received from EPA.[37] The EPA-verified data are based on any considerations from NHTSA testing, EPA 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.

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

Under the CAA, EPA is responsible for addressing air pollutants from motor vehicles. In 2007, the U.S. Supreme Court issued a decision in *Massachusetts v. Environmental Protection Agency*,[38] a case involving a 2003 EPA order denying a petition for rulemaking to regulate GHG emissions from motor vehicles under CAA Section 202(a).[39] The Court held that GHGs are 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."[40] 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.[41]

Accordingly, the NHTSA and EPA joint final rulemakings for MY 2012–2016 (2010), MY 2017 and beyond (2012), and MY 2021–2026 passenger cars and light trucks (2020 SAFE Vehicles Final Rule), as well as EPA's proposed rule issued concurrently with NHTSA's action, are part of EPA's response to the U.S. Supreme Court decision.[42] EPA is proposing to amend its CO_2 emissions standards under Section 202(a) of the CAA for MYs 2023–2026. EPA's proposed standards are estimated to require that manufacturers,

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

[38] 549 U.S. 497 (2007).

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

[40] 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.

[41] 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).

[42] 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).

on average, meet a combined average emissions level of approximately 171 grams per mile of CO_2 in MY 2026.

The NHTSA and EPA proposals to revise the standards set forth in the 2020 SAFE Vehicles Final Rule remain closely coordinated despite being issued as separate regulatory actions because of the interaction between fuel economy and tailpipe CO_2 emissions. The proposed CAFE and CO_2 standards for MY 2026 represent roughly equivalent levels of stringency and may serve as a coordinated starting point for subsequent standards. While the proposed CAFE and CO_2 standards for MYs 2024–2025 differ, this is largely due to the difference in the "start year" for the revised regulations—EPA is proposing to revise standards for MY 2023, while EPCA's lead time requirements prevent NHTSA from proposing revised standards until MY 2024. The differences in what the two agencies' standards require become smaller each year, until alignment is achieved.

1.4 Cooperating Agencies

Section 1501.6 of the pre-2020 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.[43] NHTSA invited EPA and the U.S. Department of Energy (DOE) to become cooperating agencies with NHTSA during the SAFE Vehicles Rule EIS process.

EPA and DOE accepted NHTSA's invitation and agreed to become cooperating agencies.[44] EPA and DOE personnel were asked to review and comment on this SEIS prior to publication.

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

This Draft SEIS is being issued for public review and comment concurrently with the proposed rule to amend MY 2024–2026 passenger car and light truck CAFE emissions standards. Consistent with NEPA and its implementing regulations, NHTSA mailed a notification of availability of this Draft SEIS to:

- Contacts at federal agencies with jurisdiction by law or special expertise regarding the environmental impacts involved, or authorized to develop and enforce environmental standards, including other agencies within DOT.
- The Governors of every state and U.S. territory.
- Organizations representing state and local governments.
- Native American tribes and tribal organizations.
- Individuals and contacts at other stakeholder organizations that NHTSA reasonably expected to be interested in the NEPA analysis for the MY 2024–2026 CAFE standards, including advocacy, industry, and other organizations.

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[43] 40 CFR § 1501.6 (2019).

[44] 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 emissions standards for light-duty vehicles, 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.

Individuals may submit their written comments on the Draft SEIS, identified by docket number NHTSA-2021-0054, 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-2021-0054 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/privacy-act-system-records-notices. 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 SEIS in the *Federal Register*. That notice will include a deadline by which comments on this Draft SEIS must be received. NHTSA will simultaneously issue the Final SEIS and Record of Decision (i.e., the final rule), pursuant to 49 U.S.C. § 304a(b) and DOT's *Final Guidance on the Use of Combined Final Environmental Impact Statements/Records of Decision and Errata Sheets in National Environmental Policy Act Reviews* (DOT 2019a) unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.[45]

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[45] Available at: https://www.transportation.gov/transportation-policy/permittingcenter/guidance-use-combined-feisrod-and-errata-sheets-nepa-reviews.

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 action is to set fuel economy standards for MY 2024–2026 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, the Proposed Action and alternatives would revise upwards the CAFE standards for MYs 2024–2026.

For the purpose of this analysis, the impacts of the Proposed Action and alternatives are measured relative to a No Action Alternative, which assumes that the MY 2021–2026 CAFE standards established in the SAFE Vehicles Final Rule remain unchanged and that the MY 2026 SAFE Vehicles Final Rule standards continue to apply for MY 2027 and beyond. 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

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[1] 40 CFR § 1502.14 (2019).

[2] 40 CFR § 1502.14(a), (d) (2019).

[3] 40 CFR § 1502.13 (2019). 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).

energy.[6] In addition, NHTSA considered relevant safety and environmental factors.[7] This proposal is different than the conclusion NHTSA reached in the 2020 SAFE Vehicles Final Rule because NHTSA has reconsidered how to balance relevant statutory considerations. As discussed further in the preamble to the proposed rule, the proposal responds to the President's direction in EO 13990, and also responds to the agency's statutory mandate to improve energy conservation to insulate our nation's economy against external factors and reduce environmental degradation associated with petroleum consumption. During the process of developing the fuel economy standards, NHTSA consulted with EPA and the U.S. Department of Energy (DOE) regarding a variety of matters, as required by EPCA.[8] Consistent with CEQ NEPA implementing regulations, this SEIS compares a reasonable range of action alternatives to the No Action Alternative (Alternative 0) (Section 2.2.1, *Alternative 0: No Action Alternative*).[9] NHTSA has selected Alternative 2, which is described below, as the Preferred Alternative.

Under EPCA, as amended by EISA, NHTSA is required to set the fuel economy standards for passenger cars in each model year at the maximum feasible level and to do so separately for 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 SEIS reflect the combined environmental impacts associated with the proposed standards for passenger cars and light trucks. Appendix A, *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 the MY 2021–2026 CAFE and carbon dioxide (CO_2) standards established in the SAFE Vehicles Final Rule remain unchanged. In addition, the No Action Alternative assumes that the MY 2026 SAFE Vehicles Final Rule standards continue to apply for MY 2027 and beyond. The No Action Alternative also assumes that five manufacturers (BMW, Ford, Honda, Volvo, and Volkswagen) would reduce the average CO_2 emission rates of passenger cars and light trucks they produce for the U.S. during MYs 2021–2026 (only), pursuant to their participation in a "Framework Agreement" with California.[10] The No Action Alternative further assumes that California and other "Section 177" states would enforce zero emission vehicle (ZEV) mandates.[11] The No Action Alternative provides an analytical baseline against which to compare the environmental impacts of the other

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[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).

[8] 49 U.S.C. § 32902(i).

[9] 40 CFR § 1502.14(d) (2019).

[10] https://ww2.arb.ca.gov/sites/default/files/2020-08/clean-car-framework-documents-all-bmw-ford-honda-volvo-vw.pdf (last accessed June 10, 2021)

[11] Section 177 of the Clean Air Act allows states to adopt motor vehicle emissions standards California has put in place to make progress toward attainment of national ambient air quality standards. At the time of writing, Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington have adopted California's ZEV mandate.

See Vermont Department of Environmental Conservation, Zero Emission Vehicles.

alternatives presented in the EIS.[12] NEPA expressly requires agencies to consider a ''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. The alternatives considered in this SEIS 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 MY 2024–2026 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 2.2.5, *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 2024	MY 2025	MY 2026
Passenger cars	45.9	46.6	47.3
Light trucks	32.9	33.5	33.9
Combined cars and trucks	38.1	38.8	39.4

Notes:
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, about 6 percent to 10 percent annually from the MY 2023 standards for passenger cars and light trucks. Under each action alternative, federal CO_2 standards,

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[12] 40 CFR §§ 1502.2(e), 1502.14(d) (2019). 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) 2019.] * * * 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) 2019.]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026 (Mar. 23, 1981).

manufacturers' participation in the aforementioned California "Framework Agreement", and states' enforcement of ZEV mandates are all treated in the same manner as under the No Action Alternative.

For purposes of its analysis, NHTSA assumes that the MY 2026 CAFE standards for each alternative would continue indefinitely.[13] The agency believes that, based on the different ways the agency could weigh EPCA's four statutory factors, the maximum feasible level of CAFE stringency falls within the range of alternatives under consideration.[14]

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

- 10.5 percent increase for MY 2024 over MY 2023 and a 3.26 percent annual average increase for both passenger cars and light trucks for MYs 2025–2026 (Alternative 1)
- 8.0 percent average annual increase for both passenger cars and light trucks for MYs 2024–2026 (Alternative 2—NHTSA's Preferred Alternative)
- 10.0 percent annual average increase for both passenger cars and light trucks for MYs 2024–2026 (Alternative 3)

As noted, NHTSA reasonably believes the maximum feasible standards fall within the range of alternatives presented in this SEIS. This range encompasses 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 environmental impacts of points that fall between those individual alternatives. The alternatives evaluated in this SEIS 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 6 to 10 percent. 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.

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. 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 2.2.5, *Gap between Compliance Fuel Economy and Real-World Fuel Economy,* for more discussion about the difference between adjusted and unadjusted fuel economy.)

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[13] All alternatives assume the MY 2025 (No Action Alternative) or MY 2026 (action alternatives) standards would continue indefinitely. Because EPCA, as amended by EISA, requires NHTSA to set CAFE standards for each model year, environmental impacts reported in this SEIS would also depend on future standards established by NHTSA, but cannot be quantified at this time.

[14] 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). NHTSA balances the statutory factors in Section VI.A of the preamble.

This SEIS assumes a weighted average of flexible fuel vehicles' fuel economy levels when operating on gasoline and on flex fuel (E85; an ethanol-gasoline fuel blend containing 51 to 83 percent ethanol fuel). In particular, this SEIS 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: 10.5 Percent Increase for MY 2024 over MY 2023 and a 3.26 Percent Annual Increase in Fuel Economy, MYs 2024–2026

Alternative 1 would require a 10.5 percent increase for MY 2024 over MY 2023 and a 3.26 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2024–2026. Table 2.2.2-1 lists the estimated average required fleet-wide fuel economy under Alternative 1, as estimated in the analysis performed for this SEIS.[15]

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

	MY 2024	MY 2025	MY 2026
Passenger cars	49.8	51.5	53.2
Light trucks	36.4	37.7	39.0
Combined cars and trucks	41.8	43.3	44.7

Notes:
mpg = miles per gallon

2.2.2.2 Alternative 2 (Preferred Alternative): 8.0 Percent Annual Increase in Fuel Economy, MYs 2024–2026

Alternative 2 would require an 8.0 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2024–2026. Alternative 2 is NHTSA's Preferred Alternative. Table 2.2.2-2 lists the estimated average required fleet-wide fuel economy under Alternative 2.

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

	MY 2024	MY 2025	MY 2026
Passenger cars	49.2	53.4	58.1
Light trucks	35.1	38.2	41.5
Combined cars and trucks	40.7	44.3	48.1

Notes:
mpg = miles per gallon

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[15] The analysis performed for the SEIS does not impose constraints (i.e., regarding the treatment of CAFE compliance credits and alternative fuel vehicles) required per EPCA for the analysis informing NHTSA's decisions regarding the maximum feasible levels of CAFE standards. As a result, the size and composition of the estimated future new vehicle fleet differs between the SEIS and "standard setting" analyses. Because CAFE requirements depend on the composition of the fleet (i.e., the distribution among different footprints), the projected average fuel economy requirements also differ between the two analyses.

2.2.2.3 Alternative 3: 10.0 Percent Annual Increase in Fuel Economy, MYs 2024–2026

Alternative 3 would require a 10.0 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2024–2026. Table 2.2.2-3 lists the estimated average required fleet-wide fuel economy under Alternative 3.

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

	MY 2024	MY 2025	MY 2026
Passenger cars	50.2	55.8	62.0
Light trucks	35.9	39.9	44.3
Combined cars and trucks	41.6	46.2	51.3

Notes:
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[16] CAFE fuel economy (mpg) for combined passenger cars and light trucks from 1978 through 2023 (Davis and Boundy 2021). The figure extends these fuel economy levels out to their required average fuel economy levels under Alternative 1, Alternative 2 (Preferred Alternative), Alternative 3, and the No Action Alternative (Alternative 0) to demonstrate the range of alternatives currently under consideration.

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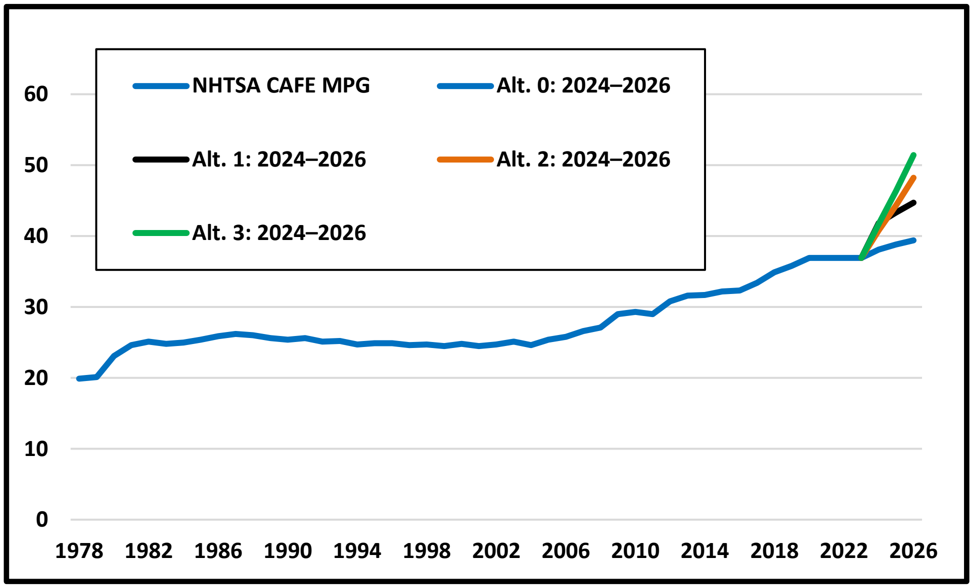
[16] Unadjusted fuel economy measures fuel economy as achieved by vehicles in the laboratory. Adjusted fuel economy, reported in EPA window stickers, includes adjustments to better estimate actual achieved on-road fuel economy, and is generally lower than its corresponding unadjusted fuel economy values. Figure 2.2.3-1 uses historical unadjusted fuel economy data as a basis to compare projected achieved fuel economy (based on Alternative 0, Alternative 1, and Alternative 3 CAFE standards) 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.

Figure 2.2.3-1. Historical CAFE Fuel Economy Requirements for Passenger Cars and Light Trucks through MY 2023 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 1978–1981, (2) a slower increase until MY 1987, (3) a gradual decrease until MY 2004, and (4) a large increase since MY 2005. The MY 2024–2026 action alternatives would further increase fuel economy to historically high levels through 2026.

2.2.4 EPA's Carbon Dioxide Standards

In conjunction with NHTSA's Proposed Action, EPA is proposing to amend its CO_2 emissions standards under Section 202(a) of the Clean Air Act (CAA) for MYs 2023–2026. Table 2.2.4-1 lists EPA's estimates of its projected overall fleet-wide CO_2 emissions compliance targets under its proposed standards.

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

	MY 2022 [a]	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	180	165	157	149	142
Light trucks	260	232	221	210	199
Combined cars and trucks [b]	220	199	189	180	171

Notes:

[a] SAFE Vehicles Final Rule targets included for reference.

[b] The combined cars and trucks CO_2 targets are a function of assumed car/truck shares. For purposes of this projected target, EPA assumed an approximately 50/50 percent split in MYs 2023–2026.

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 2012a). 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.[17]

For more discussion of the on-road fuel economy gap (the difference between adjusted and unadjusted mpg), see Chapter 2.4.8 of the Technical Support Document (TSD).

2.3 Standard-Setting and EIS Methods and Assumptions

Each of the alternatives considered here 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 3) would involve a 10 percent per year average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2024–2026. In contrast, the least stringent action alternative (Alternative 1) would require a 10.5 percent increase for MY 2024 over MY 2023 and a 3.26 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2024–2026.

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 TSD. 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 Model developed by the Volpe National Transportation Systems Center (Volpe)[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, while also simulating compliance with a given set of CO_2 standards, applying inputs accounting for manufacturers' projected responses to state ZEV mandates, and accounting for buyers' estimated willingness to pay for fuel economy given projected fuel prices. For this proposed rule, the model begins with a representation of the MY 2020 offerings for each manufacturer that includes the specific engines and transmissions on

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[17] Except as noted, when fuel economy values are cited in this SEIS, 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.

[18] NHTSA has also sometimes referred to this model as the *Volpe model*.

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 estimated future fuel prices, estimated willingness of new vehicle buyers to pay for fuel economy improvements, and the standards being considered, in ways estimated to be optimal when also accounting for many real-world constraints faced by automobile manufacturers. After simulating compliance, the model calculates a range of impacts of the simulated standards, such as changes in new vehicle sales, the rates at which older vehicles are removed from service, annual highway travel, technology costs, fuel usage and cost, emissions of air pollutants and greenhouse gases (GHGs), fatalities resulting from highway vehicle crashes, incidents of health impacts resulting from air pollution, and overall social costs and benefits.

For this SEIS, NHTSA used the CAFE Model to estimate annual fuel consumption for each calendar year from 2020, the most recent year for which the new vehicle market was observed, 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.

2.3.1.1 CAFE Model Inputs

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

- Availability, applicability, effectiveness, and cost of fuel-saving technologies.
- Several time series that describe the macroeconomic context in which the standards are implemented, including real gross domestic product (GDP), real disposable personal income, U.S. population and number of households, and consumer confidence.
- Economic factors, including 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 and other GHGs.
- Fuel characteristics and vehicular emissions rates.
- Coefficients defining the shape and level of CAFE and CO_2 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.
- Projections of vehicle model/configurations that could foreseeably be replaced with vehicles qualifying for credit toward ZEV mandates.

NHTSA uses the model for analysis; the model makes no *a priori* assumptions regarding inputs such as fuel prices, 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 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 the TSD and Preliminary Regulatory Impact Analysis (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 uses 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 SEIS and the analyses cited herein. Using this and other information, NHTSA evaluates the consistency of the regulatory alternatives with the governing statutory factors, which include environmental issues and then proposes what it tentatively believes are the maximum feasible standards based on its assessment of the appropriate balancing of those factors.

Vehicle Fleet

To determine what levels of stringency are feasible in future model years, NHTSA must project what vehicles and technologies could be produced 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. As for other recent CAFE rulemakings, the agency has developed the analysis fleet using information that can be made public, rather than constructing a market forecast using product planning provided by manufacturers on a confidential basis.

More information about the vehicle market forecast used in this SEIS is available in Chapter 2.2 of the TSD.

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 CAFE 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 SEIS can be found in Chapter 3 of the TSD and Section III.D of the NPRM. Table 2.3.1-1 lists the types of technologies considered in this analysis for improving fuel economy.

Table 2.3.1-1. Categories of 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
Improved engine friction reduction	Manual six and seven-speed transmission	Low-rolling-resistance tires (two levels)	Electric power steering/electro-hydraulic power steering
Cylinder deactivation	Six, eight, 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	12-volt stop-start
Variable valve timing	Six and eight speed dual clutch transmissions	Aerodynamic drag reduction (four levels)	48-volt belt integrated starter generator
Variable valve lift	Continuously variable transmissions	Mass reduction (six levels)	Power split hybrids
Stoichiometric gasoline direct-injection technology	Advanced continuously variable transmissions	--	P2 hybrids
Turbocharging and downsizing	--	--	Plug-in hybrid electric vehicles (20-mile and 50-mile range)
Cooled exhaust-gas recirculation	--	--	Battery electric vehicles (200-mile, 300-mile, 400-mile, and 500-mile range)
Variable turbo geometry	--	--	Fuel cell vehicles
Turbocharging and downsizing with cylinder deactivation	--	--	--
Advanced diesel engines	--	--	--
High-compression ratio (HCR) engines	--	--	--
HCR engines with cylinder deactivation			
Variable compression engines	--	--	--

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 4 through 6 of the TSD and examples of which include:

- Estimates of ways in which the quantities of new passenger cars and light trucks could change in response to future vehicle prices and fuel economy levels, accounting also for future fuel prices.
- Estimates of the fraction of the on-road fleet that remains in service at different ages, and the average annual mileage accumulated by passenger cars and light trucks over their useful lives.
- Estimates of future fuel prices.
- 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 elasticity of annual travel with respect to the per-mile cost of fuel (also referred to as the 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.
- Changes in the population-wide incidence of selected health impacts and changes in the aggregate value of health damage costs likely to result from the changes in emissions of criteria air pollutants.
- The value of increased driving range and less frequent refueling that results from increases in fuel economy.
- The costs of increased congestion and noise caused by added passenger car and light-truck use.
- The costs of light-duty traffic fatalities, injuries, and property damage 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 is issuing standards through MY 2026, 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.

NHTSA's analysis also incorporates modules that affect the composition of the on-road fleet by simulating the purchase of new vehicles and the retirement of the existing vehicle population in response to changes in new vehicle prices, relative cost per mile, and the gross domestic product 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 traveled (VMT) of less efficient, more polluting, and, generally, less safe vehicles. Chapter 4 of the TSD describes these modules in detail. The extended usage of older vehicles results in incrementally 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 initial sale, after which no vehicles produced in that model year are included in the modeling.

In addition, NHTSA's analysis continues the agency's long-standing practice of accounting for the fact that the amount of driving tends to increase as driving becomes less expensive—a market reality referred to in this context as the 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—although the additional mobility creates benefits for those drivers. 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 cost of fuel consumed per mile driven increases (as a result of higher fuel prices), vehicle use decreases. In this SEIS, the rebound effect for light-duty vehicles is assumed to be 15 percent. These VMT impacts are reflected in the estimates of emissions under each of the alternatives evaluated (Section 2.4.1, *Types of Emissions*).

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

In the NPRM, NHTSA proposed CAFE standards for MYs 2024–2026 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 has retained that approach in the proposed rule accompanying this Draft SEIS. NHTSA describes its methods for developing the coefficients defining the curves for the Proposed Action in Chapter 1 of the TSD.

2.3.2 Constrained versus Unconstrained CAFE Model Analysis

NHTSA's CAFE Model results presented in the proposal, in Chapter 6 of the PRIA and in Section V of the preamble to the proposed rule, differ slightly from those presented in this SEIS. 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 fuel technologies toward compliance in model years for which NHTSA is issuing 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 SEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuel technologies in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

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[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) (2019).

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 outputs of analysis conducted using the 2019 EIA National Energy Modeling System)		
National Energy Modeling System	• Inputs are default values for the AEO 2021 Reference Case	• Projected fuel prices for all fuels • U.S. average electricity-generating mix for future years • US Population • Real GDP and disposable income
Argonne National Laboratory: GREET (2020 Version) Fuel-Cycle Model		
Greenhouse Gases and Regulated Emissions in Transportation	• Estimates for nationwide average electricity generating mix from NEMS 2020 • Other inputs are default GREET 2018 data	• Upstream emissions for EV electricity generation • Estimates of upstream emissions associated with production, transportation, and storage for gasoline, diesel, hydrogen and E85
EPA: MOVES3 (2020)		
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 air 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 (2021 Version)		
CAFE Model	• Characteristics of analysis fleet • Availability, applicability, effectiveness, and cost of fuel-saving technologies • 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
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)

Model Title	Model Inputs	Model Outputs Used in this Analysis
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

Notes:
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 SEIS, NHTSA uses projections of energy prices, global petroleum demand, 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 a range of fuels, sectors, and geographic regions. To develop projections reported in AEOs, EIA uses its National Energy Modeling System (NEMS), which 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 AEO Reference case projections.

In this SEIS, NHTSA uses NEMS-based projections by citing directly to unmodified projections published by EIA as part of the AEO.

References to the AEO 2021 (and earlier AEOs) in this SEIS refer to the published annual AEO, and the agency is citing directly to the AEO Reference case. As published by EIA, recent editions of the AEO assume that NHTSA's and EPA's vehicle standards finalized in 2020 are fully enforced and that manufacturers generally comply with those standards. NHTSA relies on the AEO 2021 in this SEIS as it is widely used and publicly available.

In the Final EIS, NHTSA referenced AEO 2019. In this SEIS, NHTSA has updated these references to AEO 2021 to provide the most recent projections available for the decision-maker.

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 SEIS, 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, 2014a, 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.

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. Chapter 6, *Life-Cycle Implications of Vehicle Energy, Materials, and Technologies*, describes the impacts on the energy, material, and technology aspects of the vehicle lifecycle. 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

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[21] 40 CFR § 1502.22(b) (2019).

[22] 40 CFR § 1502.22(b)(3) (2019).

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 organic compounds from the vehicle's fuel storage and delivery system, and particulates generated by brake and tire wear. All downstream emission estimates in the CAFE Model use emission factors from EPA's Motor Vehicle Emission Simulator (MOVES3) model (EPA 2020a). Upstream emissions related to the action alternatives are those associated with crude-petroleum extraction, transportation, and refining and with transportation, storage, and distribution of gasoline, diesel, and other finished transportation fuels. Emissions from each of these phases of fuel supply are estimated using factors obtained from Argonne National Laboratory's Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model. Upstream emissions from electric vehicles (EVs) also include emissions associated with using primary feedstocks (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 can vary regionally. NHTSA estimated domestic upstream emissions of CO_2, criteria air pollutants, and toxic air pollutants. Upstream emissions considered in this SEIS include those that occur within the United States during the recovery, extraction, and transportation of crude petroleum, as well as during the refining, storage, and distribution of transportation of fuels.

The CAFE Model considers crude petroleum from domestic and international sources. A portion of finished motor fuels is refined within the United States using imported crude petroleum as a feedstock and GREET's emissions factors are used to estimate emissions associated with transporting imported petroleum from coastal port facilities to U.S. refineries, refining it to produce transportation fuels, and storing and distributing those fuels. GREET's emissions factors are also used to estimate domestic emissions from transportation, storage, and distribution of motor fuels that are imported to the United States in refined form.

Additionally, Section 2.4.1.1, *Downstream Emissions*, and Section 2.4.1.2, *Upstream Emissions*, describe analytical methods and assumptions used in this SEIS 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 their estimated emissions rates per vehicle-mile of each pollutant. These emissions rates and annual VMT differ between cars and light trucks, between gasoline and diesel vehicles, and by model year that is used to calculate vehicle age. With the exception of sulfur dioxide (SO_2), NHTSA 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 Motor Vehicle Emission Simulator (MOVES3) (EPA 2020a). MOVES 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), the mobile source air toxics (MSAT) rule (EPA 2007), and the Tier 3 Motor Vehicle Emission and Fuel Standards Rule (EPA 2014a). The MOVES database includes national default distributions by vehicles type and age, activity levels, regulatory class, fuel composition and supply, 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. MOVES defaults were used for all other parameters to estimate tailpipe and other components of downstream emissions under the No Action Alternative.

NHTSA's emissions analysis method assumes that no additional reduction in tailpipe emissions of criteria pollutants or toxic air pollutants will occur as a consequence of improvements in fuel economy that are not already accounted for in MOVES. In its emissions calculations, MOVES 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, vehicle weight reduction, improved aerodynamics, and lower rolling-resistance tires, are therefore reflected in the MOVES calculations of both fuel economy and emissions. Because the CAFE 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 regulated pollutant standards. Depending on which strategies are pursued to meet the increased fuel economy standards, emissions of other pollutants, both regulated and unregulated, 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 mile.
- 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 chosen fuel used, and inversely with fuel economy (mpg). Therefore, emissions factors for CO_2 and SO_2 are not constant in terms of grams emitted per mile of a specific vehicle, because fuel economy—and therefore the amount of fuel used per mile—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 given in terms of grams emitted per mile. 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 air toxics, MOVES calculates emission rates individually for specific combinations of inputs, including various vehicle types, fuels, ages, and other key parameters as noted previously.

Emissions factors in the MOVES database are initially expressed in the form of grams per vehicle-hour of operation. To convert these emission factors to grams per mile, MOVES 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. NHTSA selected 2050 in order to generate emission factors that were representative of lifetime average emission rates for vehicles meeting the Tier 3 emissions and fuel standards.[24] Separate estimates were developed for each vehicle type and model year, which also included effects to reflect regional and temporal variation in temperature and other relevant variables on emissions.

The MOVES emissions estimates were then summed across all model years and divided by total VMT in that year in order to produce per-mile emissions factors by vehicle type, fuel type, and pollutant. The resulting emissions 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 embody county-specific differences in fuel composition, as well as in the presence and type of vehicle inspection and maintenance programs.[26]

Emissions from the criteria pollutant SO_2 were calculated by using average rates in grams per gallon of fuel supplied by EPA's MOVES model. These calculations assumed that national average gasoline and diesel sulfur levels would remain at current levels for the foreseeable future,[27] because there are currently no open regulatory actions that consider fuel sulfur content. Therefore, unlike many emissions of other criteria pollutants that are affected by exhaust after-treatment devices (e.g., a catalytic converter), SO_2 emissions from vehicle use are effectively proportional to fuel consumption.

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[23] The CAFE Model's 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. On the other hand, fuel savings from higher standards offset these higher prices to a large degree, though how consumers factor in those fuel savings is contested.

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

[25] The emissions rates calculated by EPA for this analysis using MOVES include only those components of emissions expected to vary in response to changes in vehicle use. These include exhaust emissions associated with starting and operating vehicles, 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 emissions rates of 0.17 gram of SO_2 per gallon of gasoline and 0.10 gram per gallon of diesel.

NHTSA assumes 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 decrease in VMT. If the increases in fuel consumption and emissions associated with VMT rebound effect are larger than the decrease in fuel consumption due to increased fuel economy, then the net result can be a reduction in total downstream 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 decreases, NHTSA anticipates increases in upstream emissions from fuel production and distribution, because the total amount of fuel used by passenger cars and light trucks would increase. To the extent that any action alternative would lead to increased EVs adoption and use, upstream emissions associated with charging EVs could increase because of adopting that alternative. These increases would offset at least part of the reduction in upstream emissions resulting from reduced production of motor vehicle fuels due to EV adoption. 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 to meet EV charging demand, 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 percentage increases in VMT and downstream emissions from vehicle use that are uniform 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. Net emissions changes depend on the relative magnitudes of the increase in emissions from additional vehicle use due to the rebound effect and electric power production tied to EV charging and the decline in emissions resulting from reduced fuel production and distribution in that geographic region.

NEMS is an energy-economy modeling system from the EIA. For the CAFE Model analyses presented throughout this SEIS, NHTSA used the NEMS AEO 2019 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 (2020 version) (ANL 2020a) 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 SEIS assumes that the future EV fleet would charge from a nationally representative grid mix. 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 energy intensities (amount of pollutant emitted per unit of electrical energy generated) that extend to 2040.

For the action alternatives in this SEIS, NHTSA assumed that increased fuel economy affects upstream emissions by decreasing volumes of gasoline and diesel produced and consumed,[28] and by causing

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[28] 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.

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 (in 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. 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."[29] NHTSA has presented the environmental impacts of the alternatives in comparative form through each of the substantive chapters that follow in this SEIS. 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 Implications of Vehicle Energy, Materials, and Technologies*, and Chapter 7, *Other Impacts*, so they are not summarized here.

Under the alternatives analyzed in this SEIS, 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. NHTSA estimates that the proposed CAFE standards and each of the action alternatives would decrease 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 three action alternatives on energy, air quality, and climate (Table 2.5.2-1). Under NEPA, direct impacts "are caused 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

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[29] 40 CFR § 1502.14 (2019).

[30] 40 CFR § 1508.8 (2019).

[31] Ibid.

discussions of the assumptions and methods used to estimate the direct and indirect impacts, see Section 2.3, *Standard-Setting and EIS Methods and Assumptions*, Section 3.4, *Environmental Impacts* (energy), Section 4.1.2, *Methods*, (air quality), and Section 5.3, *Analysis Methods* (climate). Table 2.5.2-1 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*.

Table 2.5.2-1. Direct and Indirect Impacts

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Energy: Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2020–2050 (billion gasoline gallon equivalent)			
3510	3,409	3,334	3,282
Energy: Combined U.S. Passenger Car and Light Truck Decrease in Fuel Consumption for 2020–2050 (billion gallons)			
--	-100	-166	-227
Air Quality: Criteria Air Pollutant Emissions Changes in 2035			
--	Decrease: NO_X, PM2.5, SO_2, and VOCs. Increase: CO.	Decrease: CO and VOCs, emissions smaller than Alt. 1. NO_X and PM2.5, emissions larger than Alt. 1. Increase: SO_2, emissions larger than Alt. 1.	Decrease: CO and VOCs, emissions smaller than Alts. 1 and 2. PM2.5, emissions larger than Alts. 1 and 2. Increase: NO_X and SO_2, emissions larger than Alts. 1 and 2.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035			
--	Decrease: Benzene, DPM, and formaldehyde. Increase: Acetaldehyde, acrolein, 1,3-butadiene.	Decrease: Acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde, emissions smaller than Alt. 1. Increase: None.	Decrease: Acetaldehyde, acrolein, 1,3-butadiene, DPM, and formaldehyde, emissions smaller than Alts. 1 and 2. Benzene, emissions smaller than Alt. 1 but larger than Alt. 2. Increase: None.
Air Quality: Decreases in Premature Mortality Cases and Work-Loss Days in 2035			
--	Premature mortality: 31–71 cases Work-loss: 4,346 days	Premature mortality: 35–84 cases Work-loss: 5,827 days	Premature mortality: 35–88 cases Work-loss: 6,704 days
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 (MMTCO$_2$)			
89,600	85,500	83,200	81,000
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
789.11	788.74	788.52	788.33
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
3.484°C (6.271°F)	3.483°C (6.269°F)	3.482°C (6.267°F)	3.481°C (6.265°F)

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
76.28 (30.03)	76.25 (30.02)	76.23 (30.01)	76.22 (30.01)
Climate: Global Mean Precipitation Increase by 2100			
5.85%	5.85%	5.85%	5.85%
Climate: Ocean Acidification in 2100 (pH)			
8.2176	8.2178	8.2179	8.2180

Notes:

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; VOCs = volatile organic compounds

Table 2.5.2-2. Cumulative Impacts

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Energy: Total Combined Gasoline, Diesel, Biofuel, Hydrogen, and Electricity Fuel Consumption by All U.S. Cars and Light Trucks for 2020–2050			
Fuel consumption could change due to recent market trends that indicate 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.			

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 ($MMTCO_2$)[a]			
89,600	85,500	83,200	81,000
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
687.29	686.94	686.73	686.55
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
2.838°C (5.108°F)	2.836°C (5.105°F)	2.835°C (5.103°F)	2.834°C (5.101°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
70.22 (27.65)	70.19 (27.63)	70.17 (27.63)	70.15 (27.62)
Climate: Global Mean Precipitation Increase by 2100			
4.77%	4.76%	4.76%	4.76%
Climate: Ocean pH in 2100			
8.2723	8.2725	8.2726	8.2727

Notes:

[a] 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 (GCAMReference Scenario) used in the direct and indirect impacts analysis. NHTSA chose the GCAM6.0 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; VOCs = volatile organic compounds; 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) 2021 forecasts that transportation fuel will account for 76.9 percent of U.S. petroleum consumption in 2050 (EIA 2021a).[1] The AEO 2021 is the source for the Section 3.1, *Affected Environment*, discussion; however, this chapter also discusses how the proposed action and alternatives would affect passenger car and light truck energy consumption, as projected by the CAFE Compliance and Effects Model (referred to as the CAFE Model). Note that the AEO and CAFE Model use different underlying assumptions but show similar resulting trends in forecast energy use. Improvements in vehicle fuel economy, combined with increases in U.S. petroleum production, have substantially reduced U.S. oil imports. 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 2021 forecasts that the United States will be a net energy exporter in every year from 2020 through 2050. The United States became a net energy exporter in 2019 for the first time in 67 years due to declining net petroleum imports, increased net exports of natural gas, and continued net exports of coal (EIA 2020a). The AEO 2021 forecast reflects enacted legislation and final regulations, including the MY 2021–2026 CAFE standards established by the 2020 SAFE Vehicles Final Rule.[2]

This chapter examines the energy impacts of the Proposed Action and alternatives, which would revise upward the CAFE standards for MYs 2024–2026. For the purpose of this analysis, the impacts of the Proposed Action and alternatives are measured relative to a No Action Alternative, which assumes that the MY 2021–2026 CAFE standards established in the SAFE Vehicles Final Rule remain unchanged and that the MY 2026 SAFE Vehicles Final Rule standards continue to apply for MY 2027 and beyond (Section 2.2, *Proposed Action and Alternatives*). In addition to those standards, the No Action Alternative assumes that the manufacturers who signed the California agreement, which imposes voluntary greenhouse gas (GHG) requirements in excess of the final federal standards for MYs 2021–2026, will achieve those standards nationally. The No Action Alternative similarly accounts for rising zero emissions vehicle (ZEV) requirements in both California and the so-called "Section 177 states"[3], which have also adopted the California ZEV standard and collectively represent about 35 percent of the new passenger car and light truck vehicle market.

Past and forecast trends in U.S. energy intensity have changed the relationship between U.S. energy use and economic growth trends. 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). Readers may consult Chapter 6.2.4.2 of the TSD for a discussion on energy intensity.[4]

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[1] This chapter uses 2050 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 2024–2026 or later vehicles.

[2] The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks; Final Rule, 85 FR 24174 (Apr. 30, 2020) (hereinafter "SAFE Vehicles Final Rule").

[3] The Clean Air Act, Section 177 (42 U.S.C. § 7507), gives states the option to adopt California's emissions standards provided they are more stringent than the corresponding federal standards. More than a dozen state governments have leveraged this provision to implement California's ZEV program in their own states.

[4] The FEIS included information, such as energy intensity; however, these discussions are now available in the TSD and to avoid redundancy with related documents, this SEIS does not include a discussion on energy intensity and incorporates by reference the discussion from the TSD.

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, *Affected Environment*, describes the affected environment for U.S. energy production and consumption by primary fuel source (e.g., coal, natural gas, and petroleum) 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 3.2, *Petroleum Imports and U.S. Energy Security*, describes how improvements in the fuel economy of vehicles and increasing energy production together affect U.S. energy security by reducing the overall U.S. trade deficit and the macroeconomic vulnerability of the United States to foreign oil supply disruptions.
- Section 3.3, *Environmental Consequences*, describes the direct and indirect energy impacts of the Proposed Action and alternatives.

3.1 Affected Environment

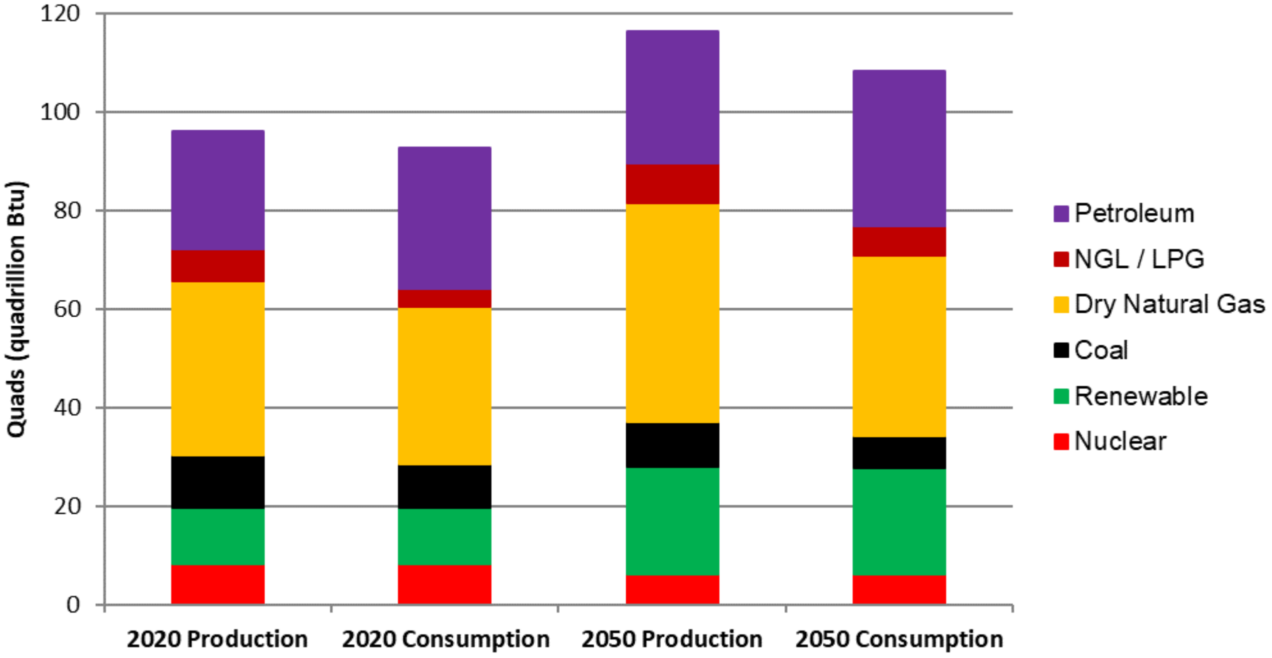
Although petroleum is overwhelmingly the primary source of energy for passenger cars and light trucks, these vehicles can use other fuels (e.g., electricity and natural gas). The Proposed Action and alternatives would affect demand for these fuels and thereby affect the availability and use of fuels 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 3.1.1, *U.S. Production and Consumption of Primary Fuels*, discusses U.S. energy production and consumption by primary fuel source (e.g., petroleum, coal, and natural gas). Section 3.1.2, *U.S. Energy Consumption by Sector*, discusses U.S. energy consumption by stationary and transportation sectors.

3.1.1 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 87.8 percent of U.S. energy consumption in 2020, whereas hydropower, biomass, solar, wind, and other renewable energy accounted for 12.2 percent of U.S. energy consumption in 2020 (EIA 2021a).

By 2050, the top five aforementioned energy sources are forecast to account for 80.2 percent of U.S. energy consumption, a reduction of 7.6 percent from their previous share, while the share of energy from renewable sources is forecast to rise to 19.8 percent (EIA 2021a). 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 in 2020 through 2050. The change in U.S. energy production and consumption from 2020 through 2050 is shown in Figure 3.1.1-1.

Figure 3.1.1-1. U.S. Energy Production and Consumption by Source in 2020 and 2050



Source: EIA 2021a
Btu = British thermal unit; NGL = natural gas liquid; LPG = liquefied petroleum gas

From 2020 to 2050, production and consumption of nuclear power is forecast to decrease from 8.2 to 6.2 quadrillion Btu (quads), and consumption of renewable fuel is forecast to increase from 11.3 quads in 2020 to 21.5 quads in 2050.[5] The forecast growth in renewable energy includes a decrease in hydropower production and consumption from 2.5 quads in 2020 to 2.3 quads in 2050. 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 8.8 quads in 2020 to 19.2 quads in 2050. Electric power generation accounts for 76 percent of forecast renewable fuel use in 2050, and the industrial sector accounts for another 14 percent. Because production and consumption are roughly equivalent for nuclear and renewable energy, there are essentially no net imports associated with these energy sources.[6] These fuels supplied 21 percent of U.S. energy consumption in 2020, and their combined share of consumption is forecast to increase to 26 percent by 2050. In addition to the Reference case forecast, the AEO 2021 also presents a side case that shows much higher use of renewable energy in a Low Renewables Cost case (which assumes a 40 percent reduction in renewable power and energy storage costs compared with the Reference case).

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[5] The EIA 2021 forecast for growth in renewable energy may be conservative, in part because this forecast assumes no changes in the status quo regulatory environment.

[6] 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 (http://www.theupa.org/_resources/news/EIA_2015_Uranium_Marketing_Annual_Report.pdf).

U.S. coal production is forecast to decline from 10.8 quads in 2020 to 9.1 quads in 2050, as coal consumption is expected to decline from 9.0 quads in 2020 to 6.6 quads in 2050. The United States is currently, and is expected to remain, a net exporter of coal energy through 2050.

U.S. production of dry natural gas (separated from natural gas liquids, discussed below) is forecast to increase from 35.1 quads in 2020 to 44.6 quads in 2050, while consumption of natural gas is expected to rise from 31.9 quads in 2020 to 36.7 quads in 2050, making the United States a net exporter of natural gas in 2020 through 2050. 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 6.6 quads in 2020 to 8.1 quads in 2050. 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 3.8 quads in 2020 to 5.8 quads in 2050. LPG production is expected to exceed LPG consumption, resulting in net exports, from 2020 through 2050.

U.S. production of crude oil is forecast to increase from 23.9 quads in 2020 to 26.6 quads in 2050. 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 increase from 28.5 quads in 2020 to 31.5 quads in 2050. However, U.S. net imports of petroleum are forecast to increase from 4.6 quads (0.79 billion barrel) in 2020 to 4.9 quads (0.86 billion barrel) in 2050, due to the projected increase in U.S. consumption exceeding the projected increase in U.S. production.[7]

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 2020 through 2050. U.S. net imports of petroleum are also expected to decline, resulting in a forecast of net energy exports from 2020 through 2050 (EIA 2021a).

3.1.2 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 35.8 quads in 2020 to 41.2 quads in 2050. In 2020, nuclear power supplied 23 percent of electric power generation source fuel, coal 22 percent, natural gas 34 percent, and renewable energy 20 percent. In 2050, nuclear power is expected to supply 15 percent of electric power generation source fuel, coal 14 percent, natural gas 30 percent, and renewable energy 40 percent. The petroleum share of electric power fuel supply is anticipated to decline from 0.4 percent in 2020 to just 0.1 percent in 2050 (EIA 2021a). Given these projections, it is clear that the U.S. energy landscape is changing with renewable energy being the fastest-growing energy source in the United States.

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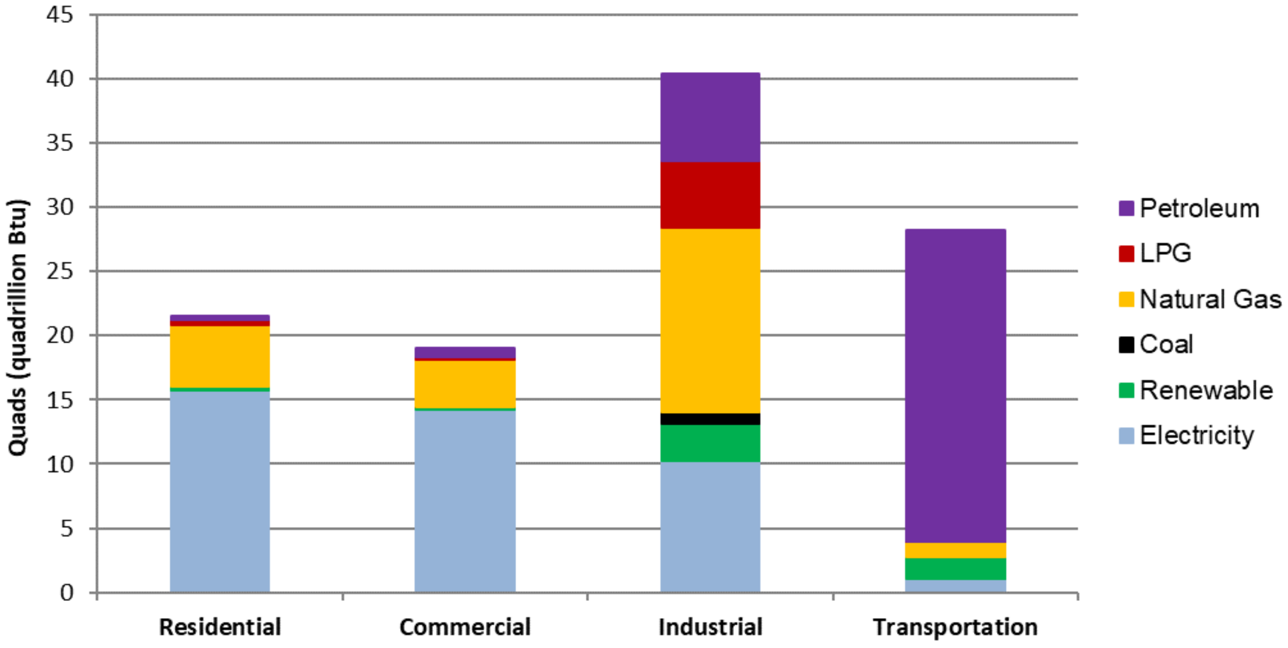
[7] NHTSA also reports on many of these results with the CAFE Model; however, AEO reporting information shown here is consistent with other information reported within this chapter.

Figure 3.1.2-1 illustrates sharply contrasting profiles for 2050 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 3.1.2.1, *Stationary-Sector Fuel Consumption*, and 3.1.2.2, *Transportation-Sector Fuel Consumption*, discuss the specifics of fuel use by those sectors, respectively.

Figure 3.1.2-1. Forecast U.S. Energy Consumption by End-Use Sector and Source Fuel in 2050



Source: EIA 2021a
Btu = British thermal unit; LPG = liquefied petroleum gas

3.1.2.1 Stationary-Sector Fuel Consumption

This section provides background information on stationary-sector fuel consumption, which could be affected by the Proposed Action and alternatives either by increased use of plug-in electric vehicles or by changes in upstream energy use related to energy production, refining, storage, and distribution. NHTSA's analysis shows manufacturers increasing the efficiency of conventional and hybrid-electric vehicles over time and also selling increasing numbers of plug-in hybrid electric vehicles and battery-only electric vehicles. NHTSA's analysis also shows vehicle miles traveled (VMT) recovering from 2020's significantly reduced levels during the early 2020s before growing gradually through 2040 and then declining slightly through 2050. Together, these changes result in declining U.S. consumption of gasoline and increased consumption of electricity, with changes in aggregate domestic upstream emissions varying over time and among pollutants and regulatory alternatives. Section 3.1.2.2, *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 2020 energy use and 95 percent of forecast 2050 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 2020 industrial sector energy use, and account for 61 percent of forecast 2050 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 increase from 20.8 quads in 2020 to 21.5 quads in 2050, with this sector accounting for 22 percent of U.S. energy consumption in 2020 and 20 percent of forecast U.S. energy consumption in 2050. Commercial-sector energy consumption is forecast to increase from 16.7 quads in 2020 to 19.0 quads in 2050, with this sector accounting for 18 percent of U.S. energy consumption in 2020 and 18 percent of forecast U.S. energy consumption in 2050. Industrial-sector energy consumption is projected to rise from 31.2 quads in 2020 to 40.3 quads in 2050, with this sector accounting for 34 percent of U.S. energy consumption in 2020 and 37 percent of forecast energy consumption in 2050. In 2050, petroleum is expected to account for just 1.3 percent of residential-sector energy consumption, 3.5 percent of commercial-sector energy consumption, and 16.6 percent of industrial-sector energy consumption.

3.1.2.2 Transportation-Sector Fuel Consumption

The AEO 2021 forecasts transportation sector fuel consumption to increase from 24.7 quads in 2020 to 28.2 quads in 2050. In 2020, petroleum supplied 91.0 percent of transportation energy use, biofuel (mostly ethanol used in gasoline blending) 5.4 percent, natural gas 3.2 percent, LPG (propane) 0.02 percent, and electricity 0.4 percent. In 2050, petroleum is expected to supply 86.1 percent of transportation energy use, biofuel 6.0 percent, natural gas 4.1 percent, hydrogen 0.01 percent (up from 0.002 percent in 2020), LPG 0.04 percent, and electricity 3.7 percent. Section 6.2, *Energy Sources*, synthesizes life-cycle findings on different fuel sources for passenger cars and light trucks, which aids the decision-maker in understanding how increases or decreases in the use of different fuel sources may affect the life-cycle GHG emissions of passenger car and light truck use.

In 2020, passenger cars and light trucks accounted for 56 percent of transportation energy consumption, medium- and heavy-duty (HD) vehicles accounted for 25 percent, air travel accounted for 8 percent, and other transportation (e.g., boats, rail, pipeline) accounted for 12 percent. In 2050, passenger cars and light trucks are expected to account for 49 percent of transportation energy consumption, HD vehicles 25 percent, air travel 15 percent, and other transportation 11 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 2020, the transportation sector accounted for 78.9 percent of total U.S. petroleum consumption. In 2050, transportation is expected to account for 76.9 percent of U.S. petroleum use, with the industrial sector accounting for 21.3 percent. The residential and commercial sectors, unspecified sector consumption, and electricity generation combined are expected to account for just 1.8 percent of U.S. petroleum consumption in 2050. With petroleum expected to be the only U.S. primary fuel with net imports in 2050 and transportation expected to account for 76.9 percent of U.S. petroleum use in 2050, U.S. net petroleum imports through 2050 are expected to result primarily from fuel consumption by the transportation sector.

The accounting for EPA CO_2 emissions standards and NHTSA CAFE standards in the AEO 2021 forecast contributes to a 34.7 percent forecast increase from 2020 to 2050 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. These standards are also reflected in the CAFE Model forecast for the No Action Alternative.[8]

The AEO 2021 also forecasts a 14.1 percent increase from 2020 to 2050 in energy used by HD vehicles, and a 52.7 percent increase in VMT for HD trucks. The large forecast increase in HD vehicle VMT results in a relatively small increase in HD vehicle fuel use because there is a large forecast increase in HD vehicle stock fuel efficiency as older vehicles are replaced by vehicles that comply with Phase 1 and Phase 2 standards for HD vehicle fuel efficiency. The 14.1 percent forecast increase in energy used by HD vehicles is associated with a 1.0 percent forecast increase from 2020 to 2050 in transportation sector diesel use, with the diesel share of HD vehicle fuel use expected to decline from 81.3 percent in 2020 to 75.3 percent of HD vehicle fuel in 2050.

3.2 Petroleum Imports and U.S. Energy Security

Section 3.1, *Affected Environment,* shows that the United States is expected to have net energy exports from 2020 through 2050 for the combination of all source fuels. Petroleum net imports are also expected to decline. In 2050, the transportation sector is expected to account for 76.9 percent of all U.S. petroleum use, with passenger cars and light trucks accounting for 50.1 percent of transportation energy consumption. 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. This SEIS describes the effect of lower gasoline use on refining and petroleum production and imports. Readers may consult Chapter 6.2.4 of the TSD for a description on considerations for energy security.

3.3 Environmental Consequences

All of the action alternatives would contribute to projected ongoing declines in U.S. energy intensity through 2050, but to a larger 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 51 percent from 2020 through 2050. Under Alternatives 1, 2 (NHTSA's Preferred Alternative), and 3, the average fuel economy of all light-duty vehicles in use would increase by 61, 67, and 73 percent, respectively, from 2020 through 2050, as older, less efficient vehicles are replaced by new vehicles that achieve much better fuel economy. Gasoline accounts for 91 percent to 95 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 3.3-1 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, hydrogen, and electricity used to power the light-duty vehicle fleet.

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[8] AEO is an energy forecast, not a rulemaking analysis. AEO uses the EIA's National Energy Modeling System (NEMS), which represents fleets and standards at a highly generalized level that, while appropriate for economy-wide energy forecasting, is too generalized to be usable for rulemaking analysis. NHTSA's analysis supporting the SEIS and preamble uses DOT's CAFE Model, which is designed to support rulemaking analysis. Since 2012, DOT, working with EPA, has significantly expanded and refined the CAFE Model, and has updated many accompanying input data and estimates. Some model inputs are considerably different from those used in 2012.

Table 3.3-1 shows 2020 to 2050 fuel use resulting from the action and alternatives compared to the No Action Alternative.

Table 3.3-1. Fuel Consumption and Decrease 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
Fuel Consumption				
Cars	1,396	1,339	1,295	1,259
Light trucks	2,114	2,070	2,049	2,023
All light-duty vehicles	3,510	3,409	3,344	3,282
Decrease in Fuel Use Compared to the No Action Alternative				
Cars	--	-56	-101	-136
Light trucks	--	-44	-65	-91
All light-duty vehicles	--	-100	-166	-227

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 3,510 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the action alternatives is projected to range from 3,409 billion GGE under Alternative 1 to 3,282 billion GGE under Alternative 3. All of the action alternatives would decrease fuel consumption compared to the No Action Alternative, with decreases that range from 100 billion GGE under Alternative 1 to 227 billion GGE under Alternative 3.

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; extracting, refining, and transporting crude oil; burning coal, natural gas, and other fossil fuels; and manufacturing chemicals and other products from raw materials as well as other industrial and agricultural operations. Air pollution from these various sources can cause adverse impacts on public health and the environment. 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 2020b).

To reduce air pollution levels, the Federal Government and state agencies have passed legislation and established regulatory programs to control sources of emissions. The Clean Air Act (CAA) is the primary federal legislation that addresses air quality. Under the CAA, as amended, EPA has established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants.[1] The criteria pollutants discussed in this SEIS 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 (VOCs). This air quality analysis assesses the impacts of Alternative 0 (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 2020, emissions from on-road mobile sources declined 90 percent for CO, 76 percent for NO_X, 72 percent for PM2.5 (1990 to 2020), 55 percent for PM10, 94 percent for SO_2, and 91 percent for VOCs (EPA 2020c, 2020d, 2020e, 2020f, 2020g, 2020h). 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 17.2 million tons[2] per year of CO (25 percent of total U.S. emissions), 90,000 tons per year (1 percent) of PM2.5, and

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[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.

[2] The term *ton(s)* as used in this chapter refers to U.S. tons (2,000 pounds).

216,000 tons per year (1 percent) of PM10 (EPA 2020c, 2020d, 2020e). 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 2014b). Almost all of the PM in motor vehicle exhaust is PM2.5 (Gertler et al. 2000; EPA 2014b); therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also emit 1.4 million tons per year (8 percent of total U.S. emissions) of VOCs and 2.4 million tons per year (29 percent) of NO_X, which are chemical precursors of ozone (EPA 2021b). Passenger cars and light trucks emit 90 percent of U.S. highway emissions of VOCs and 51 percent of NO_X (EPA 2014b). In addition, NO_X is a PM2.5 precursor and VOCs can be PM2.5 precursors.[3] 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 0.5 percent of U.S. SO_2 emissions (EPA 2020g) due to the introduction of fuel sulfur limits for both gasoline and diesel. Similarly, 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.

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 $\mu g/m^3$) present in repeated air samples taken at designated monitoring locations. These ambient concentrations of each criteria pollutant are compared to the permissible levels specified by NAAQS to assess whether the region's air quality could be unhealthful.

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

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[3] 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 2004).

Table 4.1.1-1. National Ambient Air Quality Standards

Pollutant	Primary Standards		Secondary Standards	
	Level[a]	Averaging Time	Level[a]	Averaging Time
Carbon monoxide (CO)	9 ppm (10 mg/m^3)	8 hours[b]	None	
	35 ppm (40 mg/m^3)	1 hour[b]		
Lead	0.15 µg/m^3	Rolling 3-month average	Same as primary 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]

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 2016a

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 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).[4] 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 (2017) for 20,593 tons per year (3 percent of total U.S.

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[4] 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, 1,124 tons per year (1.5 percent) of acrolein emissions, 43,019 tons per year (21 percent) of benzene emissions, 6,514 tons per year (12 percent) of 1,3-butadiene emissions, and 26,838 tons per year (2.4 percent) of formaldehyde emissions (EPA 2020i, 2020j, 2020k, 2020l, 2020m).[5]

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.[6] 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 2014c).

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.[7] 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; Zhang and Batterman 2013; Matz et al. 2019; Steib et al. 2020). The health outcomes with the strongest evidence of linkages with traffic-associated air pollutants are respiratory effects, particularly in asthmatic children, and cardiovascular effects.

Numerous reviews of this body of health literature have been published as well. In 2010, an expert panel of the Health Effects Institute (HEI) published a review of hundreds of exposure, epidemiology, and toxicology studies (HEI 2010). The panel rated how the evidence for each type of health outcome supported a conclusion of a causal association with traffic-associated air pollution as either "sufficient," "suggestive but not sufficient," or "inadequate and insufficient." The panel categorized evidence of a

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

[6] 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).

[7] 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 exacerbation of childhood asthma as “sufficient,” and categorized evidence of a 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). Researchers from the U.S. Centers for Disease Control and Prevention 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 studies have found association between exposure to ambient air pollution during pregnancy and childhood cancer risks and association between post-natal exposure and childhood cancer risks (e.g., Lavigne et al 2017; Tamayo-Uria et al. 2018).

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; Xu et al. 2016; Salvi and Salim 2019).

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; Puett et al. 2019). 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; Farzan et al. 2021; Johnson et al. 2020).

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 SEIS. 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. Section 7.5, *Environmental Justice*, addresses the impacts of air pollution and climate change on minority and low-income populations.

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 (2012a). The most recent EPA technical reports and *Federal Register* notices for NAAQS reviews provide more information on the health effects of criteria pollutants (EPA 2013a, 2015a).

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 the United States Department of Agriculture (USDA 2016), 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 (NPS 2019). 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 (Pinto et al. 2010). 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[8] 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).[9] Gasoline-fueled and diesel-fueled vehicles emit PM. In general, the

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[8] Metabolites are formed as the initial compounds break down and are transformed through metabolism.

[9] 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

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 2019a).

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,[10] 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.[11] 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

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(EPA 2012b). 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* (Long et al. 2013).

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

[11] Highway motor vehicles overall accounted for approximately 25 percent of national CO emissions in 2018 (EPA 2020c). Passenger cars and light trucks account for approximately 93 percent of the CO emissions from highway motor vehicles (EPA 2014b) while heavy-duty vehicles account for the remaining 7 percent (EPA 2019b).

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, a reddish-brown, highly reactive gas, is 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 (NO), 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 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 SEIS. This information is adapted from the preamble to the EPA Tier 3 Motor Vehicle Emission and Fuel Standards Rule.[12]

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 SEIS. These compounds, plus polycyclic organic matter and naphthalene, were identified as national or regional risk drivers or contributors in the EPA 2014 National-Scale Air Toxics Assessment and have significant inventory contributions from mobile sources (EPA 2018b). This SEIS 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 SEIS, 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 Fourteenth Report on Carcinogens (NTP 2016a), 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, 2000a). In short-term (4-week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure (National Research Council Committee on Emergency and Continuous Exposure Guidance Levels for Selected Submarine Contaminants 2009). EPA used data from these studies to develop an inhalation reference

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

concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume and bronchoconstriction upon inhaling acetaldehyde (OEHHA 2008).

Acrolein

Acrolein is extremely acrid and is irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion, and congestion. The intense irritancy of this carbonyl compound has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure (EPA 2003a). The EPA 2003 IRIS human health risk assessment for acrolein (EPA 2003a) summarizes these data and additional studies regarding acute effects of human exposure to acrolein. Evidence 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 (OEHHA 2008). Lesions to the lungs and upper respiratory tracts of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein (OEHHA 2008). Animal studies report acute exposure effects such as bronchial hyper-responsiveness (OEHHA 2008). In a recent study, the acute respiratory irritant effects of exposure to 4 ppm acrolein were more pronounced in mice with allergic airway disease compared to nondiseased mice, which also showed decreases in respiratory rate (Snow et al. 2017). 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 classifiable as “probably carcinogenic” with respect to its carcinogenicity in humans (IARC 2020; Lancet 2021).

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 2018). 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 2018; NTP 2016b).

Several adverse noncancer health effects, including blood disorders such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene (OEHHA 2014). The most sensitive noncancer effect observed in humans, based on current data, is depression of the absolute lymphocyte count in blood (OEHHA 2014; EPA 2003b). In addition, recent work, including studies sponsored by the HEI, provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known (OEHHA 2014).

1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans through inhalation (EPA 2002a, 2002b). 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 2012; NTP 2016c). 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 (EPA 2002b).

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 2002c), 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 to 1999 EPA cancer guidelines (EPA 1999). EPA published a review of diesel exhaust health effects in 2007 (Ris 2007). The assessment concluded that long-term inhalation exposure is likely to pose a lung cancer hazard to humans as inferred from epidemiologic and certain animal studies. 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) have made similar hazard classifications.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. 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 [DPM] 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 have continued 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 (HEI 2015; 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 2014; Silverman 2018). 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 1991). 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 2016d; IARC 2012).
The conclusions by IARC and the National Toxicology Program reflect the results of epidemiologic research published since 1991, in combination with previous animal, human, and mechanistic evidence. Research by the National Cancer Institute reported an increased risk of nasopharyngeal (nose and throat) cancer and specific lymphohematopoietic (lymph and blood) malignancies among workers

exposed to formaldehyde (NCI 2011). 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. 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 (Checkoway et al. 2015). 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).

Other health effects of formaldehyde were reviewed by the Agency for Toxics Substances and Disease Registry in 1999 (ATSDR 1999) and supplemented in 2010 (ATSDR 2010), National Toxicology Program (NIH 2011), 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 2010a). 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 designated formaldehyde as a High-Priority Substance in December 2019 and the chemical is currently undergoing risk evaluation. In August 2020, EPA published a final scope document outlining the hazards, exposures, conditions of use, and the potentially exposed or susceptible subpopulations the agency expects to consider in its risk evaluation (EPA 2021c).

4.1.1.3 Vehicle Emissions Standards

EPA and the California Air Resources Board (CARB) have established criteria pollutant emissions standards for vehicles under the CAA. EPA and CARB have tightened these emissions standards over time as more effective emissions-control technologies have become available.[13] 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 applied to MY 2004–2016 passenger cars and light trucks (EPA 2000c). Under the Tier 2 standards, manufacturers of passenger cars and light trucks were 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

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[13] The CAA, Section 177 (42 U.S.C. § 7507), gives states the option to adopt California's emissions standards provided they are more stringent than the corresponding federal standards; states that have done so sometimes are referred to as "Section 177" states. In addition to California and Section 177 states' GHG emissions standards, discussed in Section 8.6.3.1, *United States: Regional and State Actions*, California and Section 177 states have enacted more stringent criteria pollutant emissions standards for vehicles under the CAA. California's regulation of criteria pollutant emissions from motor vehicles dates back to the 1970s and was the precursor to Congress' grant of authority to California to regulate in Section 209 of the CAA, and to other states in Section 177 of the CAA.

vehicle emissions and fuel standards.[14] 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, which are being phased in over MYs 2017–2025 and will remain constant thereafter at the MY 2025 levels. 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 2014d).

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.

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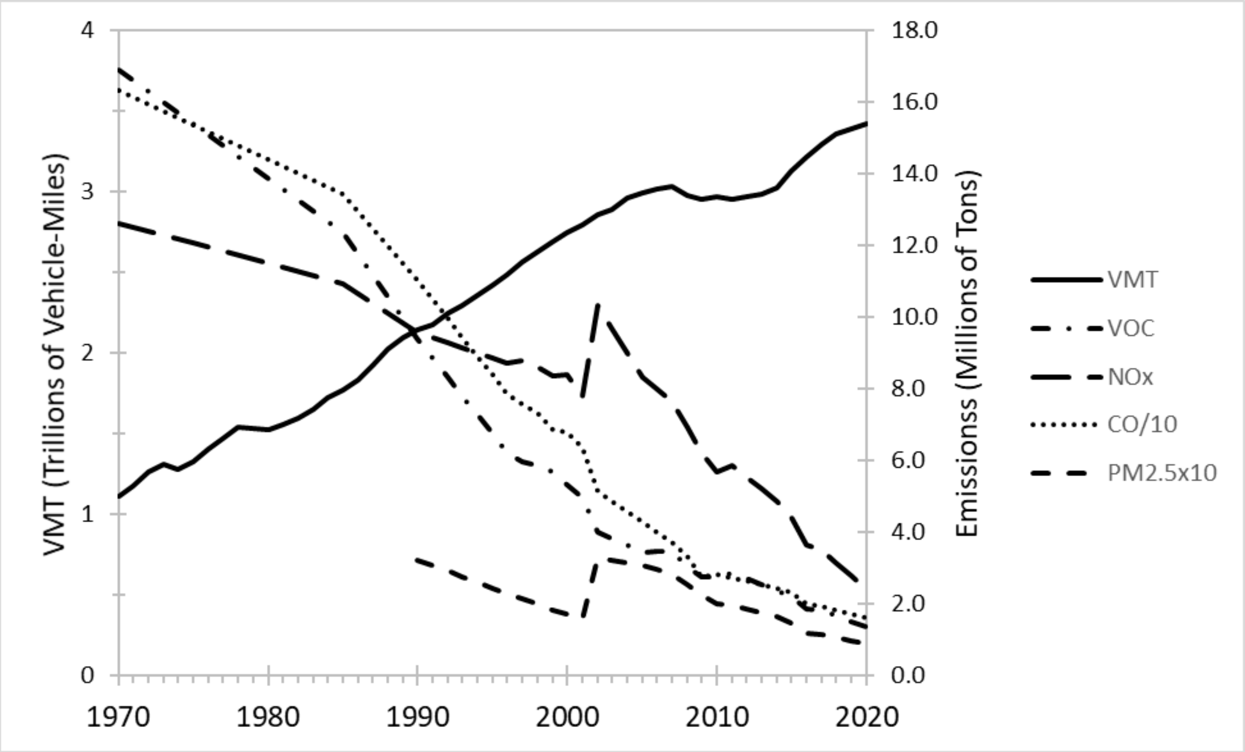
[14] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

Figure 4.1.1-1. 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 2013b).

Sources: Davis and Boundy 2021; EPA 2021a

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.[15] 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[16] applies to transportation plans, programs, and projects that are developed, funded, or approved under 23 U.S.C. (Highways) or 49 U.S.C. Chapter 53 (Public

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[15] 42 U.S.C. § 7506(c)(1)-(2).

[16] 40 CFR Part 51, Subpart T, and Part 93, Subpart A.

Transportation). The General Conformity Rule[17] 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.[18] 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."[19] Because NHTSA's Proposed Action would set fuel economy standards for passenger cars and light trucks, it would cause no direct emissions consistent with the meaning of the General Conformity Rule.[20]

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."[21] 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

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[17] 40 CFR Part 51, Subpart W, and Part 93, Subpart B.

[18] 40 CFR § 93.153(b).

[19] 40 CFR § 93.152.

[20] *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 proposed action is to amend fuel economy standards for MY 2024–2026 passenger car and light trucks; any emissions increases would occur well after promulgation of a final rule.

[21] 40 CFR § 93.152.

emissions, such initial steps do not mean that a Federal agency can practically control any resulting emissions."[22]

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.[23]

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 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. For more information on the analysis related to the General Conformity Rule, *see* Section IX.D of the preamble to the proposed rule.

4.1.2 Methods

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

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 to be proportional to the changes in emissions projected to occur under each action alternative.

The air quality analysis accounted for manufacturers' projected responses to CAFE and CO_2 standards (including agreements some manufacturers have reached with California for MYs 2021–2026), zero emission vehicle mandates in place in California and most "Section 177" states,[24] and NHTSA's estimates of future fuel prices, market demand for fuel economy, and the cost and efficacy of fuel-saving technologies. The analysis also accounted for market responses, including demand for new passenger

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[22] 40 CFR § 93.152.

[23] *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).

[24] *Section 177 states* refers to the states that have adopted California's criteria pollutant and GHG emissions regulations under Section 177 of the Clean Air Act (42 U.S.C. § 7507).

cars and light trucks, scrappage of used passenger cars and light trucks, and demand for travel (i.e., VMT), accounting for the rebound effect. The resultant change in emissions under each alternative would be the sum of the following components:

- Decreases in upstream emissions that result from decreases in gasoline consumption and, therefore, lower volumes of fuel production and distribution.
- Increases in upstream emissions that result from increases in electricity generation to power plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).
- Increases in per-vehicle downstream emissions resulting from slight shifts toward light trucks (because improving fuel economy produces larger fuel savings for light trucks than for passenger cars, and criteria pollutant and air toxic per-mile emission rates for light trucks are projected to remain higher than for passenger cars) and slightly greater reliance on older vehicles (which have higher per-mile emission rates than newer vehicles).
- Increases in emissions resulting from increased VMT due to the rebound effect.
- Decreases in downstream emissions resulting from increases in electrification.

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 extraction, production, and distribution of fuels, including contributions from the power plants that generate the electricity used to recharge electric vehicles (EVs) 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 (2020) grid mix is composed of natural gas, coal, nuclear, hydroelectric, wind, other renewable energy sources, and oil. The largest sources of electricity are from natural gas (40 percent), followed by renewables (20 percent), nuclear (20 percent), and coal (19 percent) (EIA 2021b).

To estimate upstream emissions changes resulting from changes in downstream fuel consumption, the analysis uses emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (version 2020 developed by the U.S. Department of Energy, Argonne National Laboratory). Upstream emission factors for gasoline, diesel, flex fuel (E85), and electricity in grams per million British thermal units (MMbtu) were taken from the GREET model in 5-year increments beginning in 2020 and ending in 2050. The agencies developed toxics upstream emission factors that are consistent with EPA's National Emission Inventory and emission factors from the Motor Vehicle Emissions Simulator (MOVES) model (EPA 2020a).[25] A spreadsheet model was developed to adjust upstream emission factors to account for the imported share of petroleum.

The analysis presented throughout this SEIS 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 2020 to 2050 in GREET to account for projected changes in the national grid mix. The GREET model contains information on the intensities (amount of pollutant emitted per unit of electrical energy generated) that extend to 2050. To project the U.S. average electricity-generating fuel mix, this rulemaking uses the Annual Energy Outlook 2021 forecast

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[25] 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.

from the National Energy Modeling System, an energy-economy modeling system from the U.S. Department of Energy.[26]

4.1.2.2 Regional Analysis

Over the course of the development of recent CAFE EISs (NHTSA 2010, 2012, 2020) and the medium- and heavy-duty fuel efficiency standards Phase 1 and 2 EISs (NHTSA 2011, 2016a), 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.[27] Appendix B, *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, *Relevant Pollutants and Standards*). On-road motor vehicles are a minor contributor to SO_2 emissions (less than 0.5 percent of national emissions, as noted above) (EPA 2020g) and are unlikely to affect the attainment status of SO_2 nonattainment and maintenance areas.

NHTSA's emissions analysis is national and regional but does not attempt to address the specific geographic locations of 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, *Other Past, Present, and Reasonably Foreseeable Future Actions*). Because hybrid electric vehicles and PHEVs have lower tailpipe emissions compared to conventionally fueled vehicles, and BEVs have no tailpipe emissions, greater EV 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. In addition, EV charging location and time affects emissions from power plants by changing the demand for

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[26] The Annual Energy Outlook is the annual energy consumption forecast produced by the U.S. Energy Information Administration.

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

electricity in the region where charging occurs, for the duration of charging (Section 6.2.3.1, *Charging Location*). NHTSA's emissions analysis does not assume any variation in EV charging by location or time.

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 changes 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.[28] 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; NHTSA projects that by 2025, most manufacturers could be midway through a full response to new CAFE standards.
- **2035:** A midterm forecast year; by 2035 manufacturers could be several years beyond a full response to new CAFE standards, with vehicles produced in model years beyond 2023 accounting for much of the on-road fleet's VMT.
- **2050:** By 2050, vehicles produced in model years beyond 2023 will account for almost all of the on-road fleet's VMT, such that changes in year-over-year impacts would be determined primarily by VMT growth.

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.[29] 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

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[28] 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.

[29] 40 CFR § 1502.22(b) (2019).

passenger car and light truck fleet, VMT projections, emissions from fuel refining and distribution, the future composition of the grid mix, and economic factors.

To support the information in this SEIS, NHTSA used the best available models and supporting data. The models used for the SEIS 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 impacts. To approximate the health impacts associated with each alternative, NHTSA used screening-level estimates of health impacts in the form of cases per ton of criteria pollutant emissions change. Changes in emissions of toxic air pollutants should also result in health impacts, but scientific data that would support quantification and monetization of these impacts are not available.

4.1.2.5 Allocation of Exhaust Emissions to Nonattainment Areas[30]

For each alternative, the CAFE Model 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).[31] 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. These EPA data were projected for 2028, the most representative year available in the EPA dataset. 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 Model.

NHTSA used the county-level VMT allocations, expressed as the fractions of national VMT that takes place within each county, to derive the county-level emissions from the estimates of nationwide total emissions. Emissions for each nonattainment area were then derived by summing the emissions for the counties included in each nonattainment area. Many nonattainment areas comprise one or more counties, and because county-level emissions are aggregated for each nonattainment area, uncertainties in the county-level emissions estimates carry over to estimates of emissions within each 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

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[30] 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.

[31] The VMT data provided by EPA are based on data generated by FHWA.

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 2021d). 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 2021 nonattainment area definitions. The populations of these partial-county areas were calculated using estimated population trends 2018 to 2023 (SimplyAnalytics 2017) with those trends extrapolated to the analysis years and 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; Eno Center for Transportation 2019).

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 because these are the pollutants for which nonattainment areas encompass the largest human populations. For the complete list of nonattainment and maintenance areas for all pollutants and standards, see Appendix B, *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]
Allegan County, MI	Ozone	Marginal	100
Allegheny County, PA	PM2.5	Moderate	100
Allentown, PA	PM2.5	Maintenance	100
Allentown-Bethlehem-Easton, PA	Ozone	Marginal	50
Amador County, CA	Ozone	Marginal	100
Atlanta, GA	Ozone	Marginal	100
Baltimore, MD	Ozone	Moderate	50
Baton Rouge, LA	Ozone	Maintenance	100
Berrien County, MI	Ozone	Marginal	100
Birmingham, AL	PM2.5	Maintenance	100
Butte County, CA	Ozone	Marginal	100
Calaveras County, CA	Ozone	Marginal	100
Canton-Massillon, OH	PM2.5	Maintenance	100
Charleston, WV	PM2.5	Maintenance	100
Charlotte-Gastonia-Rock Hill, NC-SC	Ozone	Maintenance	100

Nonattainment/Maintenance Area	Pollutant	Status [a]	General Conformity Threshold [b]
Chicago-Naperville, IL-IN-WI	Ozone	Serious	50
Chico (Butte County), CA	Ozone	Marginal	100
Chico, CA	PM2.5	Maintenance	100
Cincinnati-Hamilton, OH-KY-IN	Ozone	KY: Marginal OH, IN: Maintenance	100
Cleveland, OH	Ozone	Marginal	100
Cleveland, OH	PM2.5	Maintenance	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	Serious	50
Delaware County, PA	PM2.5	Maintenance	100
Denver Metro/North Front Range, CO	Ozone	Marginal	100
Denver-Boulder-Greeley-Fort Collins-Loveland, CO	Ozone	Serious	50
Detroit, MI	Ozone	Marginal	100
Detroit-Ann Arbor, MI	PM2.5	Maintenance	100
Doña Ana County (Sunland Park Area), NM	Ozone	Marginal	100
Door County, WI	Ozone	Maintenance	100
Dukes County, MA	Ozone	Marginal	50
Fairbanks, AK	PM2.5	Serious	70
Greater Connecticut, CT	Ozone	Serious	50
Harrisburg-Lebanon-Carlisle-York, PA	PM2.5	Maintenance	100
Houston-Galveston-Brazoria, TX	Ozone	Serious	50
Imperial County, CA	Ozone	Moderate	100
Imperial County, CA	PM2.5	Moderate	100
Inland Sheboygan County, WI	Ozone	Maintenance	100
Jamestown, NY	Ozone	Marginal	50
Johnstown, PA	PM2.5	Maintenance	100
Kern County (Eastern Kern), CA	Ozone	Serious	50
Klamath Falls, OR	PM2.5	Moderate	100
Knoxville, TN	Ozone	Maintenance	100
Knoxville-Sevierville-LaFollette, TN	PM2.5	Maintenance	100
Lancaster, PA	Ozone	Marginal	50
Lancaster, PA	PM2.5	Maintenance	100
Las Vegas, NV	Ozone	Marginal	100
Lebanon County, PA	PM2.5	Maintenance	100
Liberty-Clairton, PA	PM2.5	Moderate	100
Logan, UT-ID	PM2.5	Moderate	100

Nonattainment/Maintenance Area	Pollutant	Status [a]	General Conformity Threshold [b]
Los Angeles, CA	PM2.5	Serious	70
Los Angeles-San Bernardino Counties (Western Mojave Desert), CA	Ozone	Severe-15	25
Los Angeles South Coast Air Basin, CA	Ozone	Extreme	10
Los Angeles South Coast Air Basin, CA	PM2.5	Serious	50
Louisville, KY-IN	Ozone	Marginal	100
Manitowoc County, WI	Ozone	Marginal	100
Mariposa County, CA	Ozone	Moderate	100
Memphis, TN-MS-AR	Ozone	Maintenance	100
Milwaukee-Racine, WI	PM2.5	Maintenance	100
Morongo Band of Mission Indians, CA	Ozone	Serious	50
Muskegon County, MI	Ozone	Marginal	100
Nevada County (western part), CA	Ozone	Serious	50
New York-N. New Jersey-Long Island, NY-NJ-CT	Ozone	Serious	50
New York-N. New Jersey-Long Island, NY-NJ-CT	PM2.5	Maintenance	100
Nogales, AZ	PM2.5	Moderate	100
Northern Milwaukee/Ozaukee Shoreline, WI	Ozone	Marginal	100
Northern Wasatch Front, UT	Ozone	Marginal	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	Maintenance	100
Plumas County, CA	PM2.5	Moderate	100
Provo, UT	PM2.5	Serious	70
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	Serious	70
San Antonio, TX	Ozone	Marginal	100
San Diego County, CA	Ozone	Serious	50
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

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

Notes:

[a] Pollutants for which the area is designated in nonattainment or maintenance as of 2019. 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 2021d

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

For liquid and gaseous fuels, 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. 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). 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.[32] 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, 2020) and the heavy-duty fuel efficiency standards EISs (NHTSA 2011, 2016a). NHTSA made a number of important assumptions for this analysis because of uncertainty over the accuracy of the allocation of upstream emissions. A similar analysis was performed for upstream emissions from electricity for transportation use, accounting for feedstock production and then electricity generation and transmission using a nationally representative grid mix.

To analyze the impacts of the alternatives on individual nonattainment areas, NHTSA allocated projected emissions data from the EPA 2016-based air quality modeling platform (EPA 2021e). These EPA data were projected for 2028, the most representative year available in the EPA dataset. NHTSA allocated changes in nationwide total emissions, for each of the four source categories separately, to individual nonattainment areas. The EPA modeling platform includes estimates of emissions of criteria and toxic pollutants by county and by source category. Because each of the four source categories represents a separate source category in the EPA modeling platform, it is possible to estimate the share of nationwide emissions from each category that occurs within each nonattainment area. This analysis assumes that the share of emissions from feedstock extraction and fuel refining allocated to each nonattainment area does not change over time, which means, in effect, that emissions for these two source categories are assumed to change uniformly (in percentage terms) across that category nationwide as a result of each alternative.[33] This analysis also assumes that the share of emissions from feedstock and fuel TS&D allocated to each nonattainment area can change over time based on the population forecast for each area.

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 criteria pollutant emissions. 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 increased emissions or as adverse health outcomes avoided 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 change in emissions of that pollutant and to sum the results of these

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

[33] NHTSA incorporated the feedstock recovery and feedstock transportation stages in this SEIS. Emissions from the feedstock recovery and feedstock transportation stages are small relative to total upstream and tailpipe emissions and do not have a substantial effect on the SEIS results.

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 2018b. 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 2013a), Ozone NAAQS RIA (EPA 2010b), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2010c), NO_2 NAAQS RIA (EPA 2010d), and most recently updated in *Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors* (EPA 2018b).[34] NHTSA included additional updates given in Wolfe et al. 2019. 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[35] as reported in the epidemiology literature.[36]

EPA developed national per-ton estimates for selected pollutants emitted through stationary and mobile activity (EPA 2018b; Wolfe et al. 2019). 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 reductions provide 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 2013c). 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.

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[34] EPA refers to this technique as the "benefit per ton" method for estimating the health benefits of reduced emissions, and NHTSA follows this terminology below. However, this technique applies equally to estimating the additional health outcomes from increased emissions.

[35] 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).

[36] The complete method for creating the benefit-per-ton estimates used in this analysis is provided in *Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors* (EPA 2018b) 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. NHTSA intends to conduct a photochemical modeling analysis for the Final SEIS using the same methods as in the CAFE Final EISs (NHTSA 2010, 2012, 2020) and the HD Fuel Efficiency Standards Phases 1 and 2 Final EISs (NHTSA 2011, 2016a). NHTSA intends to conduct the photochemical modeling analysis using a 12-kilometer (7.5-mile) by 12-kilometer grid cell size in accordance with EPA guidance (EPA 2018c), making use of the most recent EPA emissions information that is based on a 12-kilometer by 12-kilometer grid cell size.
- 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 2013a) provides more information about the overall uncertainty in the estimates of the benefits of reducing PM2.5 emissions.

Tables 4.1.2-3a–d list the incidence-per-ton estimates for PM-related health impacts (derived by the process described above). For the analysis of direct and indirect impacts (Section 4.2, *Environmental Consequences*) NHTSA used the 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 4.1.2-3a. Health Impact per Ton of Emissions (incidence per short ton)

Calendar Year	Upstream Emissions (Refineries Sector)			Upstream Emissions (Petroleum Extraction Sector)		
	NO_X	SO_X	PM2.5	NO_X	SO_X	PM2.5
2020						
Premature Deaths - Low (Krewski)	0.00082	0.0082	0.039	0.00029	0.0025	0.015
Premature Deaths - High (Lepeule)	0.0019	0.019	0.088	0.00065	0.0056	0.033
Respiratory emergency room visits	0.00044	0.0045	0.022	0.00014	0.0012	0.0077
Acute bronchitis	0.0012	0.012	0.059	0.00036	0.0032	0.020
Lower respiratory symptoms	0.016	0.16	0.75	0.0046	0.040	0.26
Upper respiratory symptoms	0.023	0.22	1.1	0.0065	0.057	0.36
Minor Restricted Activity Days	0.66	6.7	31	0.18	1.6	10.2
Work loss days	0.11	1.1	5.3	0.031	0.28	1.7
Asthma exacerbation	0.026	0.26	1.2	0.0075	0.065	0.42
Cardiovascular hospital admissions	0.00019	0.0021	0.0095	0.000068	0.00062	0.0036
Respiratory hospital admissions	0.00019	0.002	0.0089	0.000047	0.00044	0.0025
Non-fatal heart attacks (Peters)	0.00080	0.0082	0.038	0.00028	0.0025	0.014
Non-fatal heart attacks (All others)	0.000087	0.00089	0.0041	0.000030	0.00027	0.0016
2025						
Premature Deaths - Low (Krewski)	0.00087	0.0088	0.041	0.00029	0.0025	0.015
Premature Deaths - High (Lepeule)	0.0020	0.020	0.094	0.00065	0.0056	0.033
Respiratory emergency room visits	0.00045	0.0047	0.023	0.00014	0.0012	0.0077
Acute bronchitis	0.0013	0.013	0.061	0.00036	0.0032	0.020
Lower respiratory symptoms	0.016	0.16	0.78	0.0046	0.040	0.26
Upper respiratory symptoms	0.023	0.23	1.1	0.0065	0.057	0.36
Minor Restricted Activity Days	0.67	6.8	32	0.18	1.6	10.2
Work loss days	0.11	1.2	5.4	0.031	0.28	1.7
Asthma exacerbation	0.027	0.28	1.3	0.0075	0.065	0.42
Cardiovascular hospital admissions	0.00021	0.0023	0.010	0.000068	0.00062	0.0036
Respiratory hospital admissions	0.00021	0.0022	0.010	0.000047	0.00044	0.0025
Non-fatal heart attacks (Peters)	0.00088	0.0091	0.041	0.00028	0.0025	0.014
Non-fatal heart attacks (All others)	0.000095	0.00099	0.0045	0.000030	0.00027	0.0016
2030						
Premature Deaths - Low (Krewski)	0.00094	0.0095	0.044	0.00029	0.0025	0.015
Premature Deaths - High (Lepeule)	0.0021	0.022	0.10	0.00065	0.0056	0.033
Respiratory emergency room visits	0.00047	0.0049	0.024	0.00014	0.0012	0.0077
Acute bronchitis	0.0014	0.014	0.066	0.00036	0.0032	0.020
Lower respiratory symptoms	0.018	0.18	0.84	0.0046	0.040	0.26
Upper respiratory symptoms	0.025	0.25	1.2	0.0065	0.057	0.36
Minor Restricted Activity Days	0.68	7.0	33	0.18	1.6	10.2
Work loss days	0.12	1.2	5.6	0.031	0.28	1.7
Asthma exacerbation	0.029	0.29	1.4	0.0075	0.065	0.42
Cardiovascular hospital admissions	0.00024	0.0026	0.012	0.000068	0.00062	0.0036
Respiratory hospital admissions	0.00024	0.0025	0.011	0.000047	0.00044	0.0025
Non-fatal heart attacks (Peters)	0.00097	0.010	0.045	0.00028	0.0025	0.014
Non-fatal heart attacks (All others)	0.00010	0.0011	0.0049	0.000030	0.00027	0.0016

Table 4.1.2-3b. Health Impact per Ton of Emissions (incidence per short ton)

Calendar Year	Upstream Emissions (Petroleum Transportation Sector)			Upstream Emissions (Fuel TS&D Sector)		
	NO$_X$	SO$_X$	PM2.5	NO$_X$	SO$_X$	PM2.5
2020						
Premature Deaths - Low (Krewski)	0.00043	0.0061	0.022	0.00039	0.0088	0.026
Premature Deaths - High (Lepeule)	0.00098	0.014	0.051	0.00090	0.020	0.059
Respiratory emergency room visits	0.00022	0.0031	0.013	0.00021	0.0048	0.016
Acute bronchitis	0.00057	0.0076	0.030	0.00054	0.012	0.036
Lower respiratory symptoms	0.0072	0.10	0.39	0.0068	0.15	0.46
Upper respiratory symptoms	0.010	0.14	0.55	0.010	0.21	0.65
Minor Restricted Activity Days	0.30	4.1	17	0.28	6.4	20
Work loss days	0.050	0.71	2.8	0.048	1.1	3.4
Asthma exacerbation	0.012	0.16	0.64	0.011	0.25	0.76
Cardiovascular hospital admissions	0.00011	0.0016	0.0059	0.00010	0.0023	0.0069
Respiratory hospital admissions	0.00010	0.0015	0.0056	0.00010	0.0022	0.0066
Non-fatal heart attacks (Peters)	0.00043	0.0062	0.023	0.00040	0.0091	0.027
Non-fatal heart attacks (All others)	0.000046	0.00068	0.0025	0.000043	0.00098	0.0029
2025						
Premature Deaths - Low (Krewski)	0.00040	0.0062	0.022	0.00039	0.0091	0.026
Premature Deaths - High (Lepeule)	0.00092	0.014	0.051	0.00089	0.021	0.059
Respiratory emergency room visits	0.00021	0.0032	0.013	0.00020	0.0050	0.016
Acute bronchitis	0.00054	0.0078	0.030	0.00053	0.012	0.036
Lower respiratory symptoms	0.0069	0.10	0.39	0.0068	0.16	0.46
Upper respiratory symptoms	0.010	0.14	0.55	0.010	0.22	0.66
Minor Restricted Activity Days	0.28	4.2	17	0.28	6.7	20
Work loss days	0.048	0.73	2.8	0.047	1.1	3.4
Asthma exacerbation	0.012	0.17	0.64	0.011	0.26	0.77
Cardiovascular hospital admissions	0.00010	0.0016	0.0059	0.00010	0.0024	0.0070
Respiratory hospital admissions	0.00010	0.0016	0.0056	0.00010	0.0023	0.0066
Non-fatal heart attacks (Peters)	0.00040	0.0063	0.023	0.00040	0.0094	0.027
Non-fatal heart attacks (All others)	0.000044	0.00069	0.0025	0.000042	0.0010	0.0029
2030						
Premature Deaths - Low (Krewski)	0.00039	0.0062	0.022	0.00039	0.0091	0.026
Premature Deaths - High (Lepeule)	0.00089	0.014	0.050	0.00089	0.021	0.059
Respiratory emergency room visits	0.00020	0.0032	0.013	0.00020	0.0049	0.016
Acute bronchitis	0.00053	0.0078	0.030	0.00053	0.012	0.036
Lower respiratory symptoms	0.0066	0.10	0.38	0.0067	0.16	0.46
Upper respiratory symptoms	0.0095	0.14	0.55	0.010	0.22	0.66
Minor Restricted Activity Days	0.27	4.2	17	0.28	6.6	20
Work loss days	0.046	0.72	2.8	0.047	1.1	3.4
Asthma exacerbation	0.011	0.16	0.64	0.011	0.26	0.77
Cardiovascular hospital admissions	0.00010	0.0016	0.0059	0.00010	0.0024	0.0070
Respiratory hospital admissions	0.00010	0.0015	0.0056	0.00010	0.0023	0.0066
Non-fatal heart attacks (Peters)	0.00039	0.0063	0.023	0.00039	0.0094	0.027
Non-fatal heart attacks (All others)	0.000042	0.00069	0.0025	0.000042	0.0010	0.0029

Table 4.1.2-3c. Health Impact per Ton of Emissions (incidence per short ton)

	Upstream Emissions (Electricity Generation Sector)			Vehicle Emissions (On-Road Light-Duty Gas Cars & Motorcycles Sector)		
Calendar Year	**NO_X**	**SO_X**	**PM2.5**	**NO_X**	**SO_X**	**PM2.5**
2020						
Premature Deaths - Low (Krewski)	0.00066	0.0045	0.016	0.00075	0.013	0.073
Premature Deaths - High (Lepeule)	0.0015	0.010	0.037	0.0017	0.030	0.17
Respiratory emergency room visits	0.00032	0.0022	0.0091	0.00039	0.0076	0.041
Acute bronchitis	0.00085	0.0055	0.021	0.0010	0.020	0.11
Lower respiratory symptoms	0.011	0.070	0.27	0.013	0.25	1.4
Upper respiratory symptoms	0.016	0.10	0.39	0.018	0.35	2.0
Minor Restricted Activity Days	0.46	3.0	12	0.53	11	60
Work loss days	0.077	0.51	2.0	0.090	1.8	10
Asthma exacerbation	0.018	0.12	0.46	0.022	0.42	2.3
Cardiovascular hospital admissions	0.00016	0.0011	0.0040	0.00019	0.0036	0.020
Respiratory hospital admissions	0.00015	0.0011	0.0038	0.00018	0.0034	0.018
Non-fatal heart attacks (Peters)	0.00063	0.0045	0.016	0.00075	0.014	0.076
Non-fatal heart attacks (All others)	0.000068	0.00049	0.0017	0.000080	0.0015	0.0082
2025						
Premature Deaths - Low (Krewski)	0.00070	0.0048	0.017	0.00075	0.013	0.073
Premature Deaths - High (Lepeule)	0.0016	0.011	0.039	0.0017	0.030	0.17
Respiratory emergency room visits	0.00033	0.0023	0.0094	0.00039	0.0076	0.041
Acute bronchitis	0.00089	0.0057	0.022	0.0010	0.020	0.11
Lower respiratory symptoms	0.011	0.073	0.29	0.013	0.25	1.4
Upper respiratory symptoms	0.016	0.10	0.41	0.018	0.35	2.0
Minor Restricted Activity Days	0.46	3.0	12	0.53	11	60
Work loss days	0.077	0.52	2.0	0.090	1.8	10
Asthma exacerbation	0.019	0.12	0.48	0.022	0.42	2.3
Cardiovascular hospital admissions	0.00017	0.0012	0.0044	0.00019	0.0036	0.020
Respiratory hospital admissions	0.00017	0.0012	0.0043	0.00018	0.0034	0.018
Non-fatal heart attacks (Peters)	0.00068	0.0049	0.018	0.00075	0.014	0.076
Non-fatal heart attacks (All others)	0.000074	0.00054	0.0019	0.000080	0.0015	0.0082
2030						
Premature Deaths - Low (Krewski)	0.00074	0.0051	0.018	0.00075	0.013	0.073
Premature Deaths - High (Lepeule)	0.0017	0.011	0.042	0.0017	0.030	0.17
Respiratory emergency room visits	0.00034	0.0024	0.0098	0.00039	0.0076	0.041
Acute bronchitis	0.00096	0.0062	0.024	0.0010	0.020	0.11
Lower respiratory symptoms	0.012	0.079	0.31	0.013	0.25	1.4
Upper respiratory symptoms	0.017	0.11	0.44	0.018	0.35	2.0
Minor Restricted Activity Days	0.46	3.1	12	0.53	11	60
Work loss days	0.078	0.53	2.1	0.090	1.8	10
Asthma exacerbation	0.020	0.13	0.51	0.022	0.42	2.3
Cardiovascular hospital admissions	0.00018	0.0014	0.0048	0.00019	0.0036	0.020
Respiratory hospital admissions	0.00018	0.0013	0.0047	0.00018	0.0034	0.018
Non-fatal heart attacks (Peters)	0.00074	0.0053	0.019	0.00075	0.014	0.076
Non-fatal heart attacks (All others)	0.000079	0.00058	0.0021	0.000080	0.0015	0.0082

Table 4.1.2-3d. Health Impact per Ton of Emissions (incidence per short ton)

Calendar Year	Vehicle Emissions (On-Road Light-Duty Gas Trucks Sector) NO$_X$	SO$_X$	PM2.5	Vehicle Emissions (On-Road Light-Duty Diesel Sector) NO$_X$	SO$_X$	PM2.5
2020						
Premature Deaths - Low (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
Premature Deaths - High (Lepeule)	0.0015	0.024	0.14	0.0014	0.071	0.11
Respiratory emergency room visits	0.00035	0.0061	0.035	0.00032	0.019	0.029
Acute bronchitis	0.00096	0.016	0.091	0.00085	0.047	0.075
Lower respiratory symptoms	0.012	0.20	1.2	0.011	0.59	0.95
Upper respiratory symptoms	0.017	0.28	1.7	0.015	0.84	1.3
Minor Restricted Activity Days	0.49	8.5	49	0.44	25	40
Work loss days	0.084	1.4	8.4	0.075	4.3	6.9
Asthma exacerbation	0.020	0.33	1.9	0.018	1.0	1.6
Cardiovascular hospital admissions	0.00017	0.0028	0.016	0.00015	0.0085	0.013
Respiratory hospital admissions	0.00016	0.0027	0.015	0.00015	0.0081	0.013
Non-fatal heart attacks (Peters)	0.00068	0.011	0.064	0.00060	0.033	0.053
Non-fatal heart attacks (All others)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057
2025						
Premature Deaths - Low (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
Premature Deaths - High (Lepeule)	0.0015	0.024	0.14	0.0014	0.071	0.11
Respiratory emergency room visits	0.00035	0.0061	0.035	0.00032	0.019	0.029
Acute bronchitis	0.00096	0.016	0.091	0.00085	0.047	0.075
Lower respiratory symptoms	0.012	0.20	1.2	0.011	0.59	0.95
Upper respiratory symptoms	0.017	0.28	1.7	0.015	0.84	1.3
Minor Restricted Activity Days	0.49	8.5	49	0.44	25	40
Work loss days	0.084	1.4	8.4	0.075	4.3	6.9
Asthma exacerbation	0.020	0.33	1.9	0.018	1.0	1.6
Cardiovascular hospital admissions	0.00017	0.0028	0.016	0.00015	0.0085	0.013
Respiratory hospital admissions	0.00016	0.0027	0.015	0.00015	0.0081	0.013
Non-fatal heart attacks (Peters)	0.00068	0.011	0.064	0.00060	0.033	0.053
Non-fatal heart attacks (All others)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057
2030						
Premature Deaths - Low (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
Premature Deaths - High (Lepeule)	0.0015	0.024	0.14	0.0014	0.071	0.11
Respiratory emergency room visits	0.00035	0.0061	0.035	0.00032	0.019	0.029
Acute bronchitis	0.00096	0.016	0.091	0.00085	0.047	0.075
Lower respiratory symptoms	0.012	0.20	1.2	0.011	0.59	0.95
Upper respiratory symptoms	0.017	0.28	1.7	0.015	0.84	1.3
Minor Restricted Activity Days	0.49	8.5	49	0.44	25	40
Work loss days	0.084	1.4	8.4	0.075	4.3	6.9
Asthma exacerbation	0.020	0.33	1.9	0.018	1.0	1.6
Cardiovascular hospital admissions	0.00017	0.0028	0.016	0.00015	0.0085	0.013
Respiratory hospital admissions	0.00016	0.0027	0.015	0.00015	0.0081	0.013
Non-fatal heart attacks (Peters)	0.00068	0.011	0.064	0.00060	0.033	0.053
Non-fatal heart attacks (All others)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057

Source: EPA 2018b; Fann 2020

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$_X$ = oxides of sulfur

The EPA incidence-per-ton estimates shown in Tables 4.1.2-3a–d 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 Tables 4.1.2-3a–d.

4.2 Environmental Consequences

This section examines the direct and indirect impacts on air quality associated with the Proposed Action and alternatives. NHTSA has identified Alternative 2 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[37] 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 3 (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 except for SO_2. Emissions of CO, NO_X, PM2.5, and VOC decline from 2025 to 2050 because of increasingly stringent EPA regulation of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and*

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

Standards) and from reductions in upstream emissions from fuel production, despite a growth in total VMT from 2025 to 2040 (Table 4.2.1-1 and Figure 4.2.1-2). (Note that continued growth in VMT is projected to occur under all alternatives until 2040; a slight decline is projected to occur from 2040 to 2050.) Emissions of SO_2 decline from 2025 to 2035 under Alternatives 1 and 2, and increase from 2025 to 2035 under Alternative 3, but increase under all action alternatives from 2035 to 2050. These increases reflect the projected increase in EV use in the later years, which would result in greater emissions from fossil-fueled power plants to generate the electricity for charging the EVs even as the electric grid that charges EVs gets progressively cleaner in later years.

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.

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 changes, and increases in VMT. Other CAFE Model inputs and assumptions, which are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and at length in the proposed rule preamble, Technical Support Document, and Preliminary Regulatory Impact Analysis issued concurrently with this Draft SEIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates.

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
Carbon monoxide (CO)				
2025	10,985,695	11,007,764	11,012,087	11,032,757
2035	4,538,039	4,541,054	4,527,093	4,523,047
2050	1,654,182	1,625,380	1,583,570	1,540,333
Nitrogen oxides (NO_X)				
2025	932,772	934,237	934,862	936,540
2035	407,927	405,996	407,800	410,088
2050	216,099	212,663	211,594	211,650
Particulate matter (PM2.5)				
2025	33,567	33,580	33,603	33,641
2035	25,222	25,001	25,088	25,196
2050	19,676	19,370	19,235	19,193
Sulfur oxides (SO_2)				
2025	108,819	108,940	109,227	109,478
2035	104,767	104,299	107,160	109,782
2050	110,957	111,084	112,173	114,291
Volatile organic compounds (VOCs)				
2025	1,279,119	1,279,347	1,279,253	1,280,284
2035	666,956	655,525	645,835	638,435
2050	363,923	344,117	332,466	320,440

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

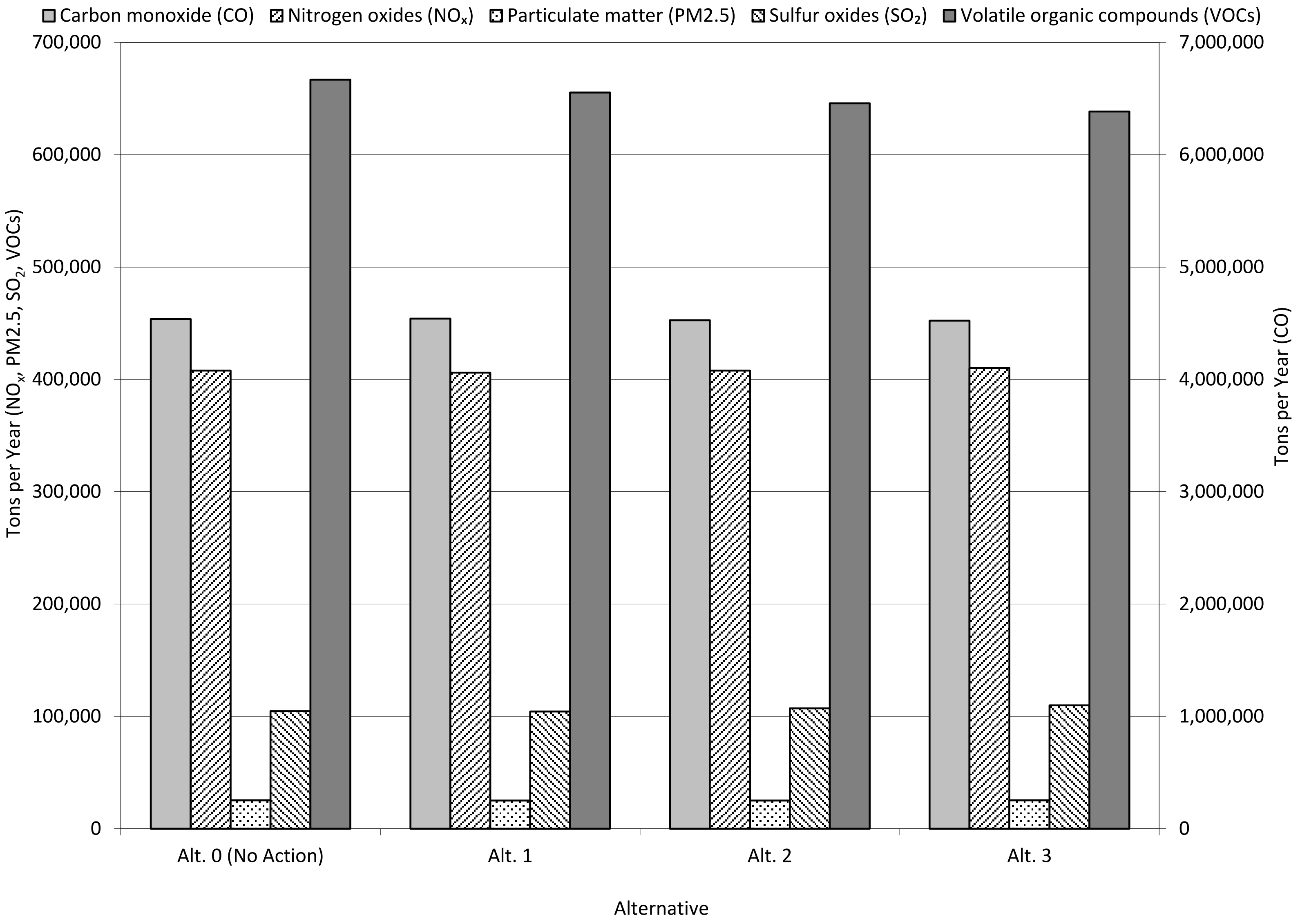


Figure 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives 1 and 3, Direct and Indirect Impacts

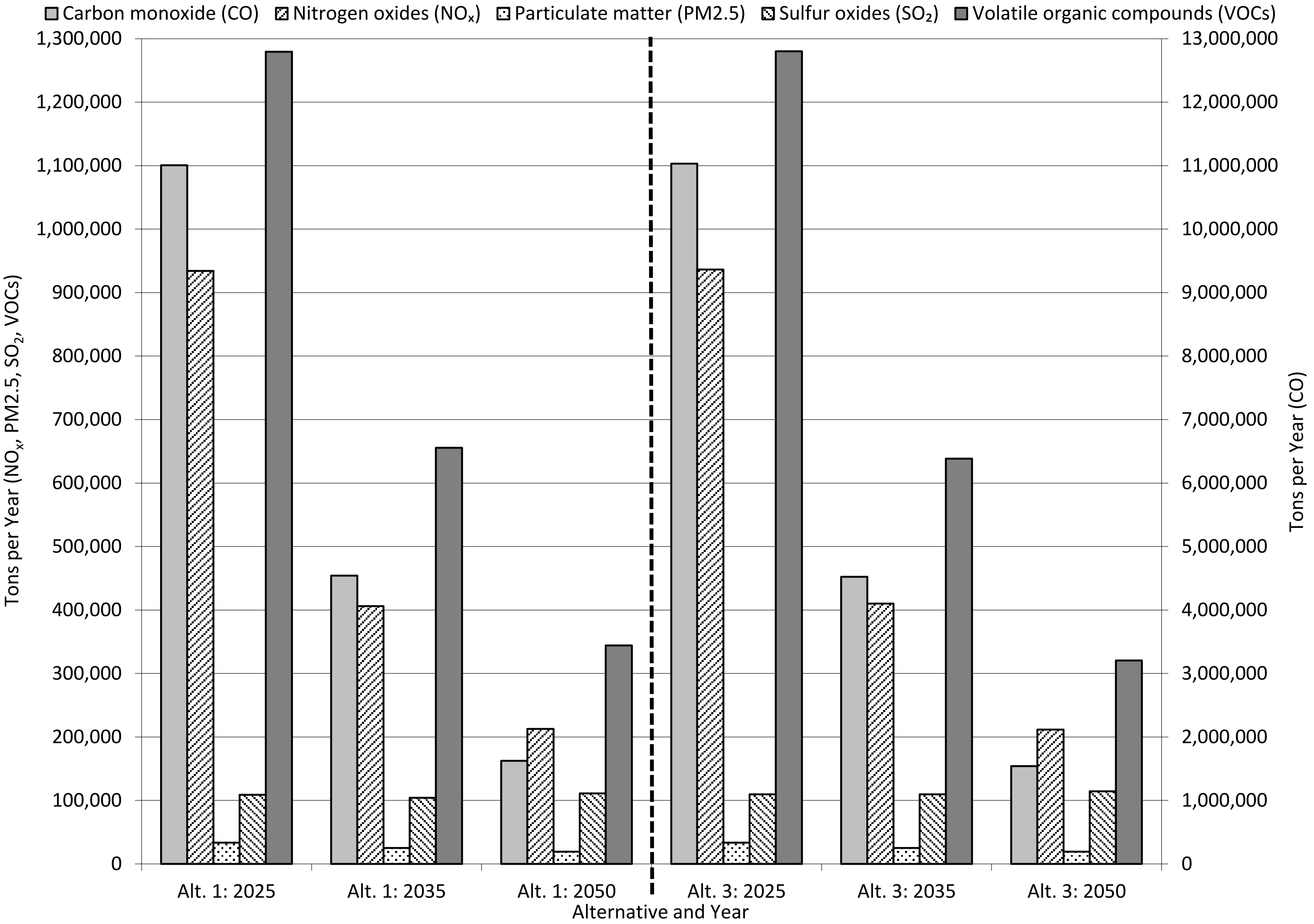


Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks by Vehicle Type and Alternative, Direct and Indirect Impacts

Vehicle Class	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Carbon monoxide (CO)				
Cars tailpipe	1,706,058	1,696,725	1,678,664	1,672,201
Cars upstream	40,038	39,304	39,508	39,479
Trucks tailpipe	2,734,835	2,748,485	2,751,476	2,752,810
Trucks upstream	57,108	56,540	57,445	58,557
Total	4,538,039	4,541,054	4,527,093	4,523,047
Nitrogen oxides (NO_X)				
Cars tailpipe	70,866	70,854	70,607	70,705
Cars upstream	74,663	73,122	73,224	73,004
Trucks tailpipe	154,973	155,778	156,278	156,901
Trucks upstream	107,425	106,242	107,691	109,478
Total	407,927	405,996	407,800	410,088
Particulate matter (PM2.5)				
Cars tailpipe	3,961	3,932	3,881	3,859
Cars upstream	6,258	6,133	6,148	6,134
Trucks tailpipe	6,023	6,052	6,050	6,037
Trucks upstream	8,979	8,883	9,010	9,166
Total	25,222	25,001	25,088	25,196
Sulfur oxides (SO_2)				
Cars tailpipe	2,756	2,604	2,457	2,358
Cars upstream	41,420	41,328	42,586	43,184
Trucks tailpipe	4,409	4,299	4,225	4,138
Trucks upstream	56,182	56,069	57,892	60,101
Total	104,767	104,299	107,160	109,782
Volatile organic compounds (VOCs)				
Cars tailpipe	115,852	115,820	115,367	115,516
Cars upstream	136,980	129,819	123,190	118,698
Trucks tailpipe	198,107	199,184	199,695	200,285
Trucks upstream	216,017	210,702	207,584	203,936
Total	666,956	655,525	645,835	638,435

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. Generally, the trend in total emissions of each pollutant relative to the stringency of the alternatives differs by forecast year.

- In 2025, emissions of all criteria pollutants increase under the action alternatives compared to the No Action Alternative. While the modeling results suggest emissions increases relative to the No Action Alternative that generally get larger from Alternative 1 through Alternative 3 (the most stringent alternative in terms of estimated required miles per gallon), these increases are quite small and, given the difficulties and assumptions involved in estimating, could easily trend in the opposite direction with slight changes in assumptions.
- In 2035, the emissions trends among the alternatives are mixed. For CO, emissions increase under Alternative 1 but decrease under Alternatives 2 and 3, with the larger decrease occurring under Alternative 3, compared to the No Action Alternative. For NO_X, emissions decrease under Alternatives 1 and 2, with the larger decrease occurring under Alternative 1, but increase under Alternative 3, compared to the No Action Alternative. For PM2.5 and VOC, emissions decrease under all action alternatives compared to the No Action Alternative. The PM2.5 emissions decreases get smaller from Alternative 1 through Alternative 3, while the VOC emissions decreases get larger from Alternative 1 through Alternative 3. For SO_2, emissions decrease under Alternative 1 but increase under Alternatives 2 and 3, with the larger increase occurring under Alternative 3, compared to the No Action Alternative.
- In 2050, emissions for all criteria pollutants (except SO_2) decrease under the action alternatives compared to the No Action Alternative. The emissions decreases get larger from Alternative 1 through Alternative 3. For SO_2 in 2050, emissions increase under the action alternatives compared to the No Action Alternative, and the emissions increases get larger from Alternative 1 through Alternative 3.

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]

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Carbon monoxide (CO)				
2025	0	22,069	26,391	47,062
2035	0	3,015	-10,946	-14,992
2050	0	-28,801	-70,612	-113,849
Nitrogen oxides (NO_X)				
2025	0	1,464	2,090	3,768
2035	0	-1,931	-127	2,162
2050	0	-3,436	-4,505	-4,449
Particulate matter (PM2.5)				
2025	0	13	37	75
2035	0	-221	-133	-26
2050	0	-306	-440	-483

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Sulfur oxides (SO_2)				
2025	0	121	408	659
2035	0	-468	2,392	5,014
2050	0	127	1,216	3,334
Volatile organic compounds (VOCs)				
2025	0	228	134	1,165
2035	0	-11,431	-21,121	-28,521
2050	0	-19,806	-31,457	-43,483

Notes:

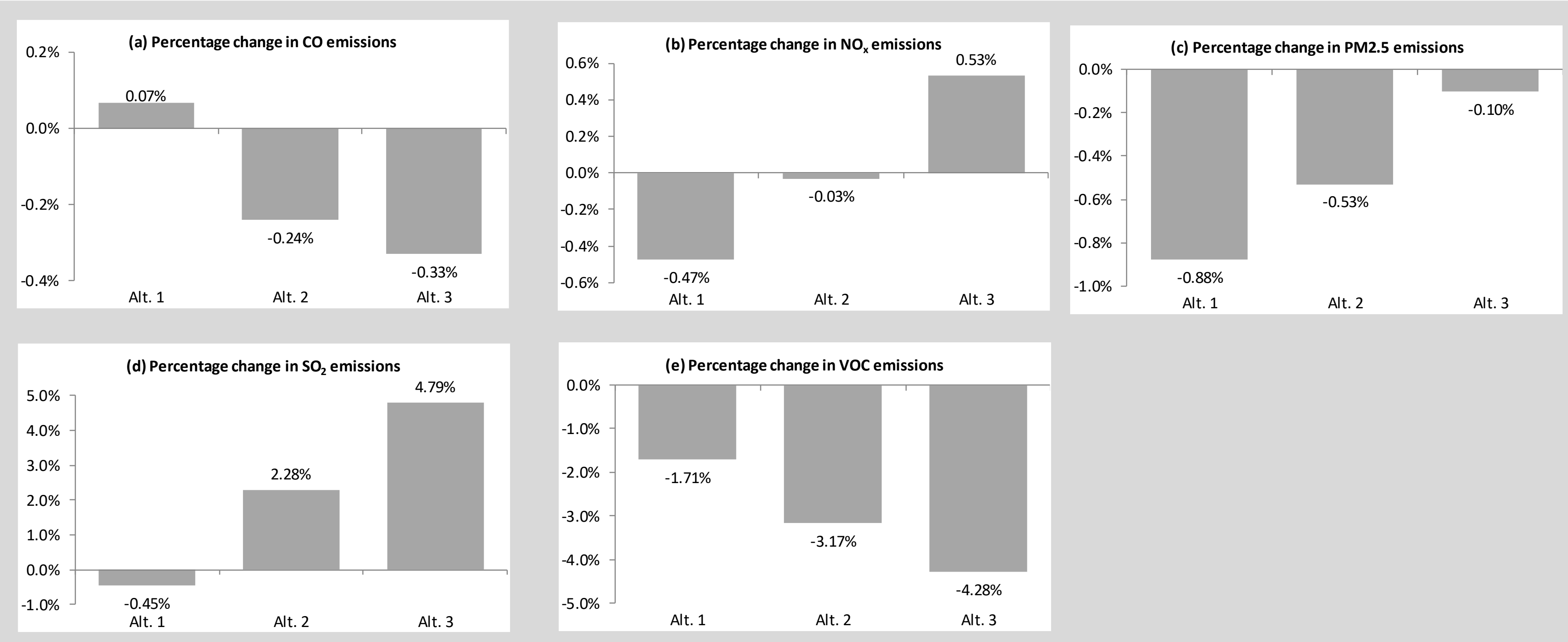
[a] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the action alternatives are compared.

Instances where downstream (tailpipe) emissions are predicted to increase (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 decrease compared to the No Action Alternative because the increases in vehicle tailpipe emissions due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy) would be offset by upstream emissions decreases due to decreases in fuel usage. Emissions of some criteria air pollutants in some years could increase compared to the No Action Alternative where the increases in vehicle emissions due to the rebound effect would not be offset by upstream emissions reductions due to decreases in fuel usage. If the estimates about rebound effect are incorrect, the emissions changes would correspondingly be incorrect. For example, if the rebound effect is lower, then emissions would be lower; if it is higher, then emissions would be higher.

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 4.8 percent under Alternative 3 in 2035 compared to the No Action Alternative. The largest relative decreases in emissions would occur for VOCs, for which emissions would decrease by as much as 11.9 percent under Alternative 3 in 2050 compared to the No Action Alternative (Table 4.2.1-1). Percentage increases and reductions in emissions of CO, NO_X, and PM2.5 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 about 12 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.

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 B, *Air Quality Nonattainment Area Results*, lists the emissions changes for each nonattainment area. The increases and decreases would not be uniformly distributed to individual nonattainment areas. Appendix B indicates that for CO, the majority of nonattainment areas would experience increases in emissions across all action alternatives in 2025, but decreases in 2035 (except under Alternative 1) and 2050, compared to the No Action Alternative. For NO_X, the majority of nonattainment areas would experience increases in emissions in 2025 (under all alternatives) and 2035 (Alternatives 2 and 3), and decreases in emissions in 2050, compared to the No Action Alternative. For PM2.5 and VOC, across all alternatives, the majority of nonattainment areas would experience increases in emissions in 2025 but decreases in emissions in 2035 and 2050, compared to the No Action Alternative. For SO_2 in all analysis years, the majority of nonattainment areas would experience decreases in emissions across all alternatives, compared to the No Action Alternative.

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 per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Carbon monoxide (CO)	Maximum increase	2,254	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 8-hour)]
	Maximum decrease	-5,460	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual)]
Nitrogen oxides (NO_X)	Maximum increase	178	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-429	2050	Alt. 2	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Particulate matter (PM2.5)	Maximum increase	11	2035	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-54	2050	Alt. 2	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]

Criteria Pollutant	Maximum Increase/Decrease	Emission Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Sulfur oxides (SO_2)	Maximum increase	1,012	2035	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-42	2035	Alt. 1	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Volatile organic compounds (VOCs)	Maximum increase	197	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-1,335	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]

Each nonattainment area implements emission controls and other requirements, in accordance with its SIP, that aim to reduce emissions so that the area will reach attainment levels under the schedule specified in the CAA. In a nonattainment area where emissions of a nonattainment pollutant or its precursors would increase under an action alternative, the increase would represent a slight decrease in the rate of reduction projected in the SIP. In response, the nonattainment area could revise its SIP to require greater emission reductions. Depending on the specific requirements in the SIP, an emissions increase under an action alternative could have the effect of shifting some of the responsibility to meet air quality requirements from the transportation sector to other sectors such as industry or electric utilities.

4.2.2 Toxic Air Pollutants

4.2.2.1 Emission Levels

Table 4.2.2-1 summarizes the total upstream and downstream[38] 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.

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

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
Acetaldehyde				
2025	7,325	7,339	7,342	7,355
2035	3,303	3,308	3,299	3,299
2050	892	874	853	831
Acrolein				
2025	394	395	395	395
2035	183	183	182	181
2050	58	57	55	54
Benzene				
2025	28,774	28,833	28,846	28,904
2035	9,923	9,908	9,885	9,886
2050	2,239	2,145	2,081	2,013
1,3-Butadiene				
2025	3,295	3,302	3,304	3,310
2035	1,259	1,261	1,257	1,256
2050	342	335	326	317
Diesel particulate matter (DPM)				
2025	34,492	34,372	34,359	34,315
2035	31,949	31,067	30,615	30,258
2050	28,388	27,189	26,645	26,169
Formaldehyde				
2025	6,283	6,292	6,294	6,304
2035	2,560	2,547	2,529	2,519
2050	868	832	805	778

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

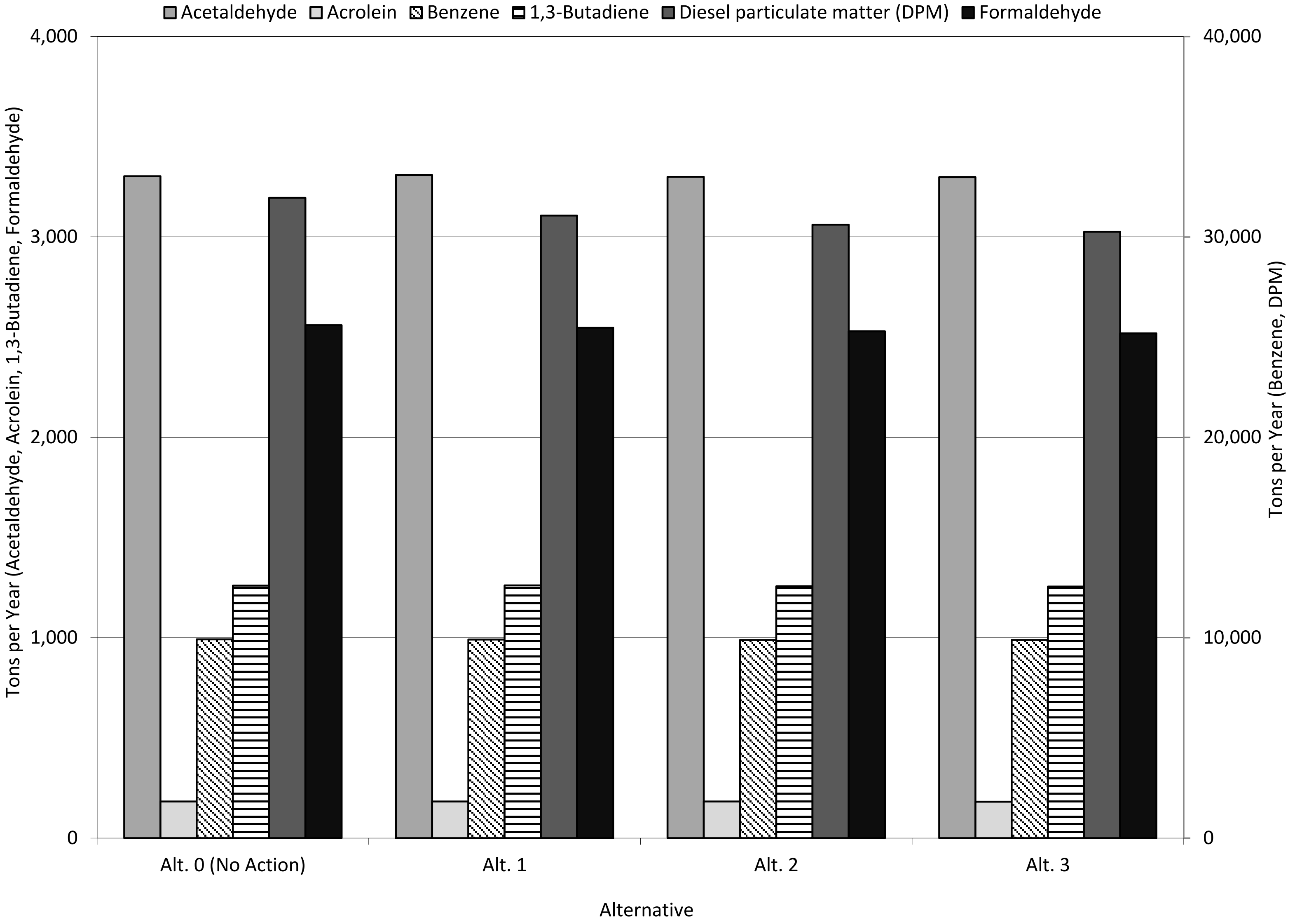


Figure 4.2.2-2 summarizes the changes over time in total national emissions of toxic air pollutants under Alternative 1 (the least stringent and highest fuel-use action alternative) and Alternative 3 (the lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts. This figure indicates a consistent trend among the toxic air pollutants. Emissions decline from 2025 to nearly 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 2040 (Table 4.2.2-2 and Figure 4.2.2-3). (Note that continued growth in VMT is projected to occur under all alternatives until 2040; a slight decline is projected to occur from 2040 to 2050.)

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. Toxic air pollutant emissions across the action alternatives increase in 2025 (except for DPM) and generally show decreases in 2035 and 2050 relative to the No Action Alternative for the same reasons as for criteria pollutants. In 2025, emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde would increase under the action alternatives (compared to the No Action Alternative) with the smallest increases occurring under Alternative 1, and the increases getting larger from Alternative 1 through Alternative 3. In 2025, the largest relative increases in emissions would occur for benzene and 1,3-butadiene, for which emissions would increase by as much as 0.5 percent (Table 4.2.2-3). Percentage increases in emissions of acetaldehyde, acrolein, and formaldehyde would be less. DPM emissions in 2025 would decrease by as much as 0.5 percent.

In 2035 and 2050, emissions of all air toxic pollutants would decrease under the action alternatives (except for acetaldehyde, acrolein, and 1,3-butadiene in 2035 under Alternative 1), compared to the No Action Alternative. In 2035 and 2050, the largest decreases occur under Alternative 3 for acetaldehyde, acrolein, benzene (only in 2050), 1,3-butadiene, DPM, and formaldehyde; the largest decrease for benzene in 2035 was under Alternative 2. In 2035, the largest relative decreases in emissions would occur for DPM for which emissions would decrease by as much as 5.3 percent under Alternative 3 compared to the No Action Alternative. In 2050, the largest relative decreases in emissions would occur for formaldehyde for which emissions would decrease by as much as 10.3 percent under Alternative 3 compared to the No Action Alternative (Table 4.2.2-3). Percentage decreases in emissions of acetaldehyde, acrolein, benzene, and 1,3-butadiene would be less. 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.

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 3, Direct and Indirect Impacts

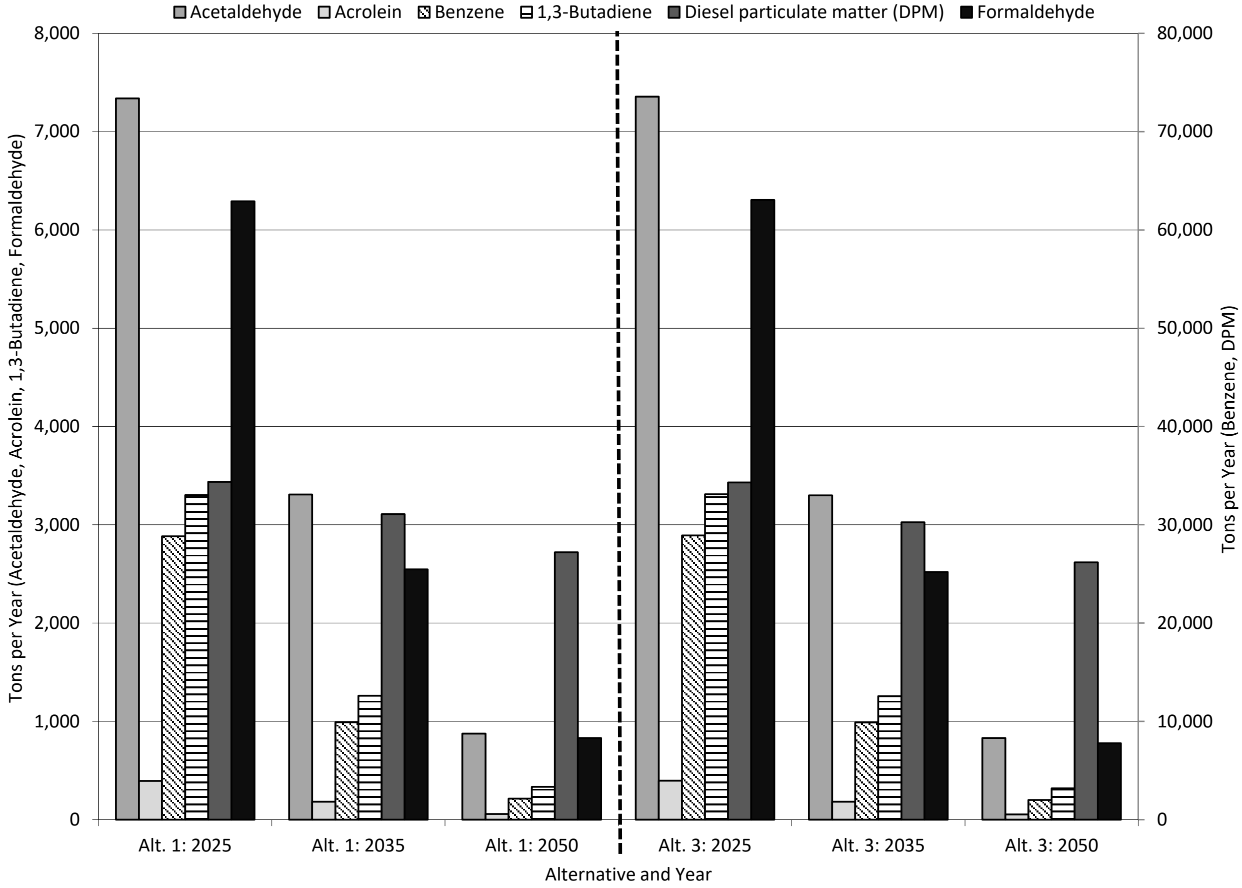


Table 4.2.2-2. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks, by Vehicle Type and Alternative, Direct and Indirect Impacts

Vehicle Class	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Acetaldehyde				
Cars tailpipe	1,204	1,200	1,190	1,188
Cars upstream	26	25	23	22
Trucks tailpipe	2,030	2,042	2,046	2,049
Trucks upstream	42	41	40	39
Total	3,303	3,308	3,299	3,299
Acrolein				
Cars tailpipe	68	68	67	67
Cars upstream	4	3	3	3
Trucks tailpipe	105	106	106	106
Trucks upstream	6	6	6	5
Total	183	183	182	181
Benzene				
Cars tailpipe	3,015	3,022	3,022	3,033
Cars upstream	534	505	476	457
Trucks tailpipe	5,525	5,554	5,574	5,599
Trucks upstream	850	828	813	796
Total	9,923	9,908	9,885	9,886
1,3-Butadiene				
Cars tailpipe	475	473	468	466
Cars upstream	6	5	5	5
Trucks tailpipe	770	774	775	776
Trucks upstream	9	9	9	9
Total	1,259	1,261	1,257	1,256
Diesel particulate matter (DPM)				
Cars tailpipe	4	4	4	4
Cars upstream	12,646	12,139	11,770	11,501
Trucks tailpipe	10	12	12	12
Trucks upstream	19,288	18,912	18,830	18,741
Total	31,949	31,067	30,615	30,258
Formaldehyde				
Cars tailpipe	737	736	731	730
Cars upstream	198	187	176	169
Trucks tailpipe	1,309	1,317	1,320	1,323
Trucks upstream	316	308	302	296
Total	2,560	2,547	2,529	2,519

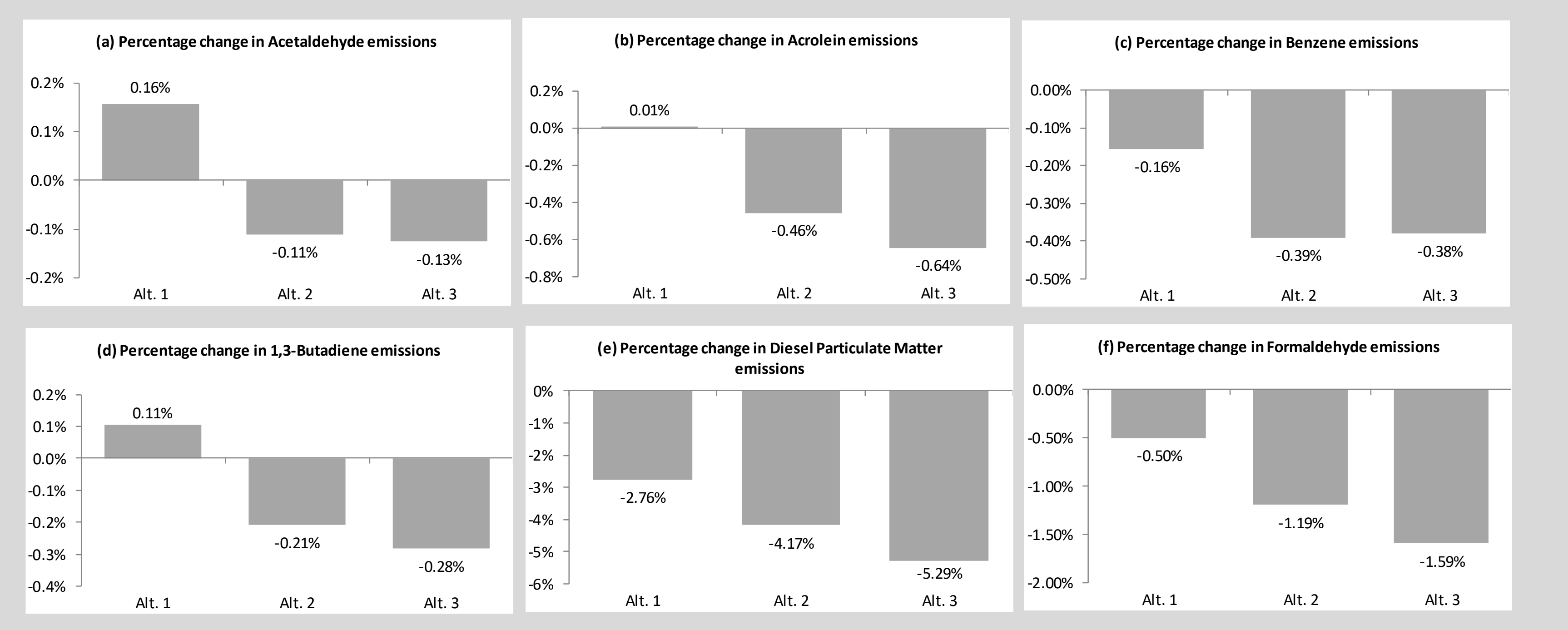
Table 4.2.2-3. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts[a,b]

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Acetaldehyde				
2025	0	14	17	30
2035	0	5	-4	-4
2050	0	-18	-39	-60
Acrolein				
2025	0	1	1	1
2035	0	0	-1	-1
2050	0	-1	-3	-4
Benzene				
2025	0	59	73	130
2035	0	-15	-39	-38
2050	0	-94	-158	-225
1,3-Butadiene				
2025	0	7	8	15
2035	0	1	-3	-4
2050	0	-7	-16	-25
Diesel particulate matter (DPM)				
2025	0	-120	-133	-177
2035	0	-881	-1,333	-1,691
2050	0	-1,199	-1,743	-2,220
Formaldehyde				
2025	0	9	11	21
2035	0	-13	-31	-41
2050	0	-36	-62	-90

Notes:

[a] 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



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 over 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.

4.2.2.2 Nonattainment Areas

EPA has not designated nonattainment areas for toxic air pollutants. To provide regional perspective, changes in toxic air pollutant emissions were evaluated for areas that are in nonattainment for criteria pollutants. For each pollutant, Table 4.2.2-4 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur.[39] Appendix B, *Air Quality Nonattainment Area Results*, lists the estimated emissions changes for each nonattainment area. The increases and decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. In 2025, compared to the No Action Alternative, in the majority of nonattainment areas all action alternatives would increase emissions of most toxic air pollutants but would decrease emissions of DPM. In 2035, compared to the No Action Alternative, the results are mixed: for acetaldehyde, emissions would increase under all action alternatives in the majority of nonattainment areas; for acrolein, 1,3-butadiene, and formaldehyde in the majority of nonattainment areas emissions would increase under Alternative 1 and decrease under Alternatives 2 and 3. For DPM, emissions would decrease under all action alternatives in the majority of nonattainment areas. In 2050, compared to the No Action Alternative, all action alternatives would decrease emissions of all toxic air pollutants in the majority of nonattainment areas.

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

Air Toxic	Maximum Increase/ Decrease	Emission Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum increase	1	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-3	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]

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[39] 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.

Air Toxic	Maximum Increase/ Decrease	Emission Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acrolein	Maximum increase	0.1	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-0.2	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
Benzene	Maximum increase	7	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-9	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
1,3-Butadiene	Maximum increase	1	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-2	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Diesel particulate matter (DPM)	Maximum increase	0.004	2035	Alt. 3	Tucson Area, AZ [CO (1971 8-hour)]
	Maximum decrease	-396	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Formaldehyde	Maximum increase	1	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-2	2050	Alt. 3	Dallas-Fort Worth, TX [Ozone (2008 and 2015 8-hour)]

4.2.3 Health Impacts

Adverse health impacts would decrease nationwide in 2025 under Alternative 1 but would increase under Alternative 3, and they would increase under Alternative 2 for some impact metrics (premature mortality, hospital admissions for cardiovascular and respiratory, and non-fatal heart attacks), compared to the No Action Alternative (Table 4.2.3-1). Adverse health impacts would decrease nationwide in 2035 and 2050 under all action alternatives. The decreases in health impacts in 2035 and 2050 would get larger from Alternative 1 to Alternative 3, reflecting the generally increasing stringency of the action alternatives, and under each action alternative the decreases in health impacts would get larger from 2025 to 2050. 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.

In 2025, emissions of PM2.5, NO_X, and SO_2 would increase under all of the action alternatives (Table 4.2.1-1) though emissions of DPM would decrease (Table 4.2.2-1). 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 2013c).

As described in Section 4.1.2.7, *Health Impacts*, the changes in premature mortality shown in these tables are measured in two ways. Benefits are measured under the Krewski method and the Lepeule method. 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.

Under any alternative, total emissions from passenger cars and light trucks are expected to decrease over time compared to existing (2021) 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
Premature mortality (Krewski et al. 2009)				
2025	0	0	1	3
2035	0	-31	-35	-35
2050	0	-46	-68	-84
Premature mortality (Lepeule et al. 2012)				
2025	0	-1	2	7
2035	0	-71	-84	-88
2050	0	-107	-160	-198
Emergency room visits: respiratory				
2025	0	-1	0	1
2035	0	-18	-23	-26
2050	0	-28	-42	-53
Acute bronchitis				
2025	0	-1	0	2
2035	0	-47	-61	-68
2050	0	-72	-110	-139
Lower respiratory symptoms				
2025	0	-17	-3	34
2035	0	-601	-775	-869
2050	0	-923	-1,398	-1,775
Upper respiratory symptoms				
2025	0	-25	-7	44
2035	0	-851	-1,105	-1,244
2050	0	-1,311	-1,986	-2,527
Minor restricted activity days				
2025	0	-810	-296	1,204
2035	0	-25,528	-34,368	-39,651
2050	0	-39,583	-60,379	-77,533
Work-loss days				
2025	0	-140	-52	204
2035	0	-4,346	-5,827	-6,704
2050	0	-6,732	-10,261	-13,161
Asthma exacerbation				
2025	0	-30	-8	53
2035	0	-996	-1,292	-1,453
2050	0	-1,535	-2,326	-2,958

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Hospital admissions: cardiovascular				
2025	0	0	0	1
2035	0	-8	-9	-9
2050	0	-12	-18	-22
Hospital admissions: respiratory				
2025	0	0	0	1
2035	0	-8	-9	-9
2050	0	-12	-17	-21
Non-fatal heart attacks (Peters et al. 2001)				
2025	0	0	1	3
2035	0	-32	-36	-36
2050	0	-47	-70	-86
Non-fatal heart attacks (All others)				
2025	0	0	0	0
2035	0	-3	-4	-4
2050	0	-5	-8	-9

Notes:

[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.[1] In this SEIS, the discussion compares projected decreases 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 MYs after 2026 at the level of the MY 2026 standards set forth by the agency. This chapter presents results through 2100.

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. This description includes a projection of the direct and reasonably foreseeable indirect GHG emissions under each of the alternatives, as well as sector-wide and national GHG emissions estimates, to provide context for understanding the relative magnitude 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 based on an appropriate literature review of the potential cumulative impacts of climate change on key natural and human resources.

5.1 Introduction

This SEIS 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.

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[1] Pursuant to Executive Order 13990, *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis*, the Council on Environmental Quality (CEQ) rescinded its 2019 Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and is reviewing, for revision and update, the 2016 Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews. National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions; Notice of Rescission of Draft Guidance, 86 FR 10252 (Feb. 19, 2021).

NHTSA relies on assessment reports because these reports assess numerous individual studies to draw general conclusions about the state of climate science and potential impacts of climate change, as summarized or found in peer-reviewed reports. These reports are reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. government agencies and individual government scientists; and in many cases reflect and convey the consensus conclusions of expert authors. These sources have been vetted by both the climate change research community and by the U.S. government. 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.

As with any analysis of complex, long-term changes to support decision-making, evaluating reasonably foreseeable impacts on the human environment involves many assumptions and uncertainties. For this reason, NHTSA relies on 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. This SEIS 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.[2] 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 SEIS, 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, the Phase 2 HD standards, and the Draft and Final EISs for the SAFE Vehicles Final Rule.

5.1.1 Uncertainty in the IPCC Framework

As with all environmental impacts, assessing climate change impacts of the Proposed Action and alternatives involves uncertainty. When agencies are evaluating reasonably foreseeable significant adverse environmental impacts and there is incomplete or unavailable information, the CEQ regulations require agencies to make clear that such information is lacking.[3] Assessing climate change impacts involves uncertainty, including with regard to discrete and localized impacts. 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 SEIS, 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 SEIS.

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

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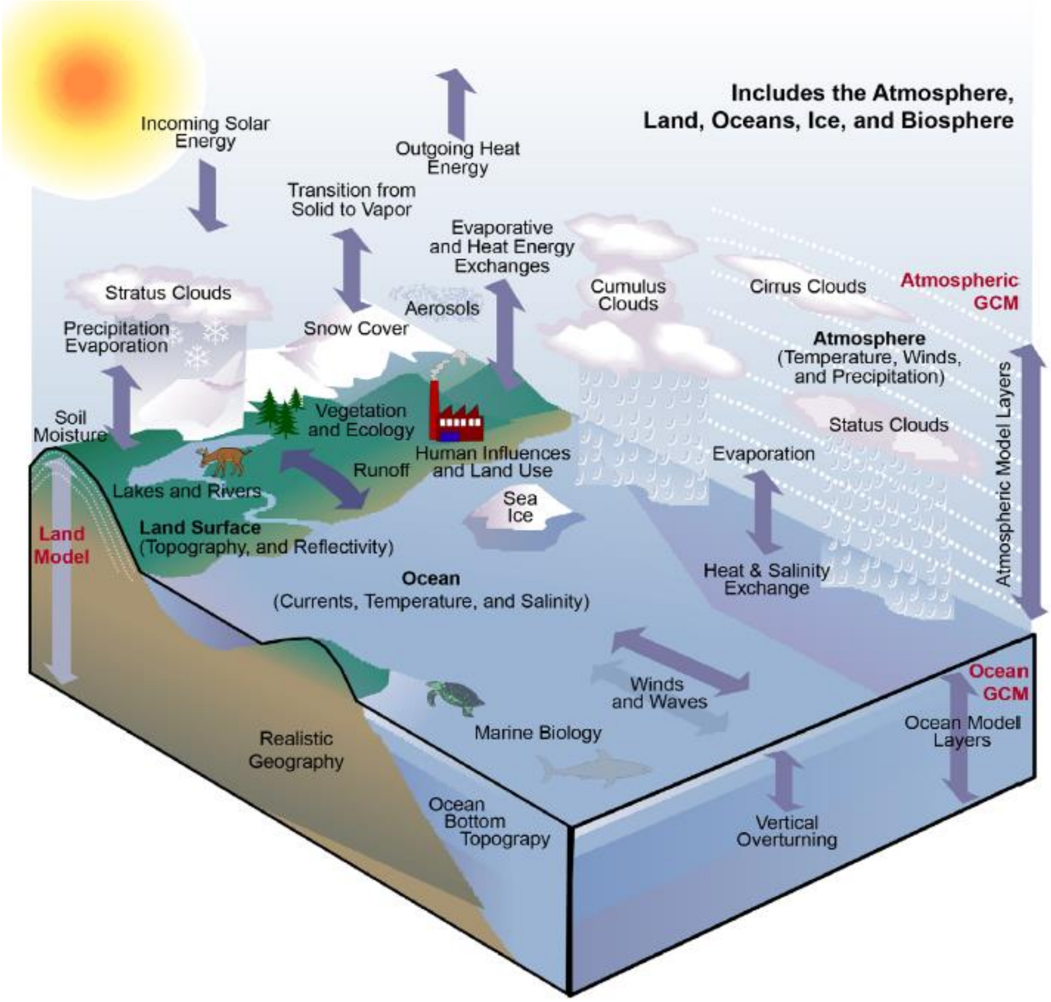
[2] The most recent comprehensive IPCC report is the Fifth Assessment Report (AR5). The IPCC's Sixth Assessment Report (AR6) is due to be released late summer 2021. Most of the references to IPCC in this report are to AR5. However, some preliminary results of AR6 have been published and are reflected where applicable within this report. Once released, NHTSA will incorporate AR6 findings into the Final SEIS to the maximum extent practicable.

[3] 40 CFR § 1502.22 (2019).

IPCC Working Group I Fifth Assessment Report Summary for Policymakers (IPCC WGI 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 SEIS 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 WGI 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. Model uncertainties can be differentiated into parametric and structural uncertainties.
- **Scenario uncertainties.** These uncertainties arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings (e.g., from solar activity).

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



Source: GCRP 2014
GCM = general circulation model

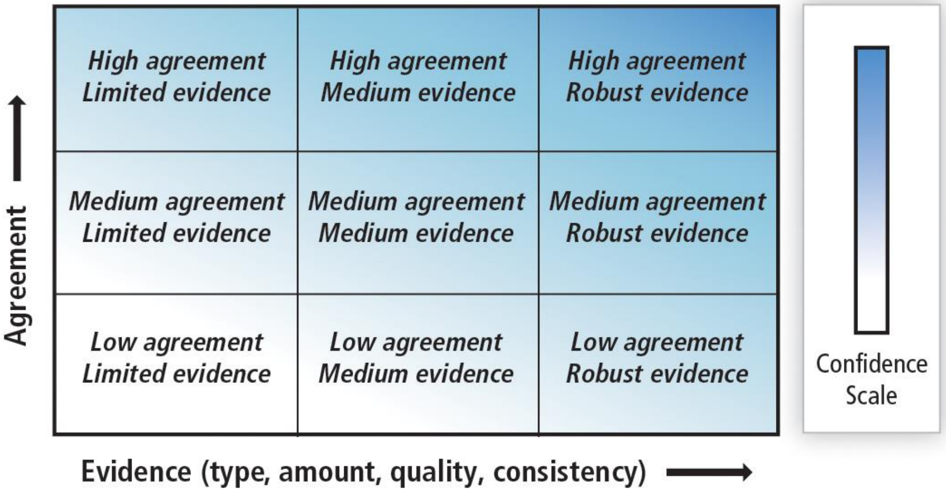
As stated in the IPCC WGI AR5, these types of uncertainties are described by using two metrics for communicating the degree of certainty: confidence in the validity of findings, expressed qualitatively, and quantified measures of uncertainties, expressed probabilistically. The confidence levels synthesize 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 WGI 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

Global climate change refers to long-term (i.e., multi-decadal) trends in global average surface temperature, precipitation, ice cover, sea level, cloud cover, sea surface temperatures and currents, and other climate conditions. Earth absorbs energy from the sun and returns most of this energy 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 since the mid-20th 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 (WGI) 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, IPCC has identified the following 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). Though most GHGs occur naturally, human activities—particularly fossil fuel burning—have significantly increased atmospheric concentrations of these gases (see IPCC 2013a for more information on human impacts on the climate and effects of different GHGs).
- **Aerosols.** Aerosols are natural (e.g., from volcanoes) and human-made particles in the atmosphere that scatter incoming sunlight back to space, causing cooling. Some aerosols 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. Natural aerosols have had a negligible cumulative impact on climate change since the start of the industrial era (IPCC 2013a).
- **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). Solar radiation has had a negligible impact on climate change since the start of the industrial era compared to other main drivers (IPCC 2013a).
- **Surface changes**. Changes in vegetation or land surface properties, ice or snow cover, and ocean color can affect surface albedo.[4] 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).

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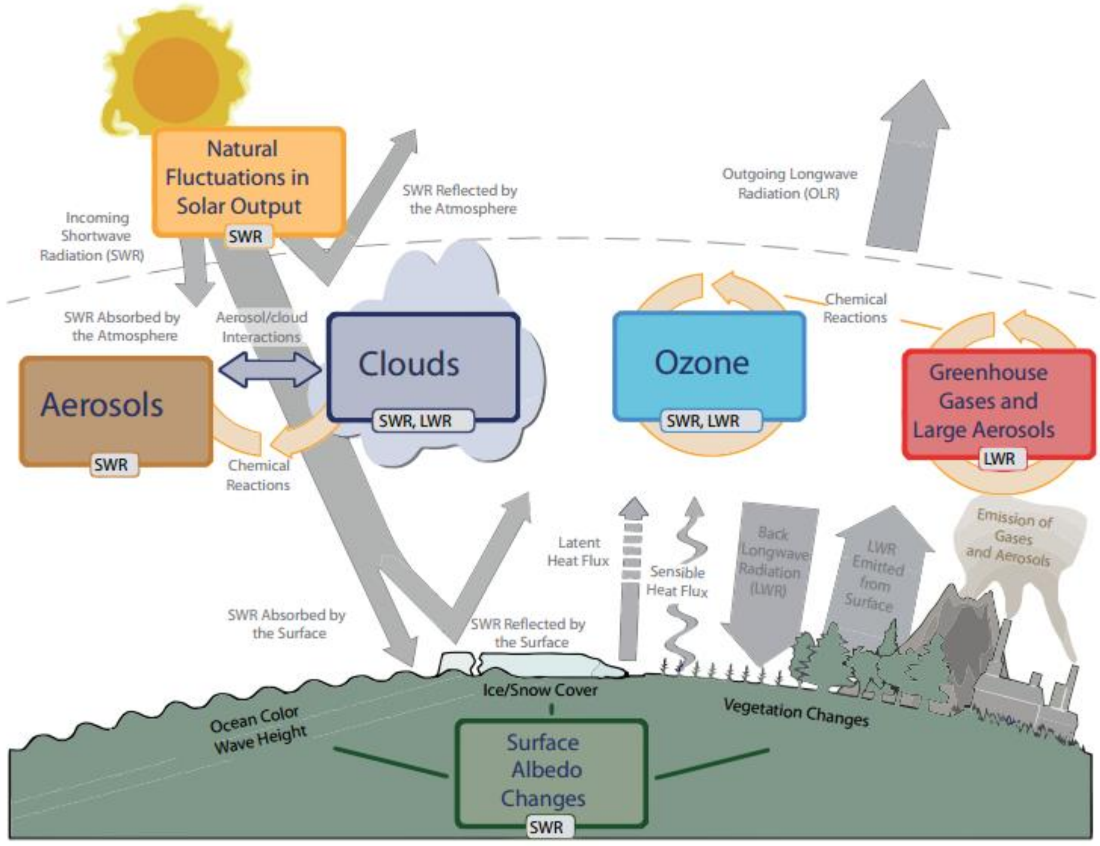
[4] Surfaces on Earth (including land, oceans, and clouds) reflect solar radiation back to space. This reflective characteristic, known as *albedo*, indicates the proportion of incoming solar radiation the surface reflects. High albedo has a cooling effect because the surface reflects rather than absorbs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

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, N_2O, CH_4, and ozone. These GHGs occur naturally and because of human activity.[5] Other GHGs, such as the fluorinated gases,[6] 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 48.4 percent, from approximately 278 parts per million (ppm) in 1750 (IPCC 2013a) to approximately 412 ppm in 2020 (NOAA 2021). Isotopic- and inventory-based studies make clear that this rise in the CO_2 concentration is largely a result of the release of carbon that had been stored underground and then used to combust fossil fuels (coal, petroleum, and natural gas) to produce electricity, heat buildings, and power motor vehicles and airplanes, among other uses (IPPC 2013a). In 2018, CO_2 emissions accounted for 73 percent of global GHG emissions on a global warming potential (GWP)-weighted basis,[7] followed by CH_4 (18 percent), N_2O (7 percent), and fluorinated gases (2 percent) (WRI 2021).[8] Atmospheric concentrations of N_2O and CH_4 increased approximately 20 and 150 percent, respectively, over roughly the same period (IPCC 2013a).

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 78 percent of global emissions in 2018; other major contributors of GHG emissions are agriculture (13 percent) and industrial processes (6 percent) (WRI 2021). Transportation CO_2 emissions—from the combustion of petroleum-based fuels—have increased by 75 percent from 1990 to 2018 and account for roughly 15 percent of total global GHG emissions (WRI 2021).[9]

In general, global GHG emissions continue to increase, although annual increases vary according to factors such as weather, energy prices, and economics. Recent trends in observed carbon emissions are comparable to projected emissions from the most fossil fuel-intensive emissions scenario (A1Fi) in the *IPCC Special Report on Emissions Scenarios* (IPCC 2000) and the highest emissions scenario representing unmitigated GHG concentration increases through the century (RCP8.5) as established by the more recent Representative Concentration Pathways (RCP)[10] (IPCC 2013a).

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[5] 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.

[6] Fluorinated GHGs or gases include perfluorocarbons, hydrofluorocarbons (HFCs), sulfur hexafluoride, and nitrogen trifluoride.

[7] Each GHG has a different radiative efficiency (i.e., the ability to absorb infrared radiation) and atmospheric lifetime. To compare their relative contributions, GHG emission quantities are converted to carbon dioxide equivalent (CO_2e) using the 100-year time horizon GWP as reported in IPCC's *Fourth Assessment Report (AR4): The Physical Science Basis* (IPCC 2007).

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

[9] 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 78 percent value for energy.

[10] 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 representing continued GHG concentration increases (RCP8.5), two stabilization pathways (RCP6.0, 4.5), and an aggressive reduction pathway (RCP2.6).

5.2.1.2 U.S. Greenhouse Gas Emissions

Most GHG emissions in the United States are from the energy sector, with the majority of those emissions being CO_2 emissions coming from the combustion of fossil fuels. CO_2 emissions from fossil fuel combustion alone account for 74 percent of total U.S. GWP-weighted emissions (EPA 2021a), with the remaining 26 percent contributed by other energy-related activities (e.g., fugitive emissions from natural gas systems), 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 transportation (37 percent of fossil fuel combustion CO_2 emissions), electric power (33 percent), industrial (17 percent), residential (7 percent), and commercial (5 percent) sectors (EPA 2021a). In 2019, U.S. GHG emissions were estimated to be 6,558.3 million metric tons carbon dioxide equivalent (MMTCO$_2$e) (EPA 2021a),[11] or approximately 14 percent of global GHG emissions (WRI 2021).[12]

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 80 percent of U.S. GHG emissions in 2019 (EPA 2021a) (on a GWP-weighted basis) and accounting for 16 percent of total global CO_2 emissions (WRI 2021).[13] 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 2021a).[14] CO_2 emissions from passenger cars and light trucks have increased 14 percent since 1990 (EPA 2021a) and account for 58 percent of total U.S. CO_2 emissions from transportation (EPA 2021a). This increase in emissions is attributed to a 47 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 2021a; DOT 2017). Although emissions typically increased over this period, emissions declined from 2008 to 2009 because of decreased economic activity associated with the recession at the time (EPA 2019a). The coronavirus disease 2019 (COVID-19) pandemic resulted in another decrease in emissions in 2020. Emissions in the first half of 2020 were 8.8 percent lower than the same period in 2019. The decline in emissions leveled off in the second half of the year as restrictions began to relax and economic activity increased (Liu et al. 2020). 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.

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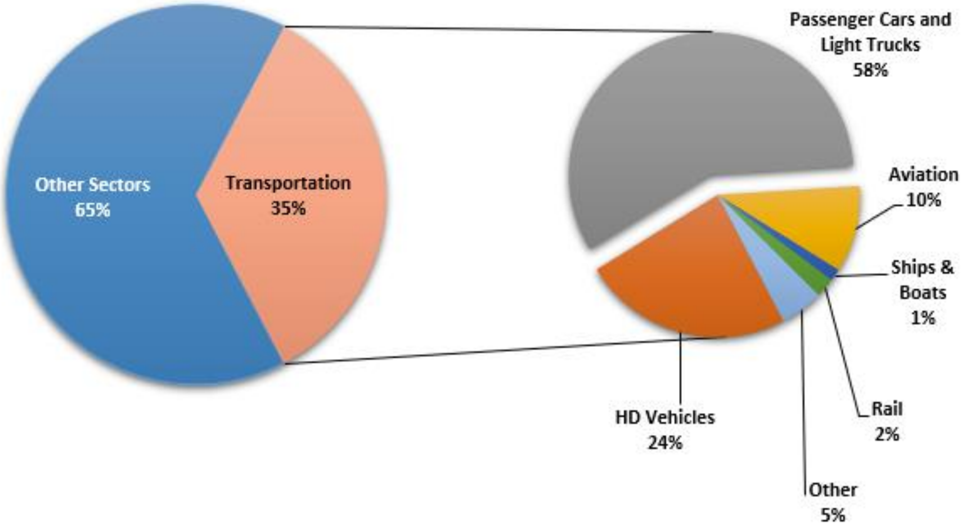
[11] Most recent year for which an official EPA estimate is available, excluding emissions and sinks from land-use change and forestry (EPA 2019a).

[12] Based on global and U.S. estimates for 2018, the most recent year for which a global estimate is available. Excluding emissions and sinks from land-use change and forestry.

[13] The estimate for global emissions from the World Resources Institute is for 2018, the most recent year with available data for all GHGs. It excludes emissions and sinks from land use change and forestry.

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

Figure 5.2.1-1. Contribution of Transportation to U.S. Carbon Dioxide Emissions by Mode (2019)



Source: EPA 2021a
HD = heavy-duty

Although CO_2 emissions represent the vast majority of the U.S. contribution to warming (80.1 percent), CH_4 accounts for 10.1 percent of U.S. GHGs on a GWP-weighted basis, followed by N_2O (7.0 percent) and the fluorinated gases (2.8 percent) (EPA 2021a).

5.2.1.3 Black Carbon and Other Aerosols

Aerosols are solid or liquid particles suspended in the 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 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 2016a).

5.2.2 Climate Change Trends

In its most recent assessment of climate change (IPCC WGI 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). Numerous long-term changes in climate have been observed at continental and global scales (IPCC 2013a), and evidence indicates unambiguously that Earth's warming "over the last half century … has been driven primarily by human activity." IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. Additionally, 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).
- There is *high confidence* that 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). Recent assessment found that the oceans have become about 30 percent more acidic over the last 150 years since the Industrial Revolution (GCRP 2017).

Developed countries, including the United States, have been responsible for the majority of GHG emissions since the mid-1800s and still have some of the highest GHG emissions per capita (WRI 2021). While annual emissions from developed countries have been relatively flat over the last few decades, world population growth, industrialization, and increases in living standards in developing countries are expected to cause global 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 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 emissions from both developed and developing countries are not reduced dramatically in the coming decades, this elevation in atmospheric CO_2 concentrations is likely to 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

Climate change is evidenced, in part, by increases in surface temperatures over time. 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. Positive RF leads to warming while negative RF leads to 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 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). Most recently, the net heat uptake rate has been shown to be increasing. From mid-2005 to mid-2019, RF estimates from both in situ and satellite observations were shown to be 0.77 W/m^2 (plus or minus 0.06 W/m^2) due to an increase in absorbed solar radiation associated with decreased reflection by clouds and sea ice and a decrease in outgoing longwave radiation due to increases in trace gases and water vapor (Loeb et al. 2021). Future projections of RF are captured in the RCPs used to model future climate conditions. These RCPs are named according to the amount of change in RF in 2100 relative to preindustrial conditions (prior to 1750): +2.6, +4.5, +6.0, and +8.5 W/m^2 (GCRP 2017).

Average Temperatures

Annual average surface temperatures have increased across much of the globe in recent decades with “sixteen of the last 17 years” being “the warmest ever recorded by human observations” (GCRP 2017) (Figure 5.2.2-1). Annual average global temperature has increased by 1.0°C (1.8°F) from 1901 to 2016, and global temperatures are rising at an increasing rate. The years 2016 and 2020 were the hottest years on record globally, at about 0.94°C (1.69°F) above the 20th century average of 13.9°C (57.0°F) (Voosen 2021).[15]

IPCC projects a continuing increase in global mean surface temperature over the course of this century, with a *likely* range of increase between 0.3°C (0.5°F) and 4.8°C (8.6°F) for the period of 2081 to 2100

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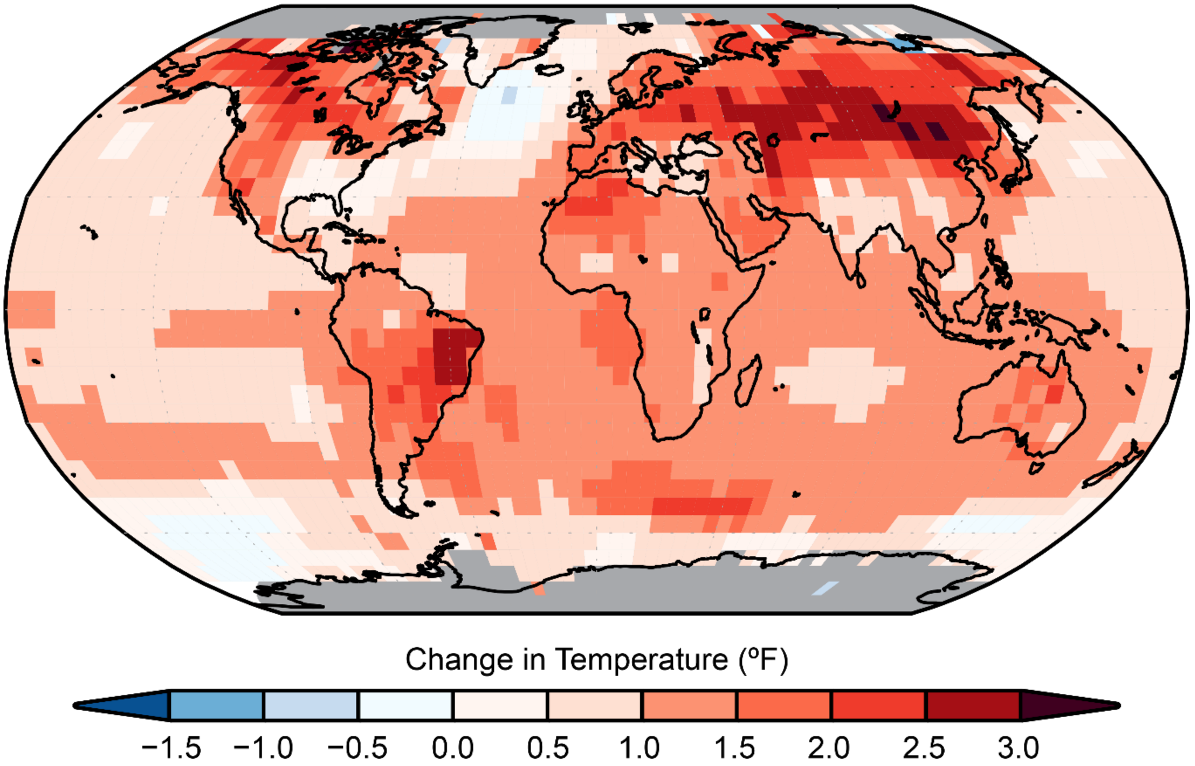
[15] The global temperatures in 2016 were influenced by strong El Niño conditions that prevailed at the beginning of the year.

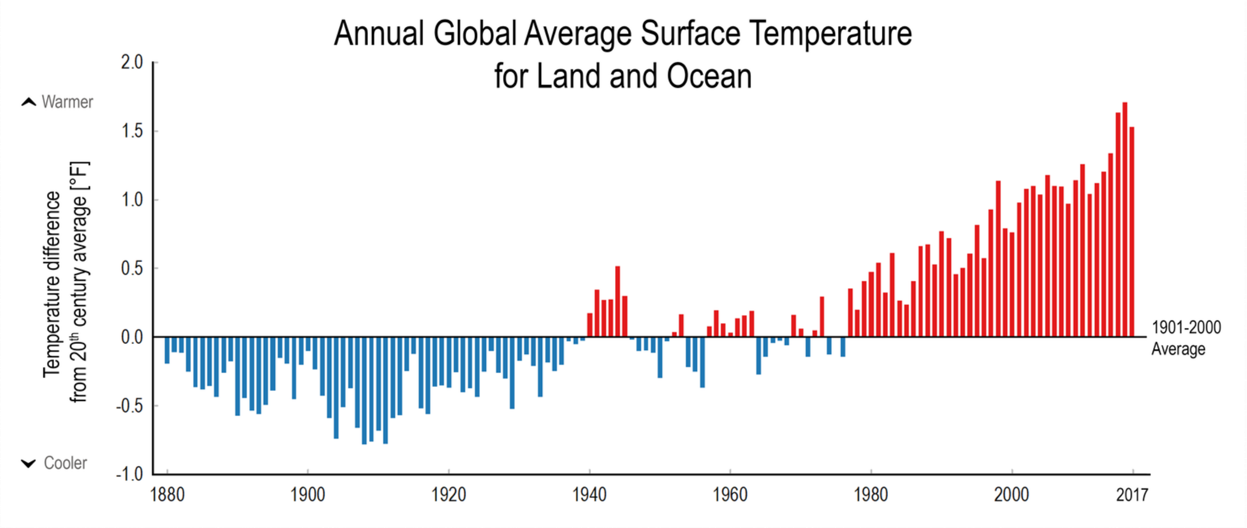
compared with the baseline period of 1986 to 2005. The lower value corresponds to substantial future mitigation of carbon emissions (RCP2.6), with considerable short-term mitigation efforts, including an overall decrease in global CO_2 emissions starting in 2020 and declining to zero in 2100 (IPCC 2013a). The next most stringent scenario (RCP4.5) also has considerable short-term mitigation efforts with global CO_2 emissions peaking around 2040 (IPCC 2013a). For further information on observed and projected global climate change trends, see IPCC 2013a and GCRP 2018a.

Figure 5.2.2-1. Global Surface Temperature Anomalies in Degrees Fahrenheit from 1986 to 2015 Relative to 1901 to 1960



Source: GCRP 2017
°F = degrees Fahrenheit

Figure 5.2.2-2. Annual Global Average Surface Temperature Increases of About 0.9°C (1.6°F) from 1880 to 2016



Source: GCRP 2018b
°F = degrees Fahrenheit

Surface temperatures are not rising uniformly around the globe. Warming has been particularly pronounced in the Arctic (GCRP 2017). The average Arctic temperature has increased at almost twice the global average rate over at least the past several decades (GCRP 2017). Similar to the global trend, the U.S. average temperature has increased about 1.0°C (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). Some areas of the southeast region of the United States have experienced “warming holes,” as indicated by 20th century temperature observations, suggesting minor to no warming trends since 1901 (GCRP 2017).

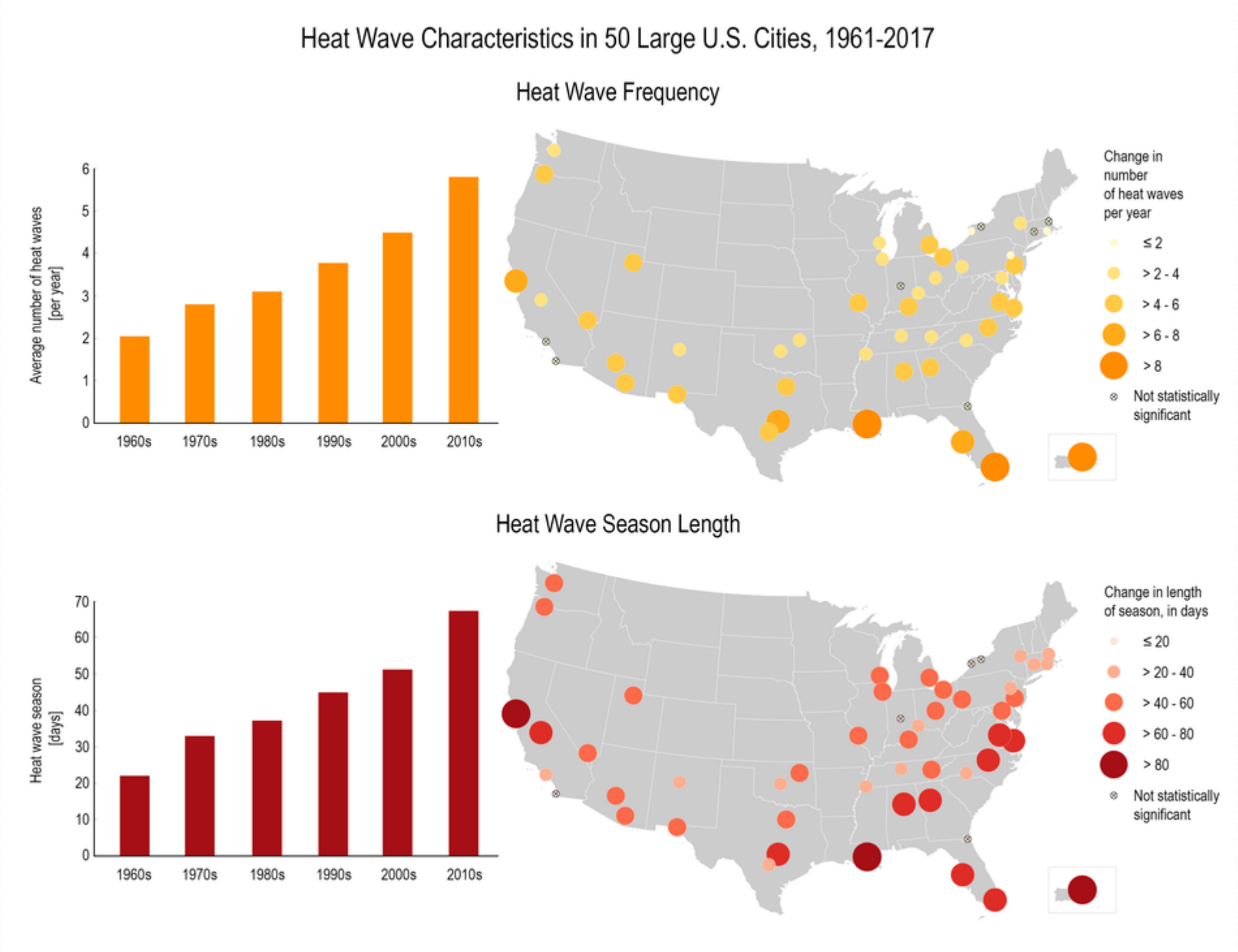
The oceans have a large heat capacity and have been absorbing more than 90 percent of warming caused by anthropogenic GHG emissions (GCRP 2017). Due to Earth’s thermal inertia—whereby oceans absorb and dissipate heat to the atmosphere over a long period of time—warming could continue for centuries, even after atmospheric CO_2 is stabilized or reduced.

Multiple lines of evidence have recorded increasing average temperatures, including measurements from weather balloons and, more recently, satellites (GCRP 2017). 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 2017). 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 2014b; GCRP 2014), and plant flowering and animal spring migrations are occurring earlier (EPA 2009; IPCC 2014b; GCRP 2014).

Extreme Temperatures

In many regions, extreme temperatures have changed substantially since about 1950. Extreme temperatures have changed both in frequency and intensity. As mean temperatures increase, the IPCC indicates it is *virtually certain* that there will be more hot and fewer cold temperature extremes; increases in the frequency, duration, and magnitude of hot extremes along with heat stress are expected; however, occasional cold winter extremes will continue to occur (IPCC 2013a). Hot days, hot nights, and heat waves have become more frequent; cold days, cold nights, and frost have become less frequent (Figure 5.2.2-3) (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 (GCRP 2017). Recent heat waves in the United States have been significant, and recent modeling shows that anthropogenic climate change is projected to dominate heat wave occurrence in the western United States and Great Lakes region as early as this decade (Lopez et al. 2018).

Figure 5.2.2-3. Heat Waves Increasing in Frequency and Duration from 1961 to 2017



Source: GCRP 2018c

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 (coincident with the expansion of the instrumental record) (GCRP 2017). Long-term warming driven by anthropogenic GHG emissions increases the likelihood of extreme temperatures and record warmth (Knutson et al. 2018; Meehl et al. 2016; Vogel et al. 2019a). 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). For example, the likelihood of consecutive years with record-breaking annual average temperatures from 2014 to 2016 was negligible (less than 0.03 percent) in the absence of human influence (Mann et al. 2017). Additionally, the 2017 heat wave in southern Europe was found to be at least three times more likely today than it was in 1950 due to anthropogenic climate change (Kew et al. 2018). Recent literature continues to support and strengthen such findings, projecting both geographic and temporal increases in extreme heat by the late century (Dahl et al. 2019). These projections result from the general warming trend, rather than a specific RCP scenario or timeframe.

Sea-Level Rise

Global temperature increases contribute to 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 global sea level to rise due to both thermal expansion of ocean water and an increased transfer of water from glaciers and ice sheets to the ocean. Since the early 1970s, the majority of observed sea-level rise has come from these sources. Other factors, such as changing ocean currents and vertical land adjustments, also affect local 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 (approximately 660 feet) (IPCC 2013a). In the top 700 meters (approximately 2,300 feet) 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, further contributing 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 confirm that they have contributed to sea-level rise in subsequent years (IPCC 2013a). Dynamic ice loss (i.e., the transfer of ice from land-based ice sheets to the ocean, which can accelerate following the collapse of supporting ice shelves) explains most (up to 74 percent) of the Antarctic net mass loss and about half of the Greenland net mass loss (IPCC 2013a).

These contributions to sea-level rise are expected to continue throughout this century. According to the IPCC, ocean warming is projected to continue throughout the 21st century, and all RCP scenarios project year-round reductions in Arctic sea ice (IPCC 2014b). Global glacier volume (excluding the Greenland and Antarctic ice sheets and glaciers on the periphery of Antarctica) is projected to decrease from 15 to 85 percent by the end of the 21st century relative to the baseline period from 1986 to 2005 (between the low estimate for RCP2.6 and the high estimate for RCP8.5) (IPCC 2013a, 2014a). While the Greenland ice sheet is currently contributing more to global sea-level rise, Antarctica could become the larger contributor by end-of-century due to rapid retreat of ice stream and glaciers draining the ice sheet (IPCC 2019a). Recent modeling indicates that the Antarctic ice sheet contribution to sea-level rise is projected to continue at about the current rate if Paris Agreement targets are reached (i.e., limiting warming to 2°C [3.6°F] or less). However, warming of 3°C [5.4°F] consistent with current policies has the potential to increase the contribution of Antarctic ice loss to sea-level rise to about 0.5 centimeter (0.2 inch) per year from 2060 to 2100, roughly 10 times faster than current rates (DeConto et al. 2021). New projections also show that limiting global warming to 1.5°C (2.7°F) above pre-industrial levels could halve land ice contribution to sea-level rise during the 21st century, resulting in median land ice contributions to sea-level rise ranging from 13 to 42 centimeters (5.1 to 16.5 inches) by 2100, with the higher projection due to rapid mass loss from the Antarctic ice sheet (Edwards et al. 2021).

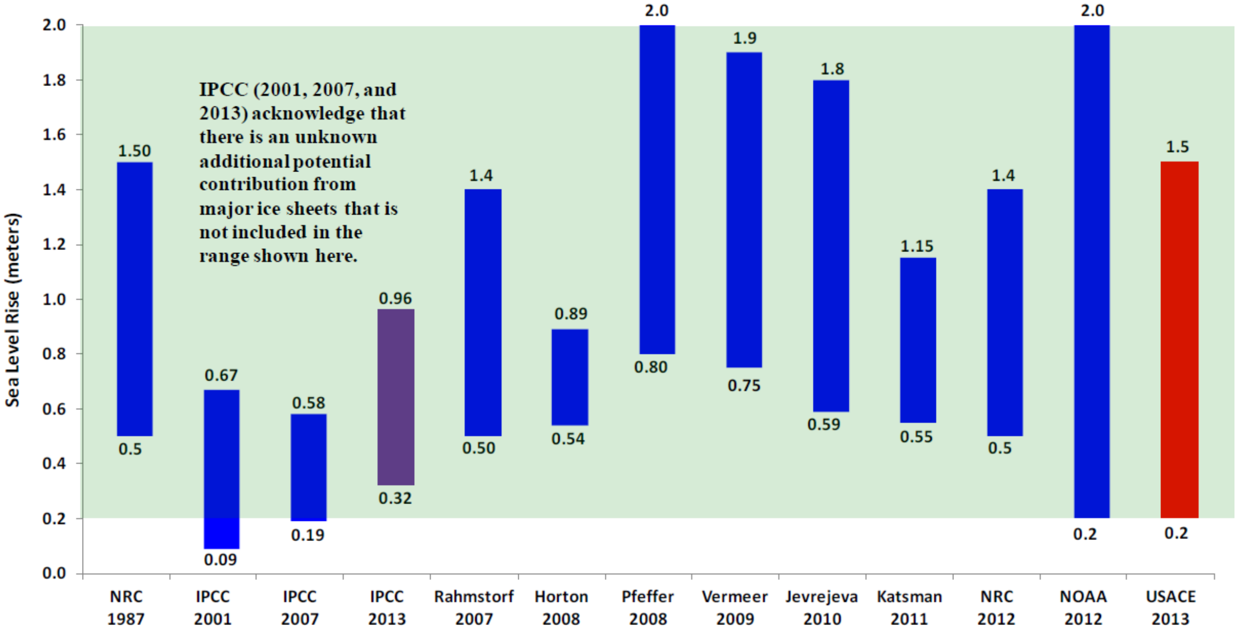
Warming ocean temperatures affect ice sheet stability through submarine melting and altering the dynamics of ice shelves, ice streams, and glaciers. The interconnectedness of the ocean and cryosphere (e.g., glaciers and ice streams that drain the Greenland and Antarctic ice sheets into the ocean) can lead to compounding impacts, whereby ocean warming triggers dramatic ice sheet instability through enhanced melting and calving at glacier and ice stream fronts. In turn, the nonlinear relationship between ocean warming and ice mass loss could be a large driver of future global sea-level rise (IPCC 2019a).

Global Sea-Level Rise

Global mean sea level rose by about 1.0 to 1.7 millimeters (0.04 to 0.07 inch) 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 inch) 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). Looking forward, IPCC projects that global sea level is likely to rise 29 to 59 centimeters (11.4 to 23.2 inches) for RCP2.6 and 61 to 110 centimeters (24.0 to 43.3 inches) for RCP8.5 compared to 1986 to 2005 (Oppenheimer et al. 2019).

In addition, other studies that consider dynamic mass loss from major ice sheets indicate that sea-level rise could be even greater (Figure 5.2.2-4) (Robel et al. 2019; Bamber et al. 2019). 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). Records of paleo sea level indicate that, when global mean temperatures increased to 2°C [3.6˚F] above preindustrial levels, global mean sea level was 5 meters (16.4 feet) higher than current levels (IPCC 2013a).

Figure 5.2.2-4. End-of-Century Estimates of Maximum and Minimum Global Mean Sea-Level Rise (2090–2100)



Source: USACE 2014

NRC = National Research Council; IPCC = Intergovernmental Panel on Climate Change; NOAA = National Oceanic and Atmospheric Administration; USACE = U.S. Army Corps of Engineers

Regional Sea-Level Rise

Sea-level rise is not uniform across the globe, primarily because dynamic ocean heights are adjusted by ocean currents and because coastline elevations change through time as a result of regional tectonics, subsidence, and isostatic rebound. The largest increases in sea level since 1992 have occurred 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). This absence of uniformity in sea-level rise is projected to continue throughout the 21st century, though it is *very likely* that sea level will rise in more than 95 percent of the ocean area (IPCC 2014b).

Nationally, relative sea level has been rising at a rate of 1.1 to 2.0 inches per decade along most of the Atlantic and Gulf coasts and more than 3 inches per decade along portions of the Louisiana and Texas coasts (where land subsidence is relatively rapid) (EPA 2021f; Argus et al. 2018; NOAA 2017). Sea level is falling (due to tectonic uplift) at the rate of a few inches per decade in parts of Alaska (EPA 2009, 2021f; Argus et al. 2018; NOAA 2017; National Science and Technology Council 2008). This pattern of relative sea-level rise along the U.S. coast is projected to continue throughout this century (GCRP 2017 citing Sweet et al. 2017). Tools such as the NOAA Seal Level Rise viewer can be used to understand the impact of coastal inundation under different sea-level rise scenarios along the coastal United States.[16]

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 inland by an average of 2.6 to 3.1 meters (8.5 to 10.2 feet) per year (26 to 31 meters [85 to 102 feet] per decade). In Louisiana, a full 90 percent of the shoreline has been eroding inland at an average rate of more than 12.0 meters (39.4 feet) per year (EPA 2009; Nicholls et al. 2007), with loss of coastal wetlands in the state occurring at a variable rate of 11 to 32 square miles per year from 1932 to 2016 (Couvillion et al. 2017).[17] As sea level continues to rise, so will the likelihood for extensive coastal erosion (GCRP 2017 citing Barnard et al. 2011, Theuerkauf and Rodriguez 2014, and Serafin and Ruggiero 2014).

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 areas to experience increases in precipitation events, while other areas are left more susceptible to droughts (Fujita et al. 2019). 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; Min et al. 2011).

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

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[16] NOAA, Office for Coastal Management, DigitalCoast, Sea Level Rise Viewer, https://coast.noaa.gov/digitalcoast/tools/slr.html.

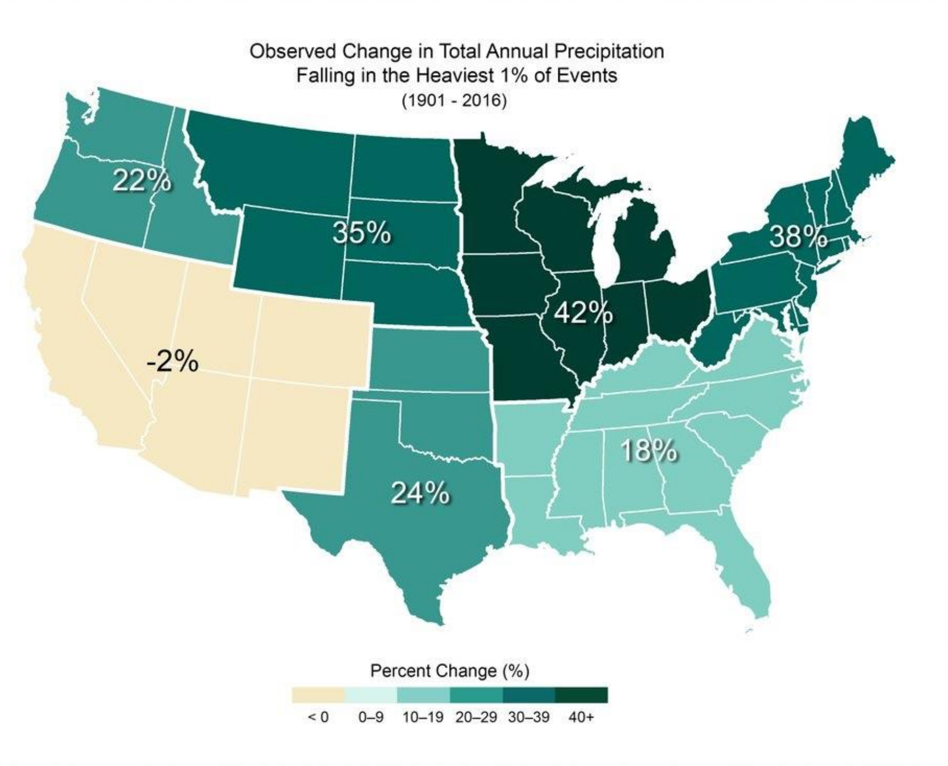
[17] The shoreline erosion in Louisiana is also affected by human alterations and loss of sediment supply (EPA 2009).

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 the Great Plains, and there were notable decreases in areas of the Southwest (GCRP 2017). Heavy precipitation events also increased in all regions except the Southwest, primarily during the last 3 to 5 decades, with more than a 40 percent increase since 1901 in the Midwest (Figure 5.2.2-5) (GCRP 2017).

Figure 5.2.2-5. Increased Heavy Precipitation Events from 1901 to 2016



Source: GCRP 2018d

In general, climate change is expected to reinforce global precipitation patterns. Under the RCP8.5 scenario, mean precipitation increases in wet regions at high and middle latitudes and the equatorial Pacific, and mean precipitation decreases in dry regions at subtropical and middle latitudes are *likely* by the end of the century (IPCC 2014b).

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. However, the United States continues to experience severe drought, including in the Southwest from 1999 to 2008 (EPA 2009), Texas and California in 2011 (GCRP 2017), the Midwest in 2012 (GCRP 2017), California in 2014 and 2015 (USGS 2015), and the western United States in 2020 and 2021, which has produced drought conditions in California not seen since 1977 (Carlowicz 2021). 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).

By the end of the 21st century, it is *likely* that currently dry regions in the world will experience more frequent droughts under RCP8.5 (IPCC 2014b). In southwest North America, where long-term droughts have historically occurred because of natural causes, aridification is projected to increase due to climate change and concomitant general drying and poleward expansion of the subtropical dry zones (IPCC 2013a citing Held and Soden 2006, Seager et al. 2007, and Seager and Vecchi 2010). Twenty-first century drought risk in the southwest and central plains will likely be higher than at any time since at least 1100 CE under both RCP4.5 and RCP8.5, increasing the possibility of megadroughts (droughts lasting 2 decades or more) in these regions (Cook et al. 2015). A more recent study expands upon this concept, showing that the 2000 to 2018 southwestern North America drought was the second driest 19-year period since 800 CE, exceeded only by a late-1500s megadrought, noting that anthropogenic warming increases the probability of otherwise moderate droughts becoming historic megadroughts (Williams et al. 2020).

While current levels of climate change already manifest moderate risks of increased water scarcity, vegetation loss, and wildfire damage, these risks are projected to become more severe with future temperature increases (IPCC 2019b). In addition, increased warming is projected to shift climate zones poleward and increase the amount of land prone to drought (IPCC 2019b).

Streamflow

Melting snow and ice, increased evaporation, and changes in precipitation patterns all affect surface water. Previous assessments indicate variable changes in streamflow and river discharge. The northwest United States has experienced long-term declines in streamflow as a result of declining winter precipitation and, more generally, the western United States has seen recent declines due to drought (GCRP 2017). In contrast, high streamflow is increasing across parts of the Midwest, Mississippi Valley and eastern United States as a result of increases in heavy precipitation (GCRP 2017). Other 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).

These streamflow drivers are expected to continue to change throughout the 21st century, with more frequent and intense heavy precipitation events (*high confidence*) and more precipitation falling as rain rather than snow, thereby decreasing snowpack and snowmelt (*high confidence*) in the United States (GCRP 2017). Changes in streamflow are also dominated by snowpack and glacier-fed mountain basins, which are projected to decline and produce earlier spring peak flows (IPCC 2019a).

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).

Spring snow cover area in the Northern Hemisphere is *likely* to decrease by 7 percent under RCP2.6 and up to 25 percent under RCP8.5 by the end of the 21st century relative to the historical baseline, based on the IPCC multimodel average (IPCC 2014b). Recent studies support these findings, and project that spring snow cover could decrease by as much as 35 percent relative to 1986 to 2005 by the end of the century under RCP8.5 (IPCC 2019a).

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). The Fourth National Climate Assessment notes that, by 2100 under the RCP8.5 emissions scenario, nearly all coral reefs are projected to be surrounded by acidified seawater that will challenge coral growth (GCRP 2017, GCRP 2018a citing Ricke et al. 2013). Further, IPCC projects that, when average global warming reaches 1.3°C (2.3°F) above preindustrial levels, tropical coral reefs are *virtually certain* to experience high risks of impacts such as frequent mass mortalities, and at 2°C (3.6°F), most available evidence (*high agreement, robust evidence*) suggests that coral dominated ecosystems will be nonexistent (IPCC 2013a citing Alvarez-Filip et al. 2009).

The global average surface ocean acidity is projected to increase in acidity (decrease in pH) by 100 to 150 percent by the end of the century under RCP8.5 relative to historical conditions (*high confidence*) (GCRP 2017).

5.2.2.2 Increased Incidence of Severe Weather Events

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 sea-surface temperatures in the North Atlantic, which includes the Gulf Stream, 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 the 1970s in that region is *virtually certain* (IPCC 2013a). Additionally, recent projections indicate that climate change could increase the frequency of the most intense tropical cyclones by the end of the century, but it is still unclear how the overall frequency of events might change (GCRP 2017).

Climate change also causes hurricanes and tropical cyclones to produce heavier precipitation (GCRP 2017). Heavy precipitation events have increased globally since 1951, with some regional and subregional variability (IPCC 2013a). A warmer atmosphere holds more moisture and increases the energy available for convection, causing stronger storms and heavier precipitation (GCRP 2017; Gertler and O’Gorman 2019). The influence of climate change on recent storms is well documented. For example, the rainfall produced in Texas and Louisiana by Hurricane Harvey in 2014 was increased by about 15 to 19 percent due to climate change (Risser and Wehner 2017; van Oldenborgh et al. 2017). Climate change also could increase the probability of a similar extreme event by 17 percent through 2100 relative to the period from 1981 to 2000 under RCP8.5 (Emanuel 2017). Looking forward, tropical cyclone rainfall amounts in the eastern United States could increase by 8 to 17 percent relative to the time period between 1980 and 2006 as a result of a warmer climate (Wright et al. 2015). Evidence is insufficient to determine whether there are trends in large-scale phenomena such as the Atlantic meridional overturning circulation (AMOC), 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). However, the frequency of weather and climate disasters (including those causing more than $1 billion in damages) has increased in the United States (GCRP 2018a).

Changes in ocean heat content and freshwater-driven buoyancy could potentially weaken the AMOC and, in turn, drive dramatic changes to the regional climates of North America and Europe. However, there is currently *low confidence* in models that show AMOC weakening over the 21st century under a high emissions scenario (RCP8.5) (GCRP 2017). Similarly, confidence in future projections of severe thunderstorms (which includes tornadoes, hail, and winds) is *low* (GCRP 2017).

Climate change is also driving increased wildfire activity. The number of large wildfires in the western United States increased from 1984 to 2011, and area burned by wildfire has been increasing since the 1970s (GCRP 2017). These changes are driven, in part, by changes in climate, such as increasing temperatures, more intense droughts, reduced snowpack, and increased fuel availability and flammability (GCRP 2017, 2018a). Observations of wildfires in western U.S. forests indicate that the area burned by wildfire from 1984 to 2015 was twice what would be expected in the absence of climate change (Abatzoglou and Williams 2016).

Wildfires are projected to further increase in intensity, duration, and frequency under climate change. Projections indicate that for the western United States, large fires will become more of an annual occurrence and very large fires (larger than 50,000 acres) will increase by 2050 under both low and high emissions scenarios (RCP4.5 and RCP8.5) (GCRP 2017). The southeast is also expected to see an increase in wildfires, though with substantial differences between ecoregions (Prestemon et al. 2016). Similarly, Alaska is expected to experience a longer fire season, with a higher risk of severe fires and greater total area burned (GCRP 2017). Wildfires are complex systems, but modeling focused on the climate variables that are closely linked to fire risk (e.g., surface temperature, snowmelt timing) is quite robust and shows that conditions conducive to wildfires are expected to continue into the future under climate change (GCRP 2017).

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). Figure 5.2.2-6 shows polar ice sheet mass change from 1992 to 2016.

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).[18] Some Arctic ice that previously was thick enough to last through summer has now thinned enough to melt completely in summer. As of 2020, the 12 lowest Arctic sea ice extents in the satellite era occurred in the last 12 years (Kumar et al. 2020a)

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. 2016). 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. 2016). 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. 2016). 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 [3.6°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).

The loss of Arctic sea ice is projected to continue throughout the 21st century, and could *very likely* result in nearly sea-ice-free late summers in the Arctic Ocean by the 2040s (*very high confidence*) (GCRP 2017). The Arctic is projected to have approximately a 1 percent chance of having sea-ice-free

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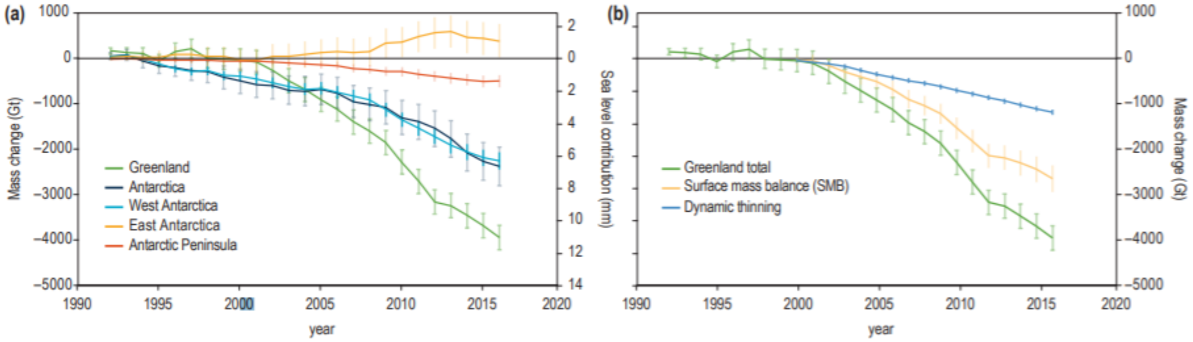
[18] Permafrost thawing releases CO_2 and CH_4 into the atmosphere.

Septembers after mid-century based on stabilized warming of 1.5°C (2.7°F), and a 10 to 35 percent chance at 2°C (3.6°F) (IPCC 2019a). At the same time, permafrost is projected to continue to decrease, with a switch from continuous to discontinuous permafrost expected over the 21st century (GCRP 2017 citing Vaughan et al. 2013, Grosse et al. 2016, and Schuur et al. 2015). Projections show that by end-of-century, near-surface (within 3 to 4 meters) permafrost could decrease by approximately 24 to 69 percent relative the 1986-to-2005 baseline time period, based on RCP2.6 and RCP8.5, respectively (IPCC 2019a).

Figure 5.2.2-6. Cumulative Ice Sheet Mass Change from 1992 to 2016



Panel (a) shows cumulative mass change and corresponding sea-level rise contributions for different ice sheet regions. Panel (b) shows Greenland Ice Sheet mass change components from surface mass balance (orange) and dynamic thinning (blue) for 2000 to 2016. Uncertainties bars are 1 standard deviation.
Source: IPCC 2019a
Gt = gigatonne

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 reductions 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 reductions of each gas by estimates of their social cost, NHTSA derived a monetized estimate of the benefits associated with the emissions reductions projected under each action alternative. NHTSA has estimated the monetized benefits associated with GHG emissions reductions in its Preliminary Regulatory Impact Analysis (PRIA), Chapter 6.5.1. See Section 6.2.1 of the Technical Support Document (TSD) for a description of the methods used for these estimates.
- **Analyzing how GHG emissions reductions 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.[19] 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 SEIS, 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 alternative. 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 reduction 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 SEIS 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 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.

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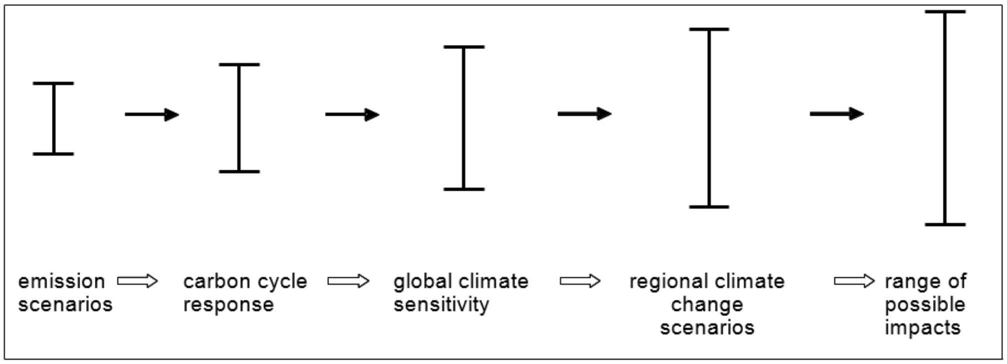
[19] In discussing impacts on ocean pH, this SEIS uses both *changes to* and *reductions of* ocean pH to describe ocean acidification. The metric pH is a parameter that measures how acidic or basic a solution is. The increase in atmospheric concentration of CO_2 is causing acidification of the oceans,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

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 SEIS 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 2008) provides a thorough discussion of the methodological limitations regarding modeling. Additionally, Chapter 9, Evaluation of Climate Models, of IPCC WGI 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 WGI 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

This SEIS compares GHG emissions under each action alternative to those under the No Action Alternative. GHG emissions under each alternative were estimated using the methods described in Section 2.3, *Standard-Setting and SEIS Methods and Assumptions*. For years 2020 through 2050, the emissions estimates in this SEIS 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 (Volpe Center) using the CAFE Compliance and Effects Model (referred to as the CAFE Model), described in Section 2.3.1, *CAFE Model*. To calculate tailpipe CO_2 emissions, the CAFE Model applies estimates of the density and carbon content of gasoline and other fuels. To calculate tailpipe CH_4 and N_2O emissions, the CAFE Model applies gram-per-mile emission factors Volpe Center staff referenced from EPA's Motor Vehicle Emissions Simulator (MOVES).[20]. To calculate GHG emissions from upstream processes such as

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[20] All downstream emission estimates in the CAFE Model use emission factors from EPA's MOVES3 model version (EPA 2020a).

refining and electricity generation, the CAFE Model applies process-specific emission factors specified on a gram-per-British thermal unit basis; Volpe Center staff developed these emission factors using the Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, developed by the U.S. Department of Energy (DOE) Argonne National Laboratory.

For the climate analysis, GHG emissions trajectories are projected through the year 2100. In order to estimate GHG emissions for the passenger car and light truck fleets for 2051 to 2100, NHTSA extrapolated from the aforementioned CAFE Model results by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM.[21] For 2051 through 2100, the GCAM Reference and GCAM6.0 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.[22] The assumptions and methods used to extrapolate GHG emissions estimates beyond 2050 for this SEIS 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), *Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2016a), and the *MY 2021–2026 Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Final EIS* (NHTSA 2020).

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).[23] The MOVES model also estimated non-GHG emissions—both criteria pollutants and air toxics—which are used as inputs in MAGICC6. Criteria pollutants included are: sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), fine particulate matter less than or equal to 2.5 microns in diameter (PM2.5), and volatile organic compounds (VOCs). Air toxics included are acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and diesel particulate matter less than or equal to 10 microns in diameter.

Fuel savings from more stringent CAFE standards would result in lower overall emissions of CO_2 (the main GHG emitted) because of reduced refining, distribution, and use of transportation fuels.[24] g Fuel

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[21] 2050 is the last year for which the CAFE Model provides estimates of fleet CO_2 emissions for this analysis.

[22] NHTSA anticipates a larger post-2050 decline in passenger car and light truck energy consumption than what is projected in the GCAM Reference scenario due to updated projections around technology availability and adoption, as well as other factors that affect fuel consumption. However, the SEIS approach for projecting emissions from 2051 to 2100 is consistent with methods used in recent NHTSA EISs, conservative in terms of estimating environmental impacts, and reasonable given the uncertainty associated with post-2050 projections.

[23] Upstream emissions considered in this SEIS include those that occur in the United States during the recovery, extraction, and transportation of crude petroleum, as well as during the refining, storage, and distribution of transportation fuels. Emissions from each of these phases of fuel supply are estimated using factors obtained from Argonne's GREET model. A portion of finished motor fuels are refined in the United States using imported crude petroleum as a feedstock, and GREET's emissions factors are used to estimate emissions associated with transporting imported petroleum from coastal port facilities to U.S. refineries, refining it to produce transportation fuels, and storing and distributing those fuels. GREET's emissions factors are also used to estimate domestic emissions from transportation, storage, and distribution of motor fuels that are imported to the United States in refined form.

[24] 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

efficiency, fuel consumption, and CO_2 emissions are closely connected. Fuel efficiency describes how much fuel a vehicle requires to perform a certain amount of work (for example, how many miles it can travel or how many tons it can carry per mile traveled). A vehicle is more fuel-efficient if it can perform more work while consuming less fuel. Lower fuel consumption reduces CO_2 emissions directly because the primary source of vehicle-related CO_2 emissions is the combustion of carbon-based fuel in internal combustion engines; combustion of a hydrocarbon essentially produces energy (used to power the vehicle), CO_2, and water. Therefore, lowering fuel consumption lowers CO_2 emissions, and greater fuel efficiency means fewer CO_2 emissions.

NHTSA estimated reductions in tailpipe CO_2 emissions resulting from fuel savings by assuming that the carbon content of gasoline, diesel, and other fuels is converted entirely to CO_2 during the combustion process.[25] Specifically, NHTSA estimated CO_2 emissions from fuel combustion as the product of the volume of each type of fuel consumed (in gallons), its mass density (in grams per gallon), the fraction of its total mass represented by carbon (measured as a proportion), and CO_2 emissions per gram of fuel carbon (the ratio of the molecular weights of CO_2 and elemental carbon). NHTSA estimated changes in tailpipe CH_4 and N_2O emissions by applying MOVES-based emission factors for these GHGs to estimated annual mileage accumulation (i.e., VMT) of vehicles of different types and vintages.

Reduced fuel consumption also lowers CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. At the same time, new CAFE standards may also lead to increased CO_2 emissions from processes involved in producing and delivering any alternative energy sources (i.e., other than petroleum) for which consumption increases. In particular, the CAFE Model shows electricity consumption by light-duty vehicles increasing more rapidly under the action alternatives than under the No Action Alternative. NHTSA estimated the 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 savings are reflected in reductions in activity during each phase of fuel production and distribution.[26] The total reduction in CO_2 emissions from improving fuel economy under each alternative is the sum of the reductions in motor vehicle emissions from reduced fuel combustion compared to the No Action Alternative plus the reduction in upstream emissions from a lower volume of fuel production and distribution than is projected under the No Action Alternative (minus the increase in upstream emissions resulting from increased electricity generation).

5.3.2 Social Cost of Greenhouse Gas Emissions

This SEIS characterizes the potential environmental impacts of the estimated changes in GHG emissions in terms of physical effects, such as changes in temperature and sea level. Chapter 6.5.1 of the PRIA characterizes the monetized social value of these estimated changes in emissions. The social cost of

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Independence and Security Act, extends only to the regulation of vehicle fuel efficiency. For reference, CH_4 and N_2O account for 4 percent of the tailpipe GHG emissions from passenger vehicles and light trucks, and CO_2 emissions account for the remaining 96 percent. Of the total (including non-tailpipe) GHG emissions from passenger cars and light trucks, tailpipe CO_2 represents approximately 97.0 percent, tailpipe CH_4 and N_2O represent approximately 0.6 percent, and HFCs represent approximately 2.4 percent (values are calculated from EPA 2021a).

[25] 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).

[26] Some modifications were made to the estimation of upstream emissions, consistent with NHTSA and EPA assumptions in the NPRM. Section 5.2 of the TSD provides more information regarding these modifications.

carbon (SC-CO_2), methane (SC-CH_4), or nitrous oxide (SC-N_2O) are metrics that estimate the social value of marginal changes in emissions and are expressed in dollars per ton of incremental emissions. Readers may consult the preamble to the proposed rule for a description of how the monetized cost-benefit analysis factors into its decision-making process. The proposed rule preamble and PRIA are both available for public review.

5.3.3 Methods for Estimating Climate Effects

This SEIS estimates and reports the projected reductions in GHG emissions, particularly CO_2, that would result from the alternatives. The reduction in GHG emissions is a direct effect of the increased stringency in passenger car and light truck fuel economy associated with the action alternatives. The reductions in CO_2 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 reductions 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 WGI 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 reductions in emissions of CO_2, CH_4, N_2O, CO, NO_X, SO_2, and VOCs 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 WGI 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 (AOGCMs) (Meinshausen et al. 2011).[27]
- MAGICC is publicly available and was designed for the type of analysis performed in this SEIS.
- More complex AOGCMs are not designed for the type of sensitivity analysis performed in this SEIS and are best used to provide results for groups of scenarios with much greater differences in emissions.

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[27] As a reduced-complexity model, MAGICC relies on a more limited number of potential climate and carbon cycle responses and a higher level of parameterization to proxy carbon cycle force than more complex models. Results from MAGICC (e.g., projected atmospheric CO_2 concentration in 2100) will, therefore, vary somewhat from those of more complex models (Meinshausen et al. 2011).

- 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 WGI AR5*;* MAGICC 4.1 was used in the *IPCC WGI AR4* (IPCC 2007).[28]

5.3.3.2 Sea-Level Rise

NHTSA estimated the projected changes in global mean sea level based on data from the IPCC WGI AR5 (IPCC 2013a).[29] The sea-level rise analysis uses global mean surface temperature data and projections from 1950 to 2100 and global mean sea-level rise projections from 2010 to 2100. These projections are based on the climate ensemble data of the RCP[30] 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.[31]

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.[32] 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)

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[28] 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.

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

[30] RCP2.6, RCP4.5, RCP6.0, and RCP8.5.

[31] The MAGICC model runs simulations from a preindustrial starting point through the year 2100. Results of this analysis are shown for the years 2040, 2060, and 2100.

[32] Preindustrial average ocean pH was 8.2. The average pH of the world's oceans has decreased by 0.1 unit compared to the preindustrial period, bringing ocean pH to 8.1 (IPCC 2013a).

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 the direct and indirect analysis for this SEIS is the GCAM Reference scenario (formerly MiniCAM), which does not assume comprehensive global actions to mitigate GHG emissions.[33] 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. The GCAM Reference scenario is the GCAM representation of a scenario that yields a radiative forcing of approximately 7.0 W/m^2 in the year 2100.

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 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 SEIS.

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, hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride. 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

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[33] For the cumulative analysis, NHTSA used the GCAM6.0 scenario as a reference case global emissions scenario; GCAM6.0 assumes a moderate level of global actions to address climate change. For further discussion, see Section 8.6.2.1, *Global Emissions Scenarios Used for the Cumulative Impact Analysis.*

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 rules that established CAFE and GHG emissions standards for MY 2017–2025 and MY 2021–2026 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 1,215 million metric tons carbon dioxide ($MMTCO_2$); the emissions in 2040 under Alternative 2 (Preferred Alternative) are estimated to be 1,127 $MMTCO_2$. The difference of 88 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global emissions for the GCAM Reference scenario in 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 the Preferred Alternative are estimated to be 88 $MMTCO_2$ less than this reference level or approximately 51,613 $MMTCO_2$ 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.

The forthcoming IPCC Sixth Assessment Report (AR6) will use updated Global Climate Models and GHG concentration scenarios developed for Coupled Model Intercomparison Project Phase 6 (CMIP6). The new GHG concentration scenarios are called Shared Socioeconomic Pathways (SSPs), which will replace the RCPs. SSPs are designed to provide an expanded set of GHG concentrations based on a range of future socioeconomic conditions (Riahi et al. 2017). A set of SSPs provide continuity with RCPs by modeling similar radiative forcing through end of this century (e.g., SSP5-8.5 is a companion to RCP8.5). SSPs also consider a greater range of future aerosol concentrations, which drives a greater range of temperature projections (Riahi et al. 2017).

CMIP6 model ensembles using SSPs yield greater warming and a larger range of projected temperature and precipitation outcomes than CMIP5. Specifically, CMIP6 models project greater warming (by close to 1.5°C [2.7°F]) at the upper end of the 5 percent to 95 percent ensemble envelope for the high SSP5-8.5 scenario, and individual Global Climate Models using SSP5-8.5 simulate warming greater than previously predicted (Tebaldi et al. 2021). CMIP6 models also have larger climate sensitivities than CMIP5 (Zelinka et al. 2020; Hermans et al. 2021), meaning that, on average, CMIP6 models simulate larger global temperature change in response to increases in CO_2 concentrations. For example, effective climate sensitivity corresponding to CO_2 quadrupling increased from 3.7 to 8.4°F in CMIP5 to 3.2 to 10.1°F in CMIP6 (Zelinka et al. 2020).

If the IPCC AR6 SSPs are released in advance of NHTSA's analysis of climate impacts for the Final SEIS for MY 2024–2026 CAFE standards, NHTSA may present in the Final SEIS additional modeling reflecting the action alternatives' climate impacts against the SSPs. Whether NHTSA is able to present such additional climate modeling results will depend on the timing of the release of the SSPs and the availability of datasets compatible with the modeling requirements used in this analysis. The SSPs and underlying data would have to be made publicly available sufficiently in advance of NHTSA's analysis of the alternatives in order for the agency to adjust its modeling method to incorporate the new scenarios and new information into the Final SEIS. Although these SSPs are anticipated to project greater climate-related impacts than the current RCPs (such as climate sensitivities; see Section 5.3.3.6, *Sensitivity Analysis*), preliminary results do not show a significant difference from each scenario's RCP counterpart (e.g., RCP8.5 compared to SSP5-8.5). NHTSA may consider the additional modeling as part of its decision-making process, but it is not anticipated to rise to the level of "significant new circumstances or information" warranting additional supplementation of this Draft SEIS.[34]

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 reductions 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.[35] 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 minus the reductions in emissions of CO_2, CH_4, N_2O, SO_2, NO_X, CO, and VOCs estimated to result from each action alternative. For example, the global emissions scenario under Alternative 2 equals the global emissions scenario minus the emissions reductions from that alternative. All SO_2 reductions were applied to the Aerosol Region 1 of MAGICC, which includes North America.
3. NHTSA used MAGICC6 to estimate the changes in global CO_2 concentrations, global mean surface temperature, and sea-level rise through 2100 using the global emissions scenario under each alternative developed in steps 1 and 2.
4. NHTSA used the increase in global mean surface temperature to estimate the increase in both global average precipitation and sea-level rise for each alternative using the global emissions scenario.

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[34] 40 CFR § 1502.9(c)(1) (2019).

[35] 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).

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 WGI 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 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 3—because this was deemed sufficient to assess the effect of various climate sensitivities on the results under the range of alternatives considered in this SEIS.

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 reductions 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 minus emissions of each pollutant under Alternative 1. Separately, NHTSA used the same approach for Alternative 3 (the lowest GHG emissions alternative) as compared to the No Action Alternative.[36] All SO_2 reductions were applied to Aerosol Region 1 of MAGICC, which includes North America.
3. NHTSA assumed a range of climate sensitivity values consistent with the 10 to 90 percent probability distribution from the IPCC WGI 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.

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[36] 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.

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).

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 a reduction in GHG emissions and associated radiative forcing, the current state of science does not allow for quantifying how reduced 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 Chapter 8, *Cumulative Impacts,* Section 8.6.5.2, *Sectoral Impacts of Climate Change*, under *Tipping Points and Abrupt Climate Change*. The analysis applies equally to direct and indirect impacts, as well as to 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 has identified Alternative 2 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 reduced GHG emissions compared with the No Action Alternative. The more an alternative would decrease GHG emissions, the more it would be expected to decrease the direct and indirect climate change impacts associated with such emissions.

5.4.1 Greenhouse Gas Emissions

Using the methods described in Section 5.3, *Analysis Methods*, NHTSA estimated projected emissions reductions under the action alternatives for 2021 through 2100. These emissions reductions 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 reduction in CO_2 emissions under each alternative. Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 96 percent, even after accounting for the higher GWPs of other GHGs—NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions expected under the Proposed Action and alternatives. However, in assessing the direct and indirect impacts and cumulative impacts on climate change indicators (i.e., global average surface temperature, sea level, precipitation, and ocean pH, as described in Section 5.4.2, *Direct and Indirect Impacts on Climate Change Indicators*, and Section 8.6.4, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*), NHTSA incorporates reductions of all GHGs by the nature of the models used to project changes in the relevant climate indicators.

Table 5.4.1-1 and Figure 5.4.1-1 show total U.S. passenger car and light truck CO_2 emissions under the No Action Alternative and emissions reductions that would result from the Proposed Action and alternatives from 2021 to 2100. All action alternatives would result in lower CO_2 emissions than the No Action Alternative because all action alternatives involve more stringent CAFE standards than the No Action Alternative. U.S. passenger car and light truck emissions from 2021 to 2100 would range from a low of 81,000 $MMTCO_2$ under Alternative 3 to a high of 89,600 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projected emissions reductions from 2021 to 2100 under the action alternatives would range from 4,100 to 8,600 $MMTCO_2$. Compared to total global emissions of 4,950,865 $MMTCO_2$ over this period (projected by the GCAM Reference scenario), this rulemaking is expected to reduce global CO_2 emissions by approximately 0.08 to 0.17 percent from projected levels under the No Action Alternative.

Table 5.4.1-1. Carbon Dioxide Emissions and Emissions Reductions($MMTCO_2$) from All Passenger Cars and Light Trucks, 2021 to 2100, by Alternative [a]

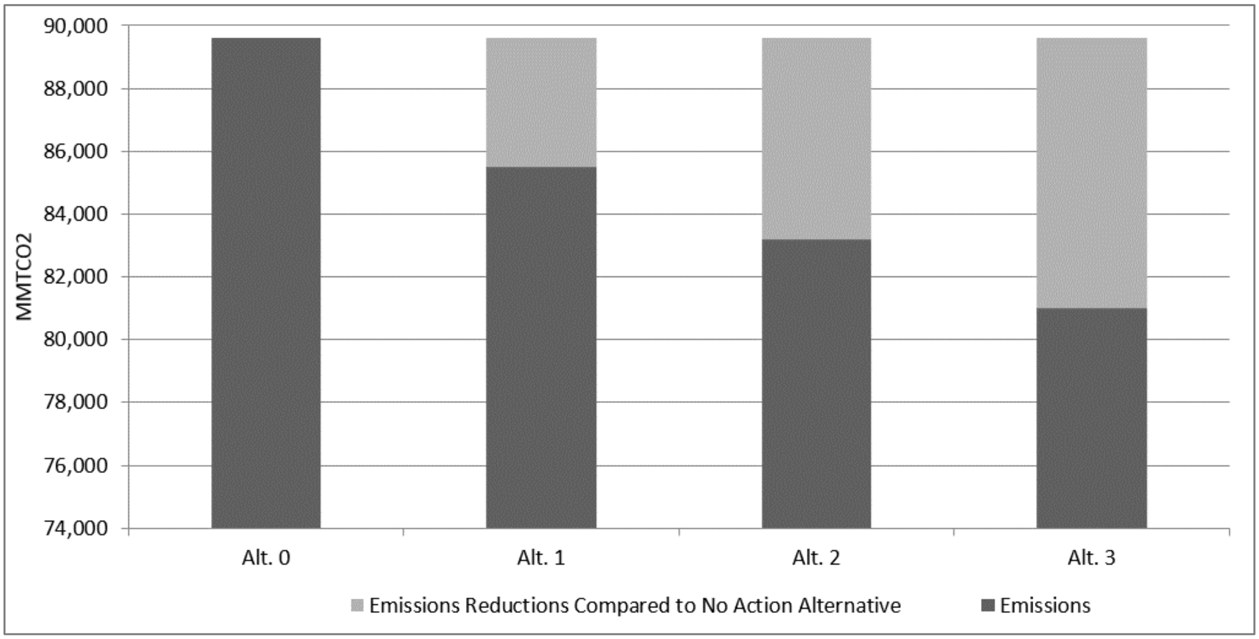
Alternative	Total Emissions	Emissions Reductions Compared to No Action	Percent (%) Emissions Reductions Compared to No Action Alternative Emissions
Alt. 0 (No Action)	89,600	-	-
Alt. 1	85,500	4,100	5%
Alt. 2	83,200	6,400	7%
Alt. 3	81,000	8,600	10%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

$MMTCO_2$ = million metric tons of carbon dioxide

Figure 5.4.1-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All Passenger Cars and Light Trucks, 2021 to 2100, by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

To get a sense of the relative magnitude of these reductions, it can be helpful to consider emissions from passenger cars and light trucks in the context of emissions projections from the transportation sector. Passenger cars and light trucks currently account for 20 percent of CO_2 emissions in the United States. The action alternatives would reduce total CO_2 emissions from U.S. passenger cars and light trucks by a range of 5 to 10 percent from 2021 to 2100 compared to the No Action Alternative. Compared to annual U.S. CO_2 emissions of 7,193 $MMTCO_2$ from all sources by the end of the century projected by the GCAM Reference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions in the year 2100 by a range of 0.8 to 1.6 percent.[37] Figure 5.4.1-2 shows the projected annual emissions from U.S. passenger cars and light trucks under the alternatives.

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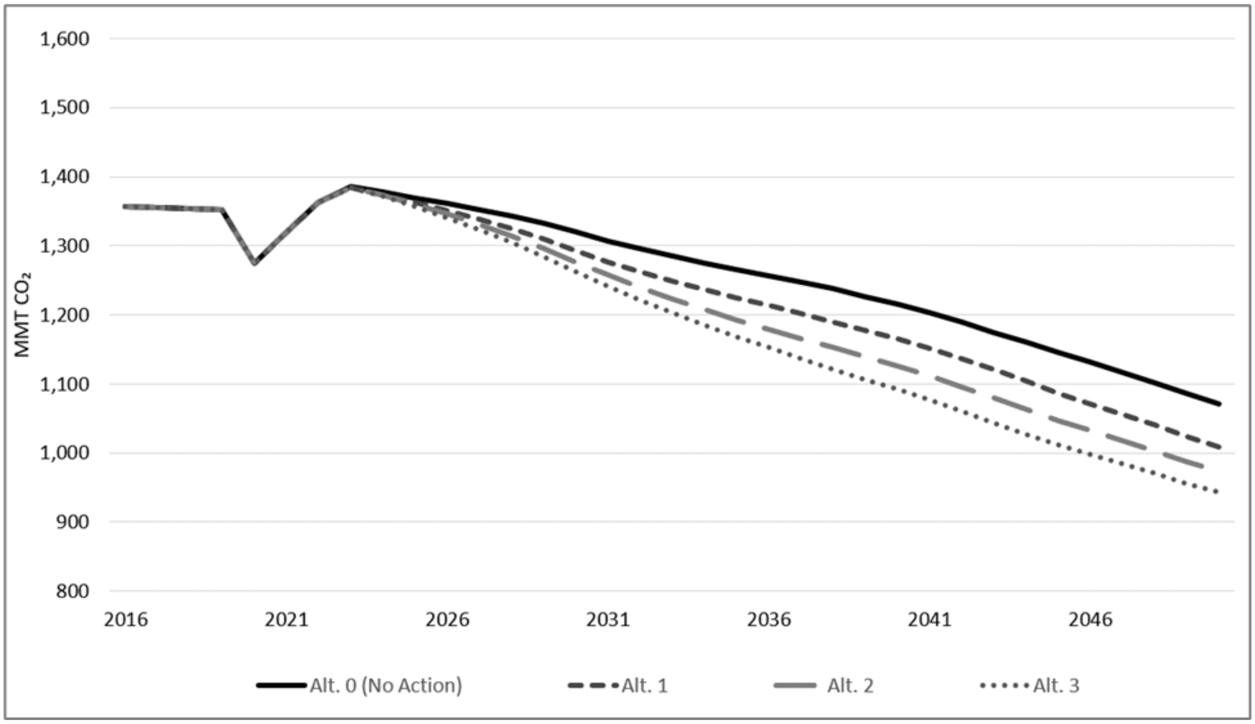
[37] Fuel consumption data is held constant after 2095, as this is the last year emissions data are available from GCAM Reference.

Figure 5.4.1-2. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All Passenger Cars and Light Trucks by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Table 5.4.1-2 also illustrates that the Proposed Action and alternatives would reduce passenger car and light truck emissions of CO_2 from their projected levels under the No Action Alternative. Similarly, under the Proposed Action and alternatives, CH_4 and N_2O emissions in future years are projected to decline from their projected levels under the No Action Alternative. These reductions are presented in CO_2 equivalents ($MMTCO_2e$) in the table below. All action alternatives would result in emissions reductions compared to the No Action Alternative. Of all the action alternatives, Alternative 3 would result in the greatest emissions reductions.

Table 5.4.1-2. Emissions of Greenhouse Gases (MMTCO$_2$e per year) from All Passenger Cars and Light Trucks by Alternative [a]

GHG and Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Carbon dioxide (CO$_2$)				
2020	1,275	1,275	1,275	1,275
2040	1,215	1,165	1,127	1,093
2060	1,065	1,003	972	940
2080	1,058	996	965	933
2100	984	927	897	868
Methane (CH$_4$)				
2020	39	39	39	39
2040	37	36	35	34
2060	34	32	31	30
2080	34	32	31	30
2100	31	30	29	28
Nitrous oxide (N$_2$O)				
2020	14	14	14	14
2040	11	11	11	10
2060	10	9	9	9
2080	10	9	9	8
2100	9	8	8	8
Total (all GHGs)				
2020	1,328	1,328	1,328	1,328
2040	1,264	1,212	1,173	1,137
2060	1,109	1,044	1,012	979
2080	1,101	1,037	1,005	972
2100	1,024	965	934	904

Notes:

[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the GCAM Reference scenario. These assumptions project a slight decline over this period.

MMTCO$_2$e = million metric tons carbon dioxide equivalent

5.4.1.1 Comparison to the U.S. Greenhouse Gas Targets Submitted to the United Nations Framework Convention on Climate Change

These results can be viewed in light of U.S. GHG emissions reduction targets. On April 22, 2021, President Biden submitted a “Nationally Determined Contribution” (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), with a target for the United States to achieve a 50 to 52 percent reduction in economy-wide net GHG pollution from 2005 levels by 2030. This target was submitted under the Paris Agreement under the UNFCCC, which entered into force on November 4,

2016. The United States formally withdrew from the Paris Agreement in November 2020, and officially rejoined the Paris Agreement in February 2021.[38]

Total GHG emissions from U.S. passenger cars and light trucks in 2030 are projected to be below 2005 levels for the No Action and action alternatives. The percentage decreases range from a 4.5 percent reduction for the No Action Alternative to an 8.7 percent reduction for the most stringent alternative (Alternative 3). These reductions in emissions alone would not reduce total passenger car and light truck vehicle emissions to a 50 to 52 percent reduction from 2005 levels by 2030.

However, the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, requires NHTSA to continue setting fuel economy standards for MYs 2027–2030, which can further contribute to meeting the U.S. target. In addition, the President’s targets outlined above do not specify that every emitting sector of the economy must contribute equally proportional emissions reductions. Thus, smaller emissions reductions in the passenger car and light truck sector could be compensated for by larger reductions in other sectors. In addition, the action of setting fuel economy standards does not directly regulate total emissions from vehicles. NHTSA’s authority to promulgate CAFE standards does not allow the agency to regulate other mobile sources of GHG emissions (e.g., HFC emissions from vehicle air conditioners) or other factors affecting transportation emissions, such as driving habits or use trends; NHTSA cannot, for example, control VMT. Under all of the alternatives, growth in the number of passenger cars and light trucks in use throughout the United States, combined with assumed increases in their average use (annual VMT per vehicle) due to economic improvement and a variety of other factors, is projected to result in growth in passenger car and light truck VMT, peaking in 2045 and declining gradually in the following years. While NHTSA does not have the authority to regulate VMT, the DOT is investing in efforts to reduce VMT to help the United States meet its emissions reductions targets. These efforts include investing in smart cities and public transportation improvements.

This projected growth in travel between 2020 and 2045 offsets some of the effect of increased passenger car and light truck fuel economy under the action alternatives, due to increases in U.S. transportation fuel consumption from vehicles. Despite expected growth in travel, CO_2 emissions are projected to decrease mainly due to a rise in average miles per gallon for all passenger cars and light trucks in use resulting from older, less efficient, vehicles being replaced by newer, more efficient, models over time. The projected decrease in CO_2 emissions highlights how this rulemaking is an important component of a variety of actions in various sectors to meet the U.S. GHG targets stated in the United States’ NDC.

5.4.1.2 Comparison to Annual Emissions from Passenger Cars and Light Trucks

As an illustration of the fuel use projected under the Proposed Action and alternatives, Figure 5.4.1-3 expresses the CO_2 reductions under each action alternative in 2025 as the equivalent number of passenger cars and light trucks that would produce those emissions in that year. The emissions reductions under the action alternatives would be equivalent to the annual emissions from 1,284,000 passenger cars and light trucks (Alternative 1) to 2,248,000 passenger cars and light trucks (Alternative 3) in 2025, compared to the annual emissions that would occur under the No Action Alternative. A total

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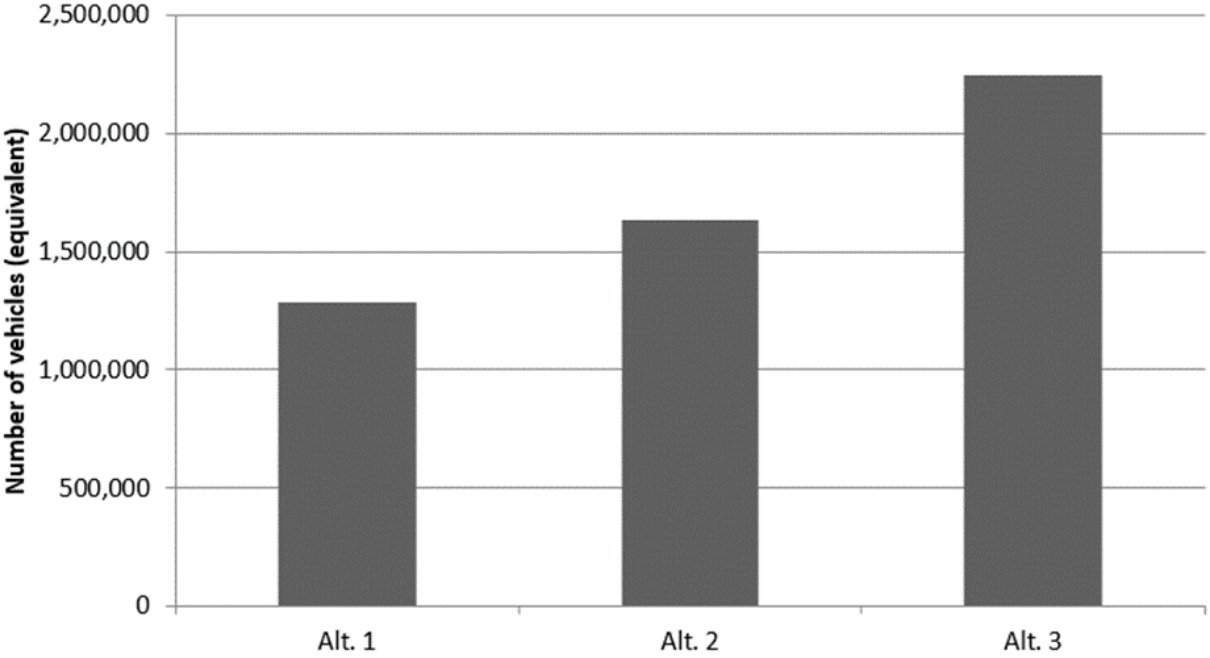
[38] United Nations. January 20, 2021. Paris Agreement Instrument of Acceptance: United States of America. Available at https://treaties.un.org/doc/Publication/CN/2021/CN.10.2021-Eng.pdf; U.S. Department of State. Press Statement. February 19, 2021. Anthony J. Blinken, Secretary of State. “The United States Officially Rejoins the Paris Agreement”. Available at https://www.state.gov/the-united-states-officially-rejoins-the-paris-agreement/#:~:text=On%20January%2020%2C%20on%20his,back%20into%20the%20Paris%20Agreement.

number of 253,949,000 passenger cars and light trucks are projected to be on the road in 2025 under the No Action Alternative.[39,40]

Figure 5.4.1-3. Number of Passenger Cars and Light Trucks Equivalent to Carbon Dioxide Reductions in 2025 Compared to the No Action Alternative



5.4.1.3 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 (3.6°F) 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 (3.6°F) is greater than 66 percent (IPCC 2013b). Since this IPCC 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 (Rogelj et al. 2019). Because of underlying uncertainties and assumptions, no one number for the remaining global carbon budget can be considered definite.

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[39] Values for vehicle totals have been rounded.

[40] 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 is projected to account for 5.39 metric tons of CO_2 emissions in 2025 based on MOVES, the GREET model, and EPA analysis.

Using the IPCC estimated carbon budget, as of 2011,[41] 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 2019, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 101 Gt C (370 Gt CO_2), leaving a remaining budget from 2020 onwards of 384 Gt C (1,406 Gt CO_2) (CDIAC 2020).[42] Under the No Action Alternative, U.S. passenger cars and trucks are projected to emit 24 Gt C (90 Gt CO_2) from 2021 to 2100, or 6.0 percent of the remaining global carbon budget. Under Alternative 3, this projection decreases to 22 Gt C (81 Gt CO_2) or 5.4 percent of the remaining budget.

The emissions reductions necessary to keep global emissions within this carbon budget must include drastic reductions in emissions from the U.S. passenger car and light truck vehicle fleet, but could not be achieved solely with those reductions. The emissions reductions needed to keep global emissions within this carbon budget would also require drastic reductions in all U.S. sectors and from the rest of the developed and developing world. Even with the full implementation of global emissions reduction commitments to date, global emissions in 2030 would still be roughly 15 $GtCO_2e$ higher than what is consistent with a scenario that limits warming to 2°C [3.6˚F] from preindustrial levels (United Nations Environment Programme 2020).

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.

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*, and Section 5.4.2.2, *Climate Change Attributes*. Section 5.4.2.3, *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. More importantly, these reductions play an important role in national and global efforts to reduce GHG emissions across a wide range of sources. The combined impact of the emissions reductions associated with the Proposed Action and alternatives with emissions reductions from other sources could have large health, societal, and environmental impacts. Finally, NHTSA is required by the Energy Independence and Security Act to set standards for MYs 2027–2030, standards that are likely to be more stringent than Alternative 2 and produce additional GHG reductions.

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[41] NHTSA intends to update this analysis to reflect the most recent carbon budget once IPCC's Sixth Assessment Report (AR6) is released.

[42] 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 2019, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 101 Gt C, leaving a remaining budget from 2020 onwards of 174 Gt C, including non-CO_2 influences (CDIAC 2020).

MAGICC6 is a reduced-complexity climate model well calibrated to the mean of the multimodel 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.[43] 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]

	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
Scenario	**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

Source: IPCC 2013b

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

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 788.74 under Alternative 1 to 788.33 ppm under Alternative 3 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, *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	478.99	565.29	788.74	1.287	2.007	3.483	22.87	36.56	76.25	8.4099	8.3477	8.2178
Alt. 2	478.96	565.19	788.52	1.287	2.007	3.482	22.87	36.55	76.23	8.4100	8.3478	8.2179
Alt. 3	478.93	565.11	788.33	1.287	2.007	3.481	22.87	36.55	76.22	8.4100	8.3478	8.2180

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[43] 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**
Reductions Under Proposed Action and Alternatives												
Alt. 1	0.05	0.15	0.37	0.000	0.001	0.002	0.00	0.01	0.03	-0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.58	0.000	0.001	0.002	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 3	0.11	0.33	0.77	0.001	0.002	0.003	0.00	0.01	0.06	-0.0001	-0.0002	-0.0004

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions and 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 less than zero but more 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 reduction 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. However, the relative impact of the Proposed Action and alternatives is demonstrated by the reduction in the rise of CO_2 concentrations under the range of action alternatives. As shown in Figure 5.4.2-2, the reduction in CO_2 concentrations by 2100 under Alternative 3 compared to the No Action Alternative is nearly twice that of Alternative 1.

Figure 5.4.2-1. Atmospheric Carbon Dioxide Concentrations by Alternative

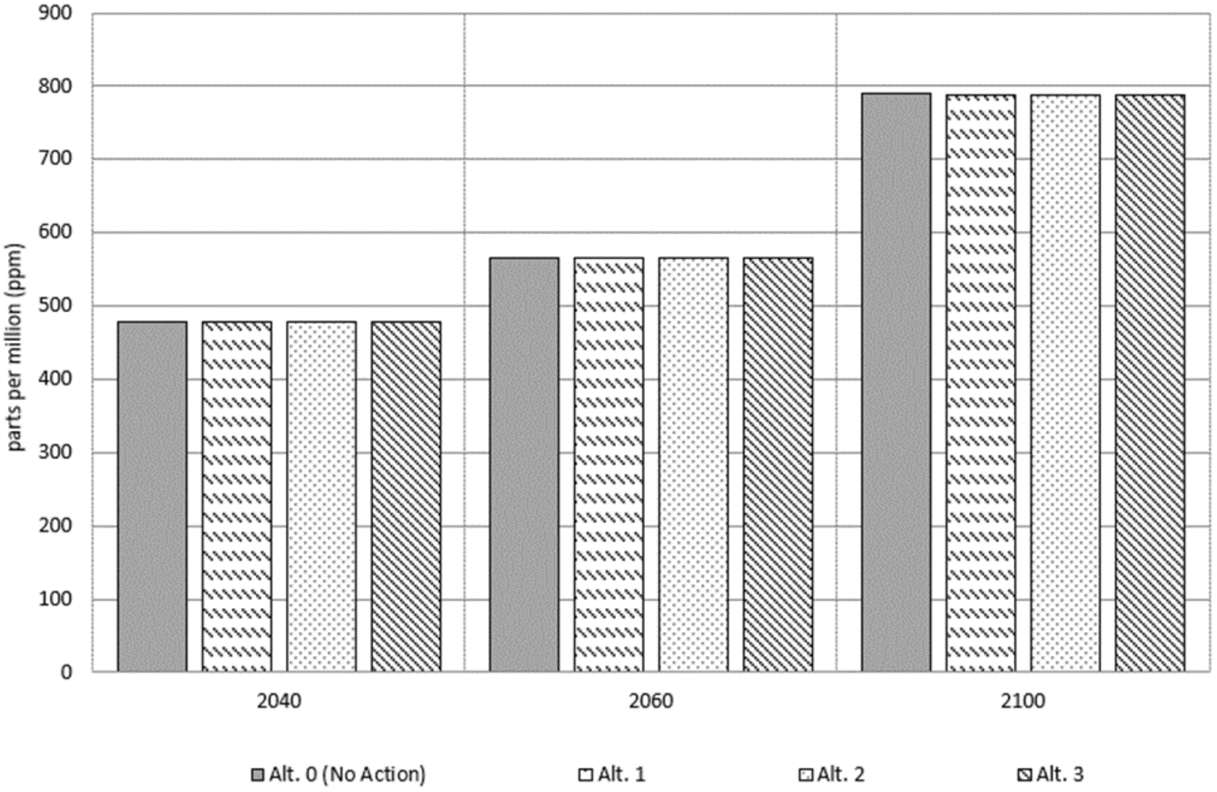
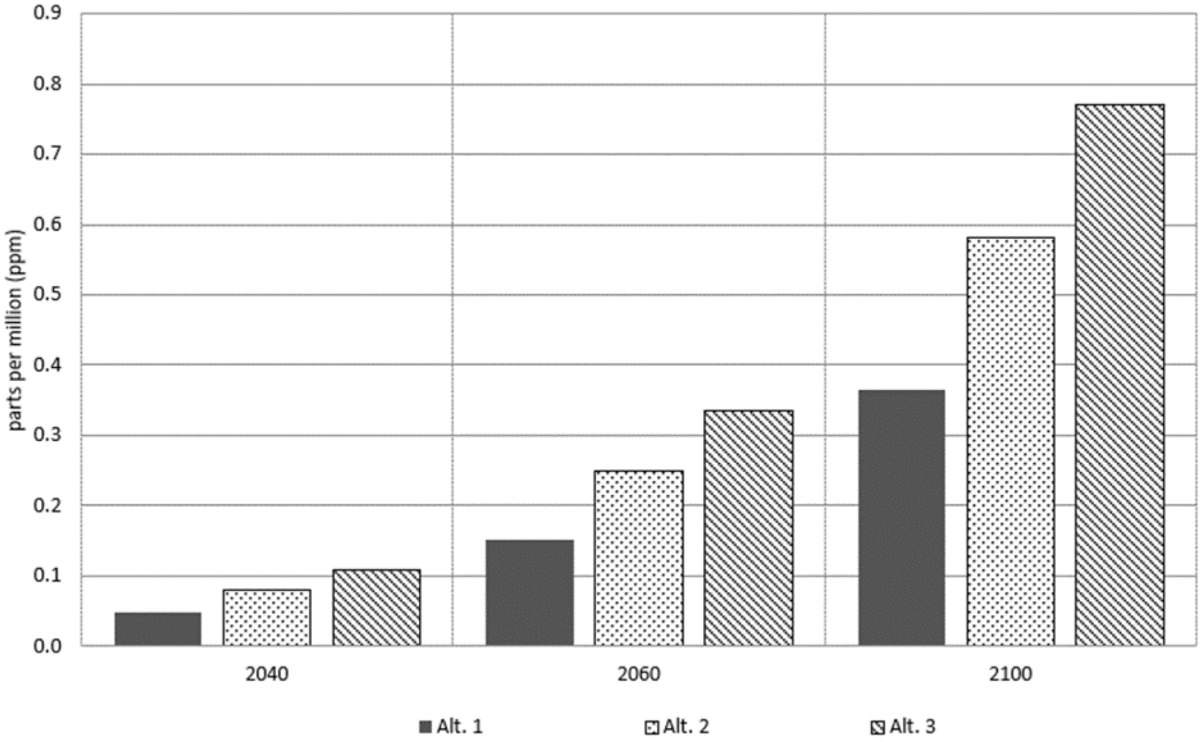


Figure 5.4.2-2. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative



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.[44] The differences among the reductions in baseline temperature increases projected to result from the various action alternatives are small compared to total projected temperature increases, which are shown in Figure 5.4.2-3. For example, in 2100 the reduction in temperature rise compared to the No Action Alternative ranges from 0.002°C (0.003°F) under Alternative 1 to 0.003°C (0.006°F) under Alternative 3.

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[44] 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

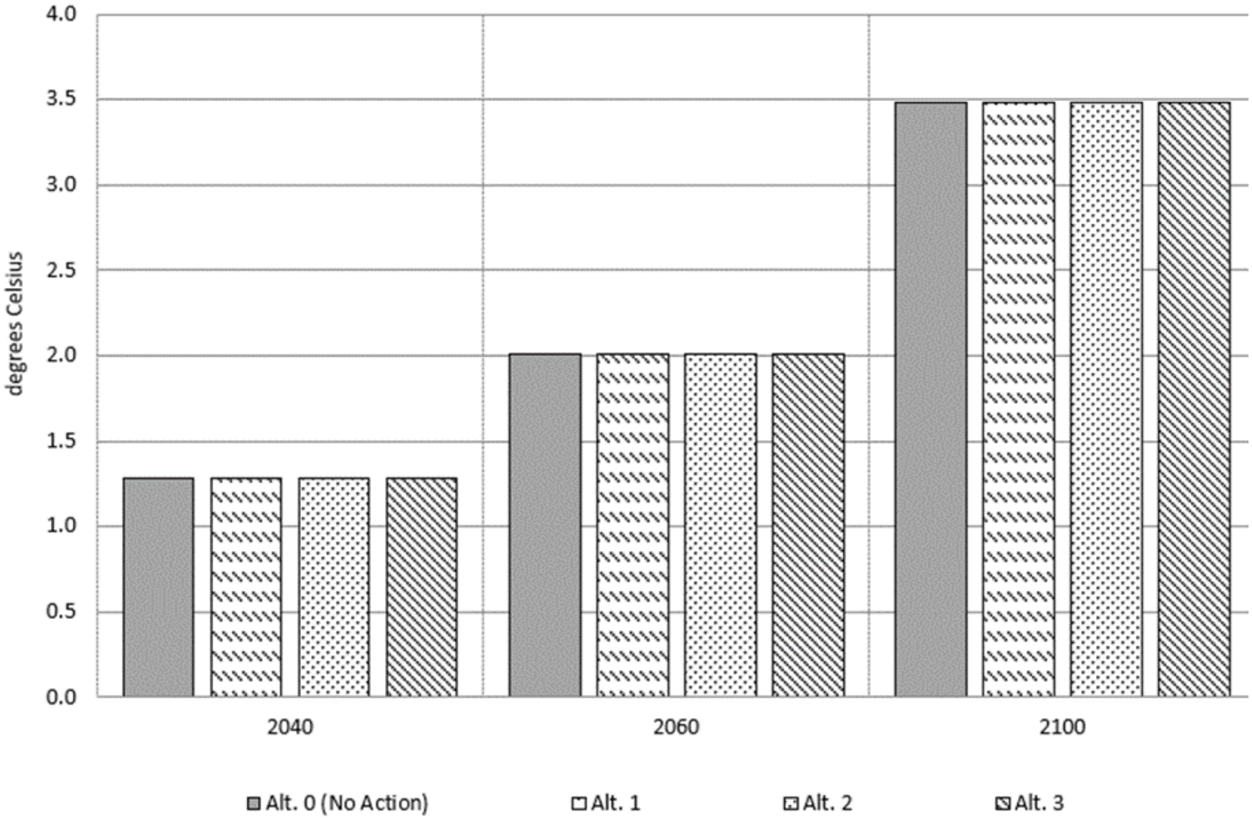

Figure 5.4.2-4 also illustrates that reduction in the growth of projected global mean surface temperature under the Proposed Action and alternatives compared to the No Action Alternative are anticipated to be small compared to total projected temperature increases. However, the relative impacts of the Proposed Action and alternatives can be seen by comparing the reductions in the rise in global mean surface temperature projected to occur under Alternatives 1 and 3. As shown in Figure 5.4.2-4, the reduction in the projected growth in global temperature under Alternative 3 is more than double that under Alternative 1 in 2100.

At this time, quantifying the changes in regional climate due to 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 reduce the regional impacts in proportion to reductions in global mean surface temperature increases. To provide context on how the projected changes in temperature from the MAGICC modeling may differentially affect geographic regions, Table 5.4.2-3 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC AR5 from present day through 2100.

Figure 5.4.2-4. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative

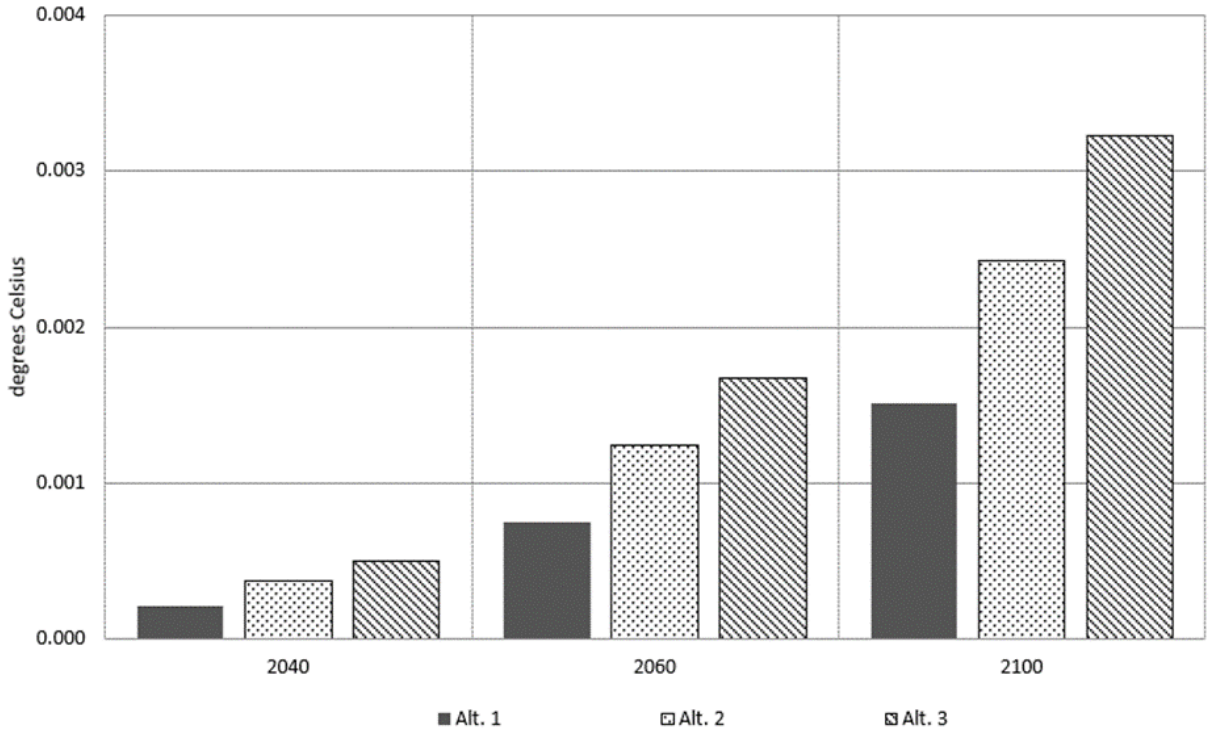

Table 5.4.2-3. Regional Changes to Warming and Seasonal Temperatures in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Fifth Assessment Report

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

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Mediterranean and Europe	Northern Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in winter temperature than in Central or Southern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves (though little change over Scandinavia)
	Central Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
	Southern Europe and Mediterranean	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
Asia	Central Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northern Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Eastern Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	West Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	South Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeast Asia	*Likely* increase in mean annual temperature [a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
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]	--

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Central and South America	Central America and the Caribbean	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeastern South America	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Amazon Region	*Very likely* increase in temperatures, greater than in other Central and South American locations	*Likely* increase in hot days and decrease in cool days, *very likely* increase in warm nights and decrease cold nights, *likely* increase in frequency and duration of heat waves
	Andes Region	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northeastern Brazil	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
Australia and New Zealand	Southern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Southwestern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Rest of Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	New Zealand	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
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	--

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Small Islands		*Very likely* increase in temperature	--

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
[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 SEIS.

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 to 2005 (IPCC 2013a). The 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate provides similar projections, with sea level likely to increase 29 to 59 centimeters (11.4 to 23.2 inches) for RCP2.6 and 61 to 110 centimeters (24.0 to 43.3 inches) for RCP8.5 compared to 1986 to 2005 (IPCC 2019a). Sea-level rise projections in the IPCC AR5 and 2019 Special Report 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 5.3.3.2, *Sea-Level Rise*, for more information.

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 76.22 centimeters (30.01 inches) under Alternative 3 and 76.25 centimeters (30.02 inches) under Alternative 1. This represents a maximum reduction of 0.06 centimeter (0.03 inch) by 2100 under Alternative 3 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 (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 (further explained in Chapter 8, *Cumulative Impacts*). 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 reduce 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 W/m^2, similar to the GCAM Reference scenario's radiative forcing of 7 W/m^2) in this analysis because MAGICC does not directly estimate changes in global mean precipitation.

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: IPCC 2013a: Figure 12-7

Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. The Proposed Action and alternatives are projected to decrease 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).

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	1.287	2.007	3.483
Alt. 2	1.287	2.007	3.482
Alt. 3	1.287	2.007	3.481
Reductions in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative) [b]			
Alt. 1	0.000	0.001	0.002
Alt. 2	0.000	0.001	0.002
Alt. 3	0.001	0.002	0.003
Global Mean Precipitation Increase by Alternative (%)			
Alt. 0 (No Action)	2.16%	3.37%	5.85%
Alt. 1	2.16%	3.37%	5.85%
Alt. 2	2.16%	3.37%	5.85%
Alt. 3	2.16%	3.37%	5.85%
Reductions 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%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

[c] The decrease 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.[45] 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

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[45] 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."

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.

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 reduce the relative precipitation changes in proportion to the reduction in global mean surface temperature rise. To provide context on how the projected changes in precipitation from the MAGICC modeling may differentially affect geographic regions, Table 5.4.2-6 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC AR5 from the present day through 2100.

Table 5.4.2-6. Regional Changes to Precipitation in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Fifth Assessment Report

Land Area	Subregion	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]	--

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
North America	Northern regions/Northern North America	*Very likely* increase in precipitation by mid-century [a]	Snow season length and snow depth are *very likely* to decrease
	Southwest	--	Snow season length and snow depth are *very likely* to decrease
	Northeast USA	--	Snow season length and snow depth are *very likely* to decrease
	Southern Canada	--	--
	Canada	*Very likely* increase in precipitation by mid-century [a]	Snow season length and snow depth are *very likely* to decrease
	Northernmost part of Canada	*Very likely* increase in precipitation by mid-century [a]	Snow season length and snow depth are *likely* to increase
Central and South America	Central America and the Caribbean	--	--
	Southeastern South America	*Very likely* that precipitation will increase	
	Amazon Region	*Very likely* that precipitation will decrease in the eastern Amazon during the dry season	
	Andes and Western South America	*Very likely* that precipitation will decrease in the Central Chile and the Northern part of this region	
	Northeastern Brazil	*Very likely* that precipitation will decrease during the dry season	
Australia and New Zealand	Southern Australia	--	--
	Southwestern Australia	--	
	New Zealand	*Likely* to increase in the western regions during winter and spring	
Polar Regions	Arctic	*Likely* increase in precipitation	--
	Antarctic	*Likely* increase in precipitation	
Small Islands	--	Rainfall *likely* to increase over certain regions	

Source: IPCC 2013a

Notes:

Information is omitted from the table where no data was available from IPCC 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

Ocean pH

Table 5.4.2-2 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative. Ocean pH under the alternatives ranges from 8.2176 under the No Action Alternative to 8.2180 under Alternative 3, for a maximum increase in pH of 0.0004 by 2100.

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]

	Climate Sensitivity	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm) [b]	Ocean pH
Alternative	(°C for 2 × CO_2)	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	469.56	545.95	737.14	0.741	1.128	1.889	41.03	8.2447
	2.0	473.04	552.94	755.14	0.941	1.445	2.450	52.72	8.2351
	2.5	476.17	559.37	772.33	1.122	1.738	2.980	64.50	8.2262
	3.0	478.99	565.29	788.74	1.287	2.007	3.483	76.25	8.2178
	4.5	485.95	580.47	833.90	1.699	2.706	4.866	110.89	8.1954
	6.0	491.29	592.72	874.45	2.019	3.278	6.168	144.64	8.1761
Alt. 2	1.5	469.53	545.85	736.95	0.740	1.127	1.889	41.02	8.2448
	2.0	473.01	552.85	754.94	0.941	1.445	2.449	52.71	8.2352
	2.5	476.14	559.27	772.12	1.122	1.737	2.979	64.48	8.2263
	3.0	478.96	565.19	788.52	1.287	2.007	3.482	76.23	8.2179
	4.5	485.92	580.37	833.65	1.698	2.705	4.865	110.86	8.1955
	6.0	491.26	592.61	874.21	2.019	3.277	6.167	144.59	8.1763

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. 3	1.5	469.50	545.77	736.77	0.740	1.127	1.888	41.01	8.2449
	2.0	472.98	552.76	754.76	0.941	1.445	2.449	52.70	8.2353
	2.5	476.11	559.19	771.94	1.122	1.737	2.978	64.47	8.2264
	3.0	478.93	565.11	788.33	1.287	2.007	3.481	76.22	8.2180
	4.5	485.89	580.28	833.45	1.698	2.705	4.864	110.83	8.1956
	6.0	491.23	592.53	873.98	2.019	3.277	6.165	144.56	8.1764
Reductions Under Alternative 1 Compared to No Action Alternative									
Alt. 1	1.5	0.05	0.15	0.34	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.05	0.15	0.35	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.05	0.15	0.36	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.05	0.15	0.37	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.05	0.16	0.37	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.05	0.16	0.43	0.000	0.001	0.003	0.06	-0.0002
Reductions Under Alternative 2 Compared to No Action Alternative									
Alt. 2	1.5	0.08	0.24	0.54	0.000	0.001	0.001	0.02	-0.0003
	2.0	0.08	0.25	0.55	0.000	0.001	0.002	0.03	-0.0003
	2.5	0.08	0.25	0.57	0.000	0.001	0.002	0.04	-0.0003
	3.0	0.08	0.25	0.58	0.000	0.001	0.002	0.05	-0.0003
	4.5	0.08	0.25	0.62	0.000	0.002	0.003	0.08	-0.0003
	6.0	0.08	0.26	0.67	0.000	0.002	0.005	0.11	-0.0003
Reductions Under Alternative 3 Compared to No Action Alternative									
Alt. 3	1.5	0.11	0.32	0.71	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.11	0.33	0.73	0.000	0.001	0.002	0.04	-0.0004
	2.5	0.11	0.33	0.75	0.000	0.001	0.003	0.05	-0.0004
	3.0	0.11	0.33	0.77	0.001	0.002	0.003	0.06	-0.0004
	4.5	0.11	0.34	0.83	0.001	0.002	0.004	0.10	-0.0004
	6.0	0.11	0.35	0.91	0.001	0.002	0.006	0.14	-0.0004

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

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.

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 3 ranges from 0.002°C (0.004°F) for the 1.5°C (2.7°F) climate sensitivity to 0.006°C (0.011°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 lower 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 lower under the Proposed Action and alternatives compared to the No Action Alternative. The range in reductions of sea-level rise under Alternative 3 compared to the No Action Alternative is 0.03 to 0.14 centimeter (0.012 to 0.055 inch), depending on the assumed climate sensitivity.

CHAPTER 6 LIFE-CYCLE ASSESSMENT IMPLICATIONS OF VEHICLE ENERGY, MATERIALS, AND TECHNOLOGIES

6.1 Introduction

The International Organization for Standardization (ISO) defines a life-cycle assessment (LCA) as the "compilation and evaluation of the input, output, and potential environmental impact of a product system throughout its life cycle" (ISO 2006). Like any product, a vehicle's life-cycle 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 during vehicle operation). Each phase of a vehicle's life cycle, including production of fuel for vehicle use and sourcing of material inputs, contributes to greenhouse gas (GHG) emissions, energy use, and other environmental impacts.

The vehicle life cycle includes three main phases: (1) the upstream phase including production of fuel for vehicle use, raw material extraction and production of vehicle inputs, and the vehicle manufacture; (2) the use phase of vehicle operation, including fuel combustion and/or electricity use and vehicle maintenance; and (3) the downstream phase of recycling or disposal of the vehicle and vehicle parts. These are discussed further in Section 6.1.1, *Life-Cycle Assessment for Vehicles*.

Life-cycle considerations are already included in other analyses in this SEIS. 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 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 SEIS, 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 2024–2026 fuel economy standards.

- The specific design of multiple fuel efficiency technologies and their manufacturing processes, application to vehicles, and disposal after use.
- Interactions between applications of multiple fuel savings technologies.
- Regional fuel sourcing projections.
- Primary data on the variety of vehicle types, manufacturers, and uses expected in the future, including unprecedented detail regarding specific vehicle componentry, materials, and supply chain and manufacturing processes.

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 the 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. Because the information necessary to quantitatively differentiate between the alternatives in this chapter is too extensive and unknowable, the intent of this chapter instead is to understand the life-cycle implications of energy production, material substitution, and fuel efficiency technologies for passenger cars and light trucks. This information is helpful to the decision-maker in understanding the potential life-cycle impacts of manufacturer responses to different levels of stringency based on forecasts of materials and technologies manufacturers could employ to meet 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 chapter also discusses the extent to which the Proposed Action and alternatives could result in significant life-cycle GHG emissions and energy benefits, based on the different technology penetration rates projected by NHTSA's CAFE Model across alternatives.

The 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 that Affect Vehicle Life-Cycle Emissions,* 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 fuel use and upstream emissions already incorporated in the analyses in Chapters 3, 4, and 5, as well as the material and technology life-cycle 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 3, 4, and 5.

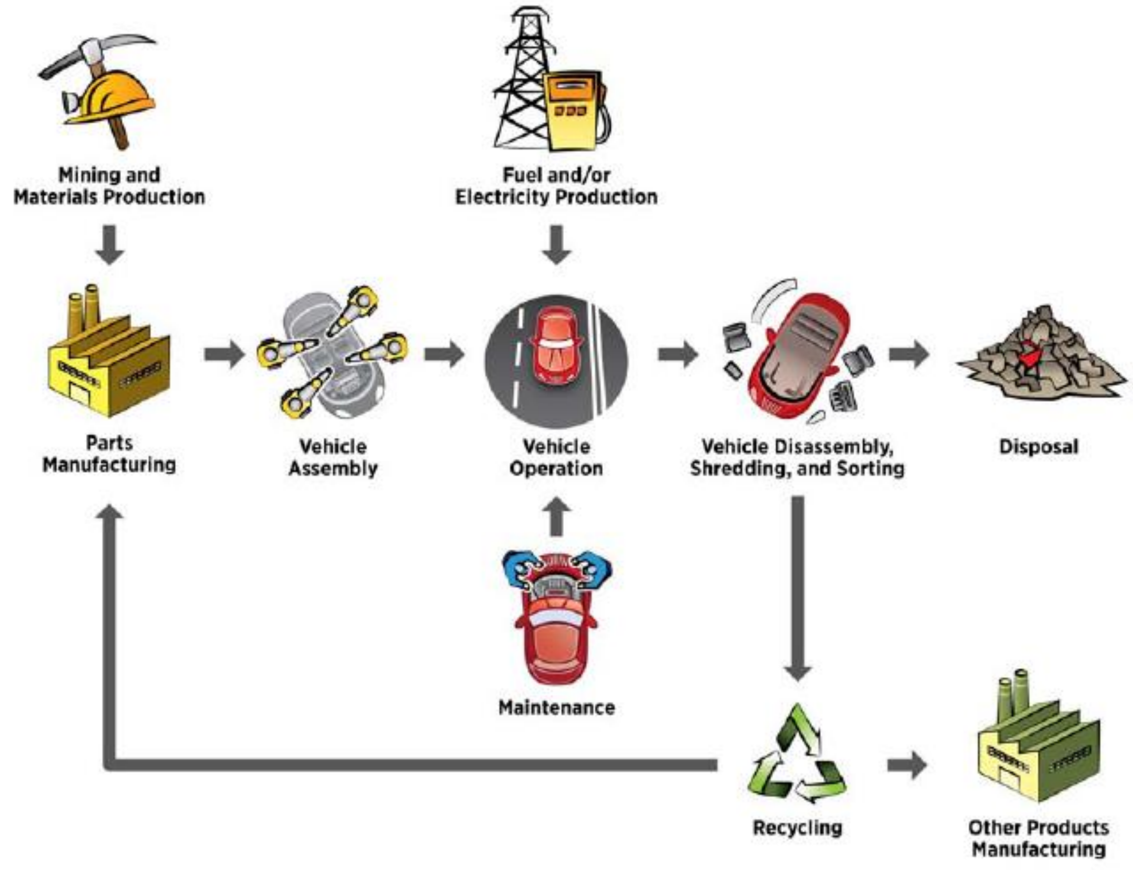
6.1.1 Life-Cycle Assessment for Vehicles

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. While recycling processes require energy and produce emissions, recycling vehicle components can save energy and resources and can reduce emissions by displacing the production of virgin materials (e.g., ore, bauxite). For example, recycling aluminum requires less than 10 percent of the energy required to produce aluminum from raw materials (Aluminum Association 2021a). 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 technologies and material alternatives. 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 reviewed for this chapter's analysis evaluate different classes 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

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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.

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 2020a). 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 studies. The intent is to synthesize the key existing and emerging topics in LCAs of passenger cars and light trucks, including research challenges and opportunities.

6.1.2 Life-Cycle Assessment Literature

NHTSA identified LCA 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. The vast majority of studies identified were published within the last 10 years. NHTSA prioritized more recent literature and LCAs specifically focused on passenger car and light truck technologies, including studies that take into account full fuel life cycles. 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 2016a).

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 LCAs, the functional unit represents the basis for which all environmental impacts are quantified to generate results throughout a product's or process' 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 (AEO) 2021* (U.S. Energy Information Administration [EIA] 2021a), the transportation sector accounted for 78.9 percent of total U.S. petroleum consumption in 2020, and transportation is expected to account for 76.9 percent of U.S. petroleum use in 2050. Passenger cars and light trucks accounted for 55.5 percent of transportation energy consumption in 2020, and they are expected to account for 48.6 percent of transportation energy consumption in 2050. Despite a 31.2 percent forecasted increase in vehicle miles traveled by passenger cars and light trucks from 2020 to

2050, transportation sector gasoline consumption is projected to decrease by 1.7 percent, largely due to increased fuel economy.[3]

According to the AEO 2021, gasoline accounted for 99.2 percent of passenger car and light truck fuel consumption in 2020, and is projected to account for 96.2 percent of consumption in 2050. As illustrated in Table 6.2-1, AEO projects the gasoline share of passenger car and light truck fuel use to decline slightly as a result of projected growth in electricity and diesel.[4]

Table 6.2-1. Energy Consumption for Passenger Cars and Light Trucks for 2020 and 2050

Fuel	2020 (%)	2050 (%)
Gasoline	99.2	96.2
Electricity	0.1	2.8
Diesel	0.4	0.8
E85	0.2	0.2
Other fuels	0.1	<0.1

Source: EIA 2021a

The AEO 2021 projections represent hypothetical scenarios based on policies in place at the time of the AEO's publication (early February 2021), 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 2021 reference case as a guide in analyzing the most relevant trends for passenger cars and light trucks. Note that the AEO reference case does not yet reflect more recent policies that likely will affect the market for electric vehicles (EVs), such as the current administration's call for the replacement of the federal fleet with EVs[5] and increased investment in the expansion of vehicle charging infrastructure.[6] NHTSA's CAFE Model projects that the electricity share of total light-duty fuel use will be 5.2 percent in the No Action Alternative and 8.4 percent in Alternative 3 in 2050.

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, *Electricity*, 6.2.4, *Biofuels*, and 6.2.5, *Hydrogen Fuel Cells*. The synthesis of LCA studies related to fuel cells is relatively brief because the AEO 2021 does not forecast substantial changes in fuel cell use, and this rulemaking is not expected to have a large impact

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[3] The projected reduction in gasoline consumption is lower than projected previously by EIA because of the increase in estimated vehicle miles traveled.

[4] In the CAFE Model, used to estimate the impacts of the alternatives considered in this SEIS, NHTSA relies on different assumptions than the AEO regarding the cost and application of alternative fuel technologies that ultimately affect projected alternative fuel use. These CAFE Model inputs are described in detail in Chapter 3 of the Technical Support Document (TSD) that accompanies NHTSA's proposed rule and in Section III.C of the proposed rule preamble. Differences in outputs from AEO and the CAFE Model are expected due to these differing assumptions, model design, and purposes of these models.

[5] Executive Order 14008, Tackling the Climate Crisis at Home and Abroad, Sec. 205, 86 FR 7619 (Feb. 1, 2021).

[6] The White House, Fact Sheet: Biden Administration Advances Electric Vehicle Charging Infrastructure (Apr. 22, 2021). Available at: https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-biden-administration-advances-electric-vehicle-charging-infrastructure/.

on the extent of fuel cell use. NHTSA's CAFE Model shows that fuel cell use will stay low in future years—at less than 0.01 percent technology penetration rate in all alternatives in all future model years.

6.2.1 Diesel and Gasoline

Gasoline and diesel represent the largest share of light-duty vehicle fuel consumption, both now (99.6 percent of total fuel consumption in 2020 for diesel and gasoline) and in the future (97.0 percent in 2050) based on the AEO 2021 projections (EIA 2021a). Life-cycle GHG emissions from the extraction, refining, supply, and combustion of gasoline and diesel generally account for 80 percent of total vehicle life-cycle emissions, but this can vary based on vehicle type and supply chain characteristics (Hawkins et al. 2012; Ambrose and Kendall 2016). 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 2020, 2021). 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 rapid rise of U.S. shale oil production in the years leading up to 2020, declines in crude oil prices, growing availability of low-cost renewable energy sources, and the cancellation of the permit for and subsequent abandonment by developers of the Keystone XL pipeline that was intended to bring petroleum from Canadian oil sands to the U.S. market creates uncertainty in the long-term growth of oil sands production (Findlay 2016; Kirk 2021; TC Energy 2021).

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).

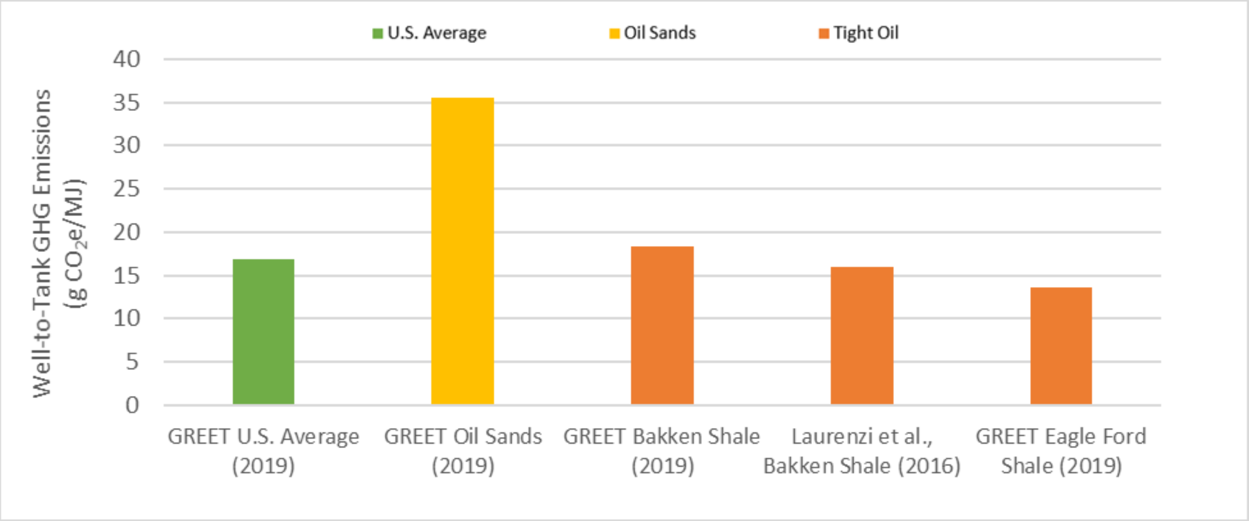
In addition to upstream GHG emissions from extraction and processing, the mining of oil sands affects land to a higher degree than conventional oil extraction. Surface mining involves land clearance and extraction of shallow deposits, and *in situ* recovery involves drilling wells and injecting steam 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

(0.14 and 0.001 ounce) of carbon dioxide equivalent[7] 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 2020, shale oil represented the largest portion of U.S. oil production (65.7 percent), totaling 7.54 million barrels per day (EIA 2021a).

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 2015 and 2020, 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 (ANL 2020a; Englander and Brandt 2014; Ghandi et al. 2015; Brandt et al. 2015). GREET's 2020 version uses EIA projections for crude oil supplies to generate a default average (77 percent conventional, 16 percent shale oil, 7 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 GREET, including a shale oil LCA that focuses on the same Bakken region assessed in the GREET model (Laurenzi et al. 2016).[8]

Figure 6.2.1-1. Well-to-Tank GHG Emissions for Gasoline



Source: ANL 2020a; Laurenzi et al. 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

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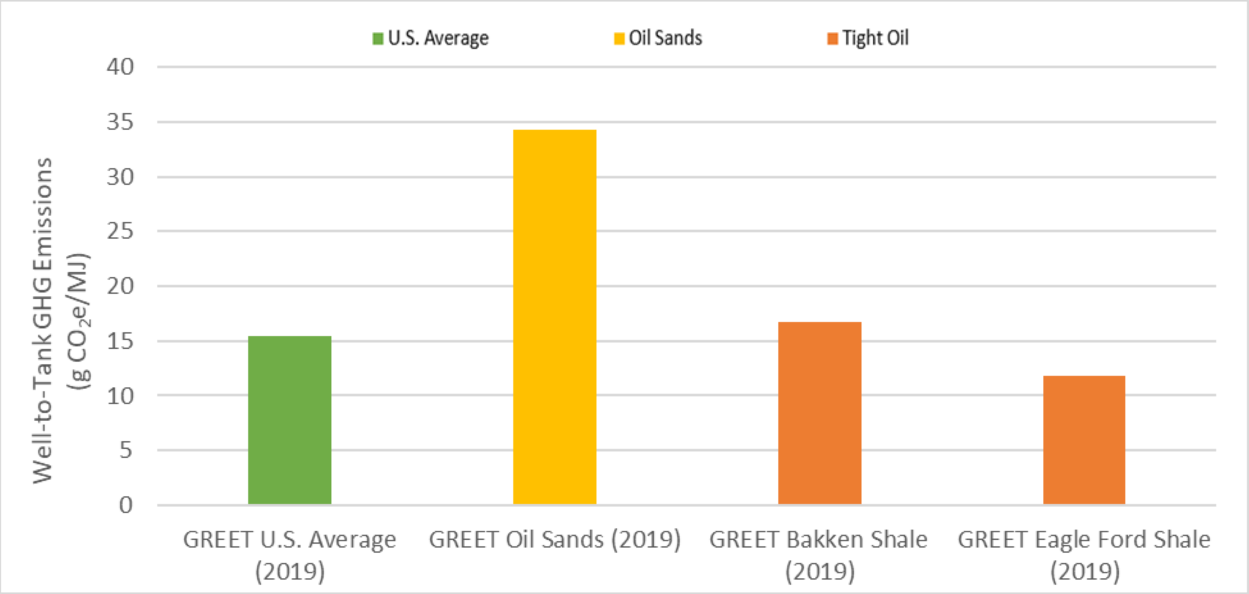
[7] Carbon dioxide equivalent (CO_2e) is a measure that expresses the relative global warming potential of greenhouse gas emissions, usually measured over 100 years.

[8] 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 is constant and CO_2 accounts for the vast majority of well-to-tank GHG emissions.

Diesel production has similar but slightly lower well-to-tank LCA results than gasoline, but slightly higher emissions from combustion (Tong et al. 2015). 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 2020 simulation of refining processes.

Figure 6.2.1-2. Well-to-Tank Greenhouse Gas Emissions for Diesel



Source: ANL 2020a

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 carbon dioxide (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)

Fuel	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	CO_2e Totals
Diesel	74.9	0.027	0.0002	75.7
Gasoline	72.7	0.002	0.002	73.2

Source: ANL 2020a

[a] The values are calculated using AR5 global warming potential factors.

g CO_2e/MJ = grams of carbon dioxide equivalent per megajoule; CO_2e = carbon dioxide equivalent

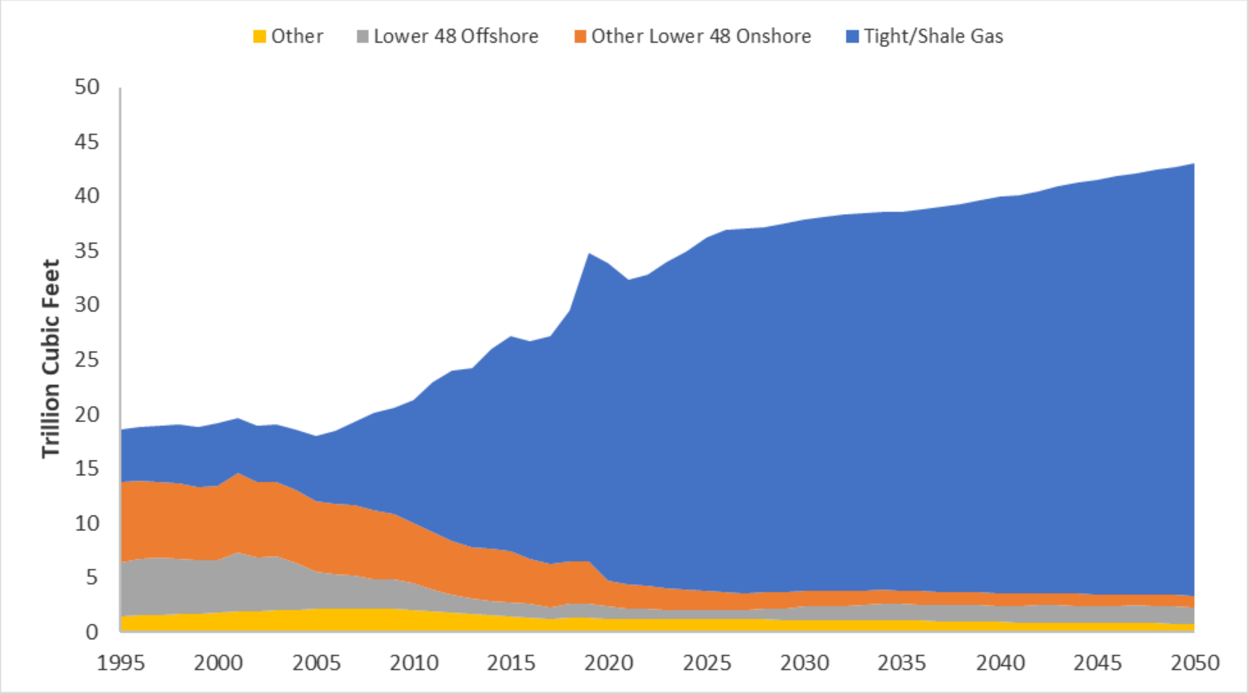
The use of unconventional oil is expected to grow as extraction costs decline through drilling efficiency improvements (EIA 2016b). Because extraction of unconventional sources of oil results in higher GHG emissions per unit of energy, their increased use could lead to higher upstream GHG emissions for diesel- and gasoline-powered vehicles. However, more stringent CAFE standards and increased market penetration of EVs could reduce the market for these unconventional fuels used for vehicles (ANL 2020a; EIA 2021a). This could represent an even greater emissions reduction if the share of unconventional oil fuels in the vehicle fuel mix increases. The market share of unconventional petroleum varies by region, which creates further uncertainty when trying to calculate avoided emissions from using EVs (EPA 2021g).

6.2.2 Natural Gas

Natural gas can be used in vehicles in compressed or liquid forms. It is also a fuel used for electricity generation that in turn can power EVs. In 2020, natural gas represented 0.02 percent of the total fuel supplied for direct use in passenger cars and light trucks. This share is projected to remain steady through 2050 (EIA 2021a).[9] However, natural gas has recently become a significantly larger portion of U.S. electricity generation—reaching 40.2 percent in 2020. That share is projected to decrease to 35.8 percent of generation capacity by 2050, even though the overall amount of electricity generated from natural gas is projected to increase by 19.4 percent in the same time period. The decline in the natural gas share of electricity generation is due to the anticipated growth in electricity generation from renewable sources. EV sales are expected to increase in the future compared to current levels (notice of proposed rulemaking [NPRM] preamble, Tables V-10 through V-18), and electricity is projected to be the largest source of non-gasoline light-duty vehicle fuel consumption by 2035 (EIA 2021a). Based on this, the life-cycle impacts of natural gas production and consumption are considered here.

Increased market penetration of natural gas in the industrial and power sectors is a result of increased U.S. 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 2021a).

Figure 6.2.2-1. U.S. Natural Gas Production by Source, Annual Energy Outlook 2021 Reference Case



Source: EIA 2021a

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[9] Some compressed and liquefied natural gas used in vehicles is considered renewable natural gas, 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. EIA estimated that 257 billion cubic feet of compressed natural gas or liquefied natural gas derived from renewable natural gas was collected and burned in 2019, amounting to 0.3 percent of total U.S. utility-level generation in 2019 (EIA 2020b). 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.

During the vehicle use phase for vehicles running on natural gas fuels, natural gas results in lower CO_2 emissions per unit of energy than other fossil fuels (EIA 2021a, 2021c, 2021d); however, NHTSA's analysis shows natural gas use in light-duty vehicles remaining exceedingly limited through 2050 (NPRM preamble, Section III.C.7). When substituted for coal to produce heat or electricity, natural gas has lower emissions of sulfur dioxide, nitrogen oxides, and mercury (Moore et al. 2014).

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 2019 (EPA 2021a). From 1990 through 2019, annual U.S. methane emissions decreased by 15 percent, largely because of emissions reductions from landfills, coal mining, and natural gas systems (EPA 2021a). Natural gas systems are currently the largest source of anthropogenic methane emissions in the United States (EPA 2021a). In 2019, approximately 24 percent of the methane emitted in the United States was attributed to natural gas systems, and 6 percent was from petroleum systems. 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 2019, the United States emitted 157.6 $MMTCO_2e$ of methane from upstream natural gas systems and 39.1 $MMTCO_2e$ from upstream oil processes. For natural gas, 59.5 percent of methane emissions were from field production, 7.9 percent were from processing, 23.5 percent were from transmission and storage, and 8.9 percent were from distribution. For oil, field production is the primary source of emissions with 96.8 percent of total emissions and 3.2 percent from transportation and refining (EPA 2021a). These emissions do not include emissions related to use of natural gas (i.e., combustion of natural gas in vehicles or combustion in power plants). The primary sources of methane emissions from natural gas and oil systems are as follows:

- **Production (natural gas and oil)**. In 2019, the most significant identified natural gas production sources of methane emissions identified in the EPA Inventory[10] are gathering stations, pneumatic devices, Kimray pumps, liquids unloading, condensate tanks, gathering pipeline leaks, and offshore platforms. Sources of emissions in oil production include pneumatic devices and controllers, offshore oil platforms, gas venting and flaring, engines, chemical injection pumps, oil tanks, hydraulically fractured well completions, and oil wellheads (EPA 2021a).
- **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

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[10] Annually, EPA compiles the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* report, referred to here as the EPA Inventory. The EPA 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 2019 (EPA 2021d).

processing, and during the processing stage methane emissions arise mainly from compressors (EPA 2021a).

- **Transmission and storage (natural gas).** 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 compressor stations, pneumatic devices, and pipeline venting. 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. Natural gas also leaks from pipelines during routine maintenance (EPA 2021a).
- **Distribution (natural gas).** During distribution, natural gas is emitted mainly from the gate stations and pipelines (EPA 2021a).

A reduction in leaks and venting throughout upstream natural gas life-cycle stages has resulted in a 9 percent decrease in overall natural gas methane emissions from 1990 to 2019. Methane emissions from petroleum production and use declined by 20 percent between 1990 and 2019 due to decreases in vented methane and more efficient storage tanks (EPA 2021a).

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 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 identify emissions-reduction opportunities. 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 Inventory leak rate in 2019 for emissions from oil and gas systems was about 5.4 percent of total production and 6.1 percent of transmission and distribution (EPA 1995a, 2021a; IPCC 2006; EIA 2019a, 2019b).

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, and some examined its use specifically in EVs. An LCA assessing natural gas pathways for direct use in alternative light-duty fuel vehicles and in natural-gas-powered EVs found that, on a life-cycle basis, vehicles fueled directly with compressed natural gas became less fuel efficient than conventional gasoline vehicles at given upstream methane leak rates (1 to 11 percent) depending on the vehicle and GWP timeframe (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 latest 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 in 2015 the EPA Inventory was underreporting supply chain methane emissions from oil and natural gas industries by about 60 percent. The authors found that this underreporting was due to the inventory estimation methods at the time not capturing methane emissions from abnormal operating conditions in production (Alvarez et al. 2018).

Studies have found that EVs powered by natural-gas-fueled electricity resulted in significantly lower life-cycle GHG emissions—36 to 47 percent lower (Ou et al. 2013) and 40 percent lower (Tong et al. 2015)—compared to those for gasoline-fueled internal combustion engines (ICE). Because these results are sensitive to methane leak rates, identifying and eliminating upstream leaks could be environmentally important for deciding whether to shift the fleet toward EVs (with electricity powered by natural gas) and away from gasoline. Ou et al. 2013 also found that applying CO_2 capture and storage nearly doubled the emissions reduction benefit for EVs that use natural-gas-powered electricity.

6.2.2.2 Shale Gas and Hydraulic Fracturing

Hydraulic fracturing of shale gas deposits had previously 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 2019, hydraulically fractured wells accounted for 86 percent of marketed U.S. natural gas production. This share is projected to increase to 92 percent of natural gas production by 2050 (EIA 2021a).

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 (NREL) 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.[11] 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

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[11] Life-cycle emission calculations assume natural gas will be combusted for electricity generation.

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 CO_2e/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, nitrogen oxides, sulfur oxides, and particulate matter less 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 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).

Hydraulic fracturing intentionally induces small-scale seismic events in order to increase the connective space between pores in impermeable rock holding the natural gas (López-Comino et al. 2018); however, growing evidence suggests that this process could cause small, unintentional seismic events as well. A U.S. Geological Survey (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 earthquakes once or twice annually. Since 2014, these low-magnitude events have been occurring daily, with limited instances of higher-magnitude events (USGS no date; EPA 2016b). In the regions of the United States with increased seismic activity that track increases in hydraulic fracturing, many studies have linked the seismic activity to the process of storing wastewater from hydraulic fracturing deep underground (Brudzinski and Kozłowska 2019; USGS 2017; Bao and Eaton 2016). However, evidence from Western Canada and the Sichuan Basin in China shows the effect of hydraulic fracturing in areas that are near pre-existing faults, where larger earthquakes that cause more extreme risk to safety and property can be triggered by the fracturing process (Meng et al. 2019; Bao and Eaton 2016). Low-magnitude earthquakes caused by wastewater storage and by increased pressure on fault lines are capable of causing as much damage as a higher-magnitude natural earthquake because of the depth at which they occur. Earthquakes caused by hydraulic fracturing or wastewater storage typically originate less than 5 kilometers (3.1 miles) deep, whereas natural earthquakes usually originate between 5 and 20 kilometers (between 3.1 and 12.4 miles) underground. As the earthquakes begin closer to the surface, there is less time for the waves to be absorbed by rocks sitting above the origin, which leaves more waves to reach the surface and cause damage (Lei et al. 2017).

6.2.2.3 Natural Gas Representation in GREET

Argonne National Laboratory accounts for natural gas from conventional and renewable sources in GREET, which is used in the CAFE Model for estimating emission rates from fuel production and distribution processes. Conventional sources are distributed between North American, non-North American, and shale gas reservoirs while renewable sources include gas produced as a byproduct of landfills, wastewater treatment, and animal waste. Supply production is split evenly between conventional and shale gas wells and much of it is utilized for heat in the industrial, commercial, and residential sectors. The remaining gas supply is then compressed or liquefied for use as a transportation fuel or as a feedstock for electricity generation, or otherwise converted into another fuel product such as naphtha or dimethyl ether. In GREET 2020, roughly one-third of all electricity is generated from natural gas sources in 2018 and after, although without any meaningful growth in its electric grid mix share over time.

According to AEO 2021 projections, natural gas is far less common as a transportation fuel. Compressed natural gas, liquefied natural gas, or liquefied petroleum gas constitute only an insignificant fraction of total fuel use in the transportation sector—less than a 1-percent share of all light-duty vehicles and less than a 3-percent share of all freight trucks from 2020 to 2050. Currently, electricity is more likely than natural gas to be used as a motor vehicle fuel, and is projected to remain more popular through 2050 (EIA 2021a).

6.2.3 Electricity

Electricity currently makes up 0.1 percent of light-duty vehicle fuel use, but the AEO 2021 projects this proportion to increase to 2.8 percent by 2050, representing the largest share of fuel consumption outside of gasoline (EIA 2021a). Current U.S. policies expanding the federal EV fleet and improving vehicle charging infrastructure are anticipated to drive this number higher. NHTSA's CAFE Model projects that by 2050, the electricity share of total light-duty fuel use will be 5.2 percent in the No Action Alternative and 8.4 percent in Alternative 3. Worldwide, projections estimate that more than 125 million EVs will be on the road by 2030 (Miao et al. 2019). 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 HEVs, PHEVs, and BEVs (Notter et al. 2010; Patterson et al. 2011; U.S. Department of Energy [DOE] 2013a). HEVs incorporate a battery and electric motor combined with an ICE (or fuel cell), and have regenerative 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 ICE or fuel cell as backup when battery power is depleted. BEVs are purely electrically powered, requiring charging from the electric grid, and do not incorporate an ICE. 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 Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, 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 Chapters 4 and 5 are based on recent forecasts for the mix of fuels used for U.S. electricity generation, consistent with the AEO 2021 forecast. The 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 ICE vehicles have also examined the impacts from end-of-life management of vehicle batteries, as summarized in Section 6.3.3, *Vehicle Batteries*.

Overall, production emissions account for roughly 40 percent of the lifetime GHG emissions for a BEV, as opposed to less than 10 percent for ICE vehicles (Ambrose et al. 2020). In comparison to ICE vehicles, BEVs have higher emissions (between 1.3 to 2.0 times) associated with raw material acquisition and processing as well as vehicle production stages. This is due to the energy-intensive process of making BEV batteries. Under a scenario where nearly all of the electricity on the grid is generated by renewable sources, emissions from the production of a BEV could reach up to about 65 percent of the lifetime emissions of that vehicle (Ambrose et al. 2020). However, these upstream emissions are not large enough to negate the large-scale reduction in emissions for EVs throughout the remainder of the vehicle life cycle (Xiong et al. 2021; Kamiya et al. 2019). Given that BEVs have significantly lower vehicle in-use stage emissions, they have lower life-cycle emissions than ICE vehicles (Congressional Research Service 2020; Ehrenberger et al. 2019). For this reason, to a large extent, the success of decarbonizing the transport sector relies in part on further development of battery technologies (Wessel et al. 2021).

Figure 6.2.3-1 shows that oil, natural gas, wind, and solar power accounted for most electricity capacity additions from 2005 through 2020, 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. EIA projects that electricity generation in the United States will increase steadily through 2050, with large gains in solar and wind generating capacity, and decreases in coal-fired generation facilities, as shown in Figure 6.2.3-3. 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 emissions from BEV use, over time.

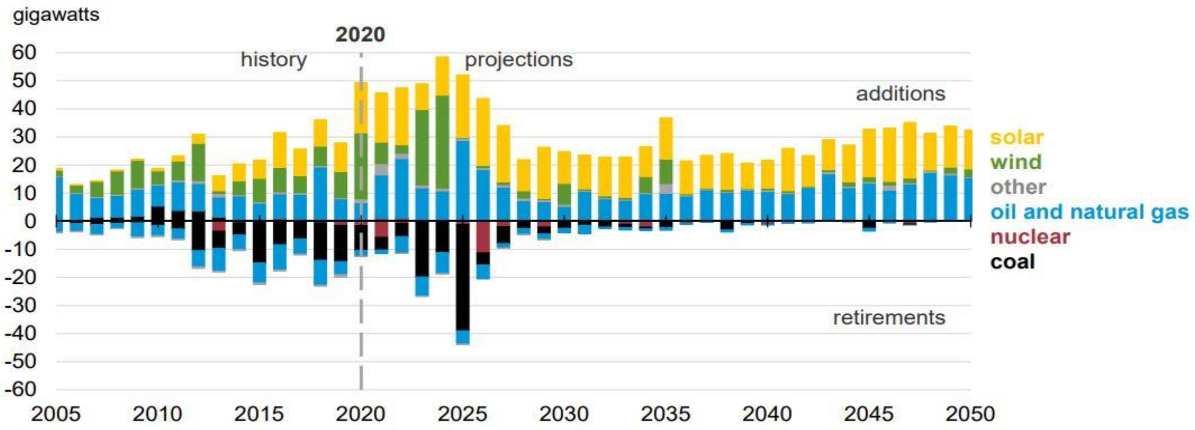
The CAFE Model projects that EVs will comprise a growing share of manufacturers' vehicle fleets in future years and particularly in Alternatives 2 and 3. As shown in Table 6.2.3-1, Alternatives 2 and 3 would result in significantly higher penetration of EVs in the light-duty vehicle fleet (11 and 15 percent, respectively, by MY 2029) as compared to the penetration of EV technologies under the No Action Alternative (approximately 6 percent). LCA studies show that EVs present lower overall life-cycle vehicle GHG emissions compared to ICE vehicles in most of the country, regardless of the grid mix. The CAFE Model thus predicts that alternatives with higher increases in fuel economy would result in lower life-cycle vehicle GHG emissions. When considered with the projected cleaner U.S. grid mix, this life-cycle GHG benefit will grow in future years; the life-cycle GHG benefit will also be more significant in regions where the grid mixes incorporate a greater share of renewables, natural gas, and nuclear.

Table 6.2.3-1. Electric Vehicle Technology Penetration Rates for Model Year 2029

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
PHEVs	**0.12%**	**0.32%**	**0.33%**	**0.73%**
PHEV20: 20-mile PHEV with HCR Engine	0.07%	0.26%	0.26%	0.53%
PHEV20T: 20-mile PHEV with Turbo Engine	0.05%	0.06%	0.06%	0.11%
PHEV20H: Special 20-mile PHEV with HCR Engine	0%	0%	0.01%	0.10%
Dedicated EVs	**6.0%**	**7.7%**	**11%**	**14%**
BEV200: 200-mile EV	3.0%	3.6%	3.8%	3.9%
BEV300: 300-mile EV	2.7%	3.8%	7.0%	9.9%
BEV400: 400-mile EV	0.3%	0.3%	0.3%	0.3%
Total for PHEVs and Dedicated EVs	**6.2%**	**8.0%**	**11%**	**15%**

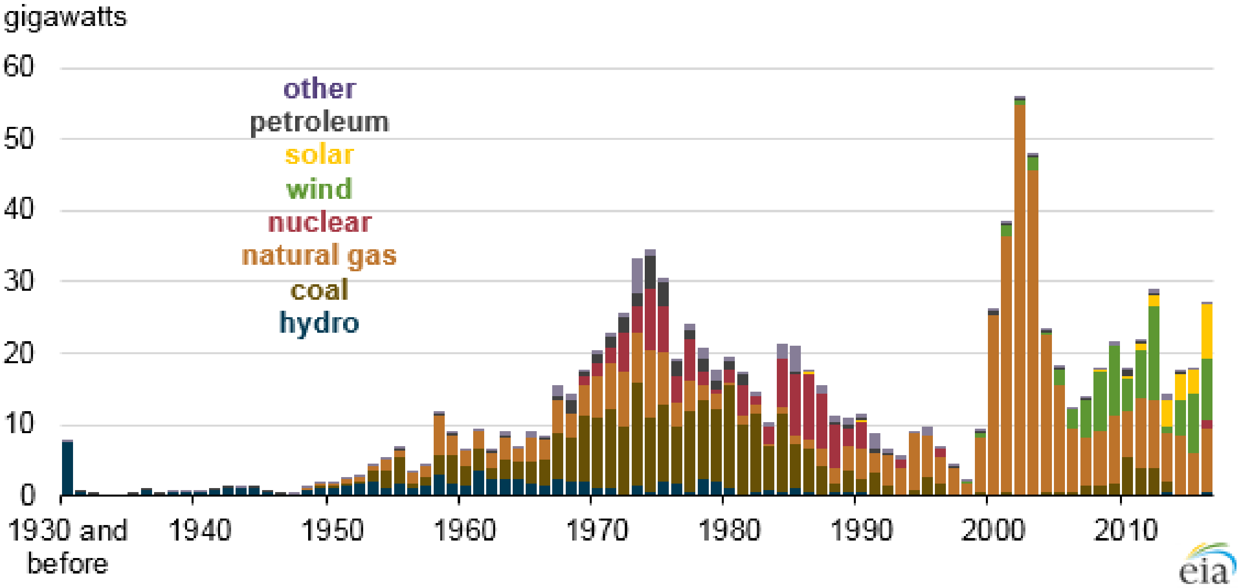
For BEV200, BEV300, and BEV400, the number refers to the EV's mileage driving range.
PHEV = plug-in hybrid electric vehicle; EV = electric vehicle; BEV = battery electric vehicle

Figure 6.2.3-1. Historical and Projected U.S. Utility-Scale Electric Capacity Additions and Retirements (2005 to 2050)



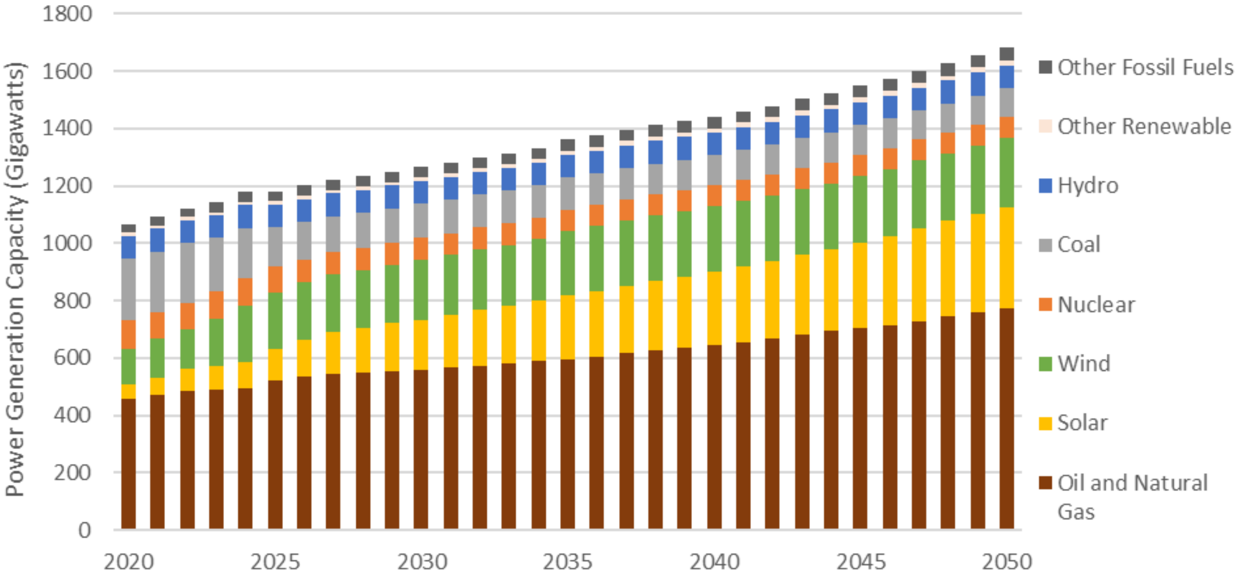
Source: EIA 2021a

Figure 6.2.3-2. Historical U.S. Utility-Scale Electric Generating Capacity by Initial Operating Year (as of December 2016)



Source: EIA 2017a

Figure 6.2.3-3. U.S. Electricity Generating Capacity by Year, Projections to 2050



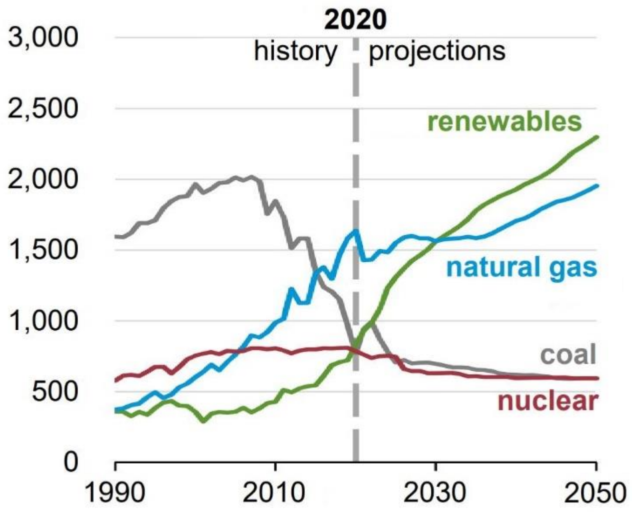
Source: EIA 2021a

The increase in natural gas power plant capacity since the 1980s is primarily from the addition of combined-cycle units (EIA 2011). 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 (kWh; 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 kWh, compared to average heat rates above 10,000 Btu per kWh for coal power plants and older natural gas combustion turbine and steam turbine plants (2017b).

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 an average of 8,471 BTU per kWh in 2006 to 7,732 in 2019 (EIA 2017b, 2020c). In the AEO 2021, EIA reported an increase of 3.4 gigawatts of natural gas combined cycled capacity between 2020 and 2021. Steam power capacity from oil and natural gas declined by 1.2 gigawatts, and natural gas and diesel combustion turbine capacity added 3.3 gigawatt of capacity over this same period (EIA 2021a).

Figure 6.2.3-4 shows that U.S. electricity generation from coal fell from approximately 2,000 billion kWh in 2010 to 750 billion kWh in 2020, reflecting the combined impact of additional natural gas and renewable energy generating capacity and historically low natural gas prices. The 2021 AEO projects that electricity generation from coal will remain near this level to 2050 (EIA 2021a).

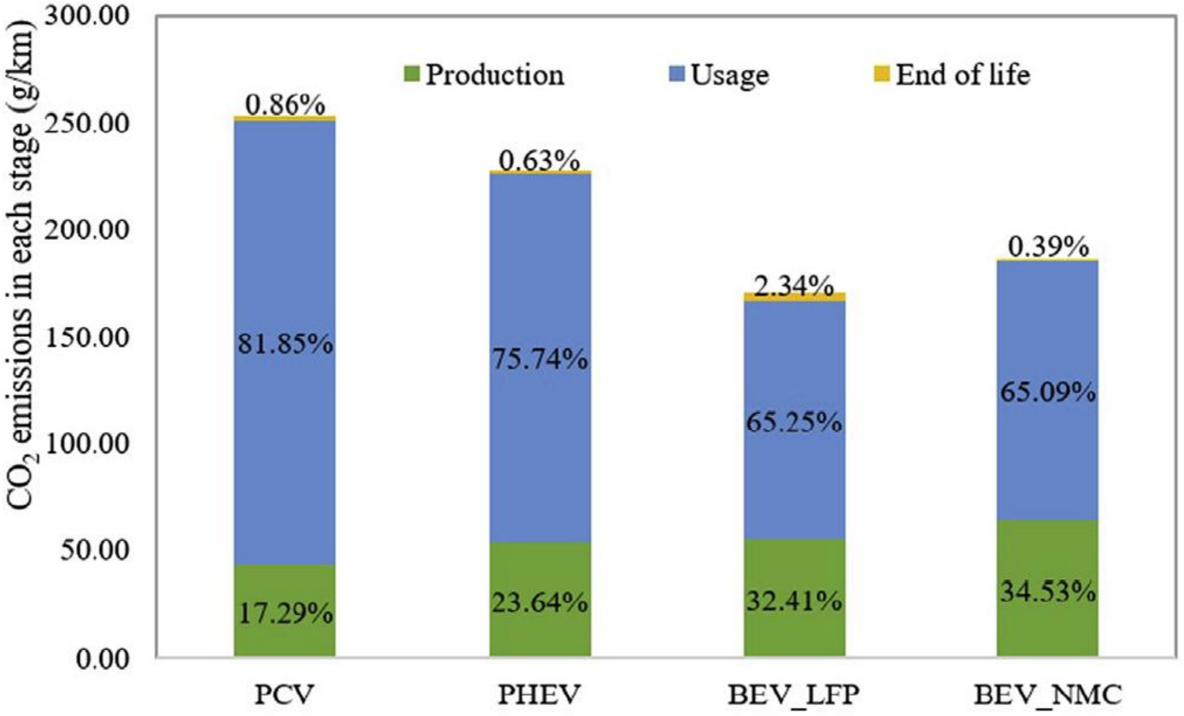
Figure 6.2.3-4. Net Electricity Generation by Source (1990 to 2050)



Source: EIA 2021a

Figure 6.2.3-5 shows the relative contributions of these phases to life-cycle EV GHG emissions, including variations for two battery types: lithium iron phosphate (LFP), and lithium nickel manganese cobalt oxide (NMC) from an LCA published by Xiong et al. (2021). Retired NMC batteries contain high-value materials that can be recycled, so those avoided CO_2 emissions are counted as negative credits against the life-cycle emissions for that category. The operation phase (more specifically, electricity consumption during operation) accounts for a significant portion of a vehicle's life-cycle environmental impacts, but the production phase for HEVs and BEVs represents a larger percentage of their life-cycle emissions than it does for ICE vehicles (Xiong et al. 2021; Gaines et al. 2011; Notter et al. 2010).

Figure 6.2.3-5. Life-Cycle GHG Emissions of Electric Vehicles



Source: Xiong et al. 2021
GHG = greenhouse gas; CO_2 = carbon dioxide; PCV = passenger internal combustion vehicles; PHEV = passenger hybrid electric vehicle; BEV_LFP = battery electric vehicle with lithium iron phosphate battery; BEV_NMC = battery electric vehicle with nickel manganese cobalt oxide battery.
Emissions calculated for a high-coal scenario with a grid mix of 67 percent coal, 3 percent renewable energy, and 18 percent hydroelectric.

Increased market penetration of EVs also likely offers substantial health benefits and associated cost savings across the United States. Peters et al. (2020) found that, at 25 percent EV adoption with the current mix of fuels supplying the domestic grid, there would be a 242 million ton reduction in CO_2 emissions, over 550 fewer deaths due to air pollution, and savings of almost $17 billion on vehicle pollution-related illnesses. This effect would be magnified as the grid itself increases the supply of electricity from renewable sources and as EV usage becomes more common. Similarly, Choma et al. (2020) found that pollution from ICE vehicles causes on average 6.5 deaths per million miles in metropolitan areas, while pollution from BEVs cause 2.8 deaths per million miles. Additionally, this study found that the reduction in air pollutants caused by replacing an ICE vehicle with an EV yields roughly $8,600 in health-related cost savings per 150,000 miles (Choma et al. 2020).

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 ICE vehicles, which increase overall environmental impacts outside of vehicle operations (Gradin et al. 2017). Similarly, rare earth metals (platinum, palladium) are required for emissions controls in catalytic converters for ICE vehicles, and material demands will increase with stricter controls (Seo and Morimoto 2017). Associated impacts of EV and vehicle material production and end-of-life management are examined in Section 6.3.3, *Vehicle*

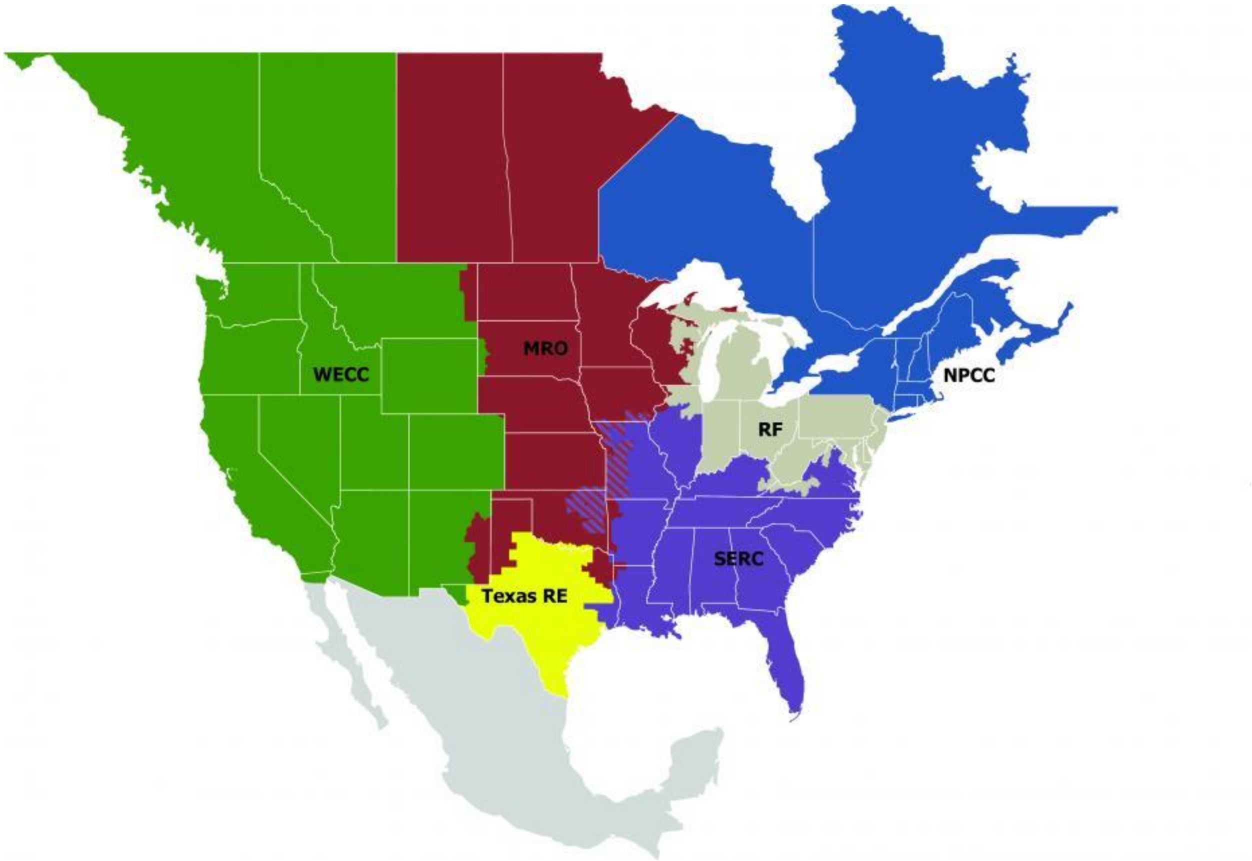
Batteries. Upstream electricity emissions from feedstock extraction, refining, and transportation prior to the use phase are considered in the CAFE Model using available GREET data.

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. 2014; Nealer and Hendrickson 2015; Onat et al. 2015; Tamayao et al. 2015; Kawamoto et al. 2019; Kamiya et al. 2019). This is primarily because the grid mix used to supply electricity to EVs varies by location. Where EVs are driven and charged can affect their overall life-cycle emissions: those charged in areas with more carbon-intensive grid mixes have higher use-phase emissions than those charged in areas with greater shares of natural gas, nuclear, hydropower, or renewable energy in the grid mix. While the production of batteries for EVs is energy intensive, the environmental benefits of EV charging in locations with less carbon-intensive electricity can outweigh the upstream impacts, as discussed further below and in Section 6.3.3, *Vehicle Batteries*.

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 6.2.3-6) 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 6.2.3-7) (Tamayao et al. 2015). For example, in the eGRID subregion that includes Missouri and much of Illinois, the majority (67 percent) of electricity was generated by coal in 2019, while in most of Alaska, the majority (63 percent) of energy came from hydropower in the same year, indicating that the magnitude of emissions associated with EVs charged in the two subregions would likely differ significantly (EPA 2021g). A breakdown of grid mix by eGRID subregion is shown in Figure 6.2.3-8.

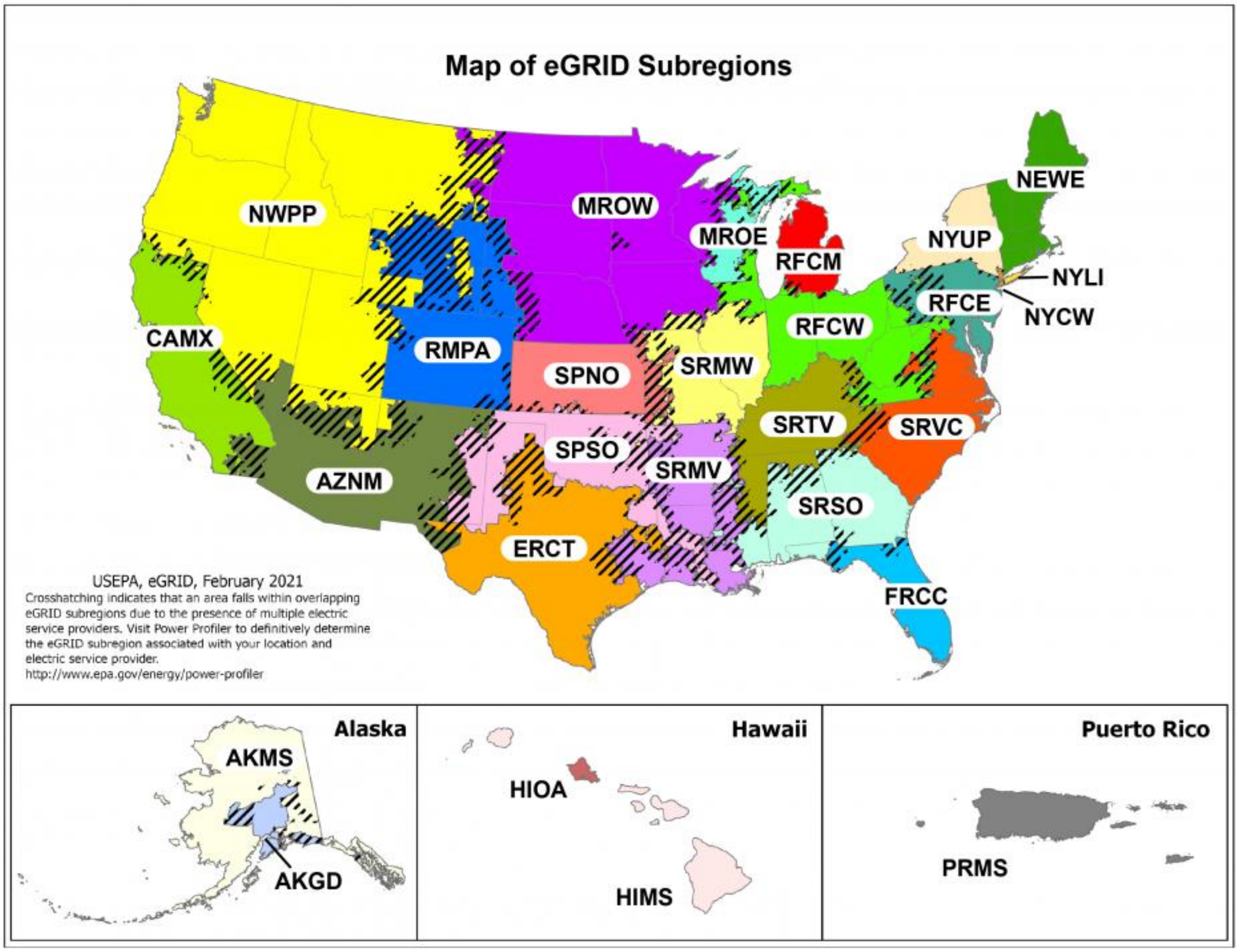
Figure 6.2.3-6. National Electricity Reliability Commission Regional Map



Source: EPA 2019c

MRO = Midwest Reliability Organization; NPCC = Northeast Power Coordinating Council; RF = Reliability First; SERC = SERC Reliability Corporation; Texas RE = Texas Reliability Entity; WECC = Western Electricity Coordinating Council

Figure 6.2.3-7. Environmental Protection Agency eGRID Subregions



Map of eGRID Subregions

USEPA, eGRID, February 2021

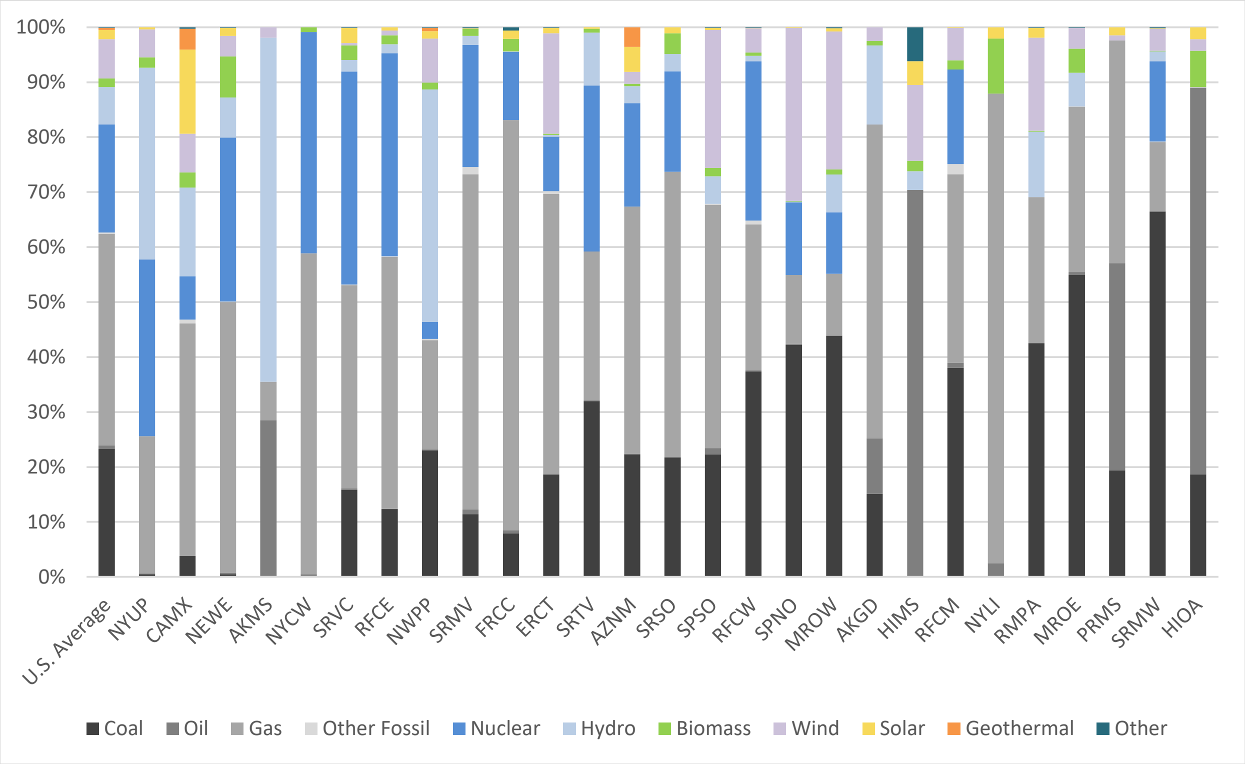
Crosshatching indicates that an area falls within overlapping eGRID subregions due to the presence of multiple electric service providers. Visit Power Profiler to definitively determine the eGRID subregion associated with your location and electric service provider.

http://www.epa.gov/energy/power-profiler

Source: EPA 2021h

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; PRMS = Puerto Rico Miscellaneous.

Figure 6.2.3-8. 2019 U.S. Average and eGRID Subregion Grid Mix

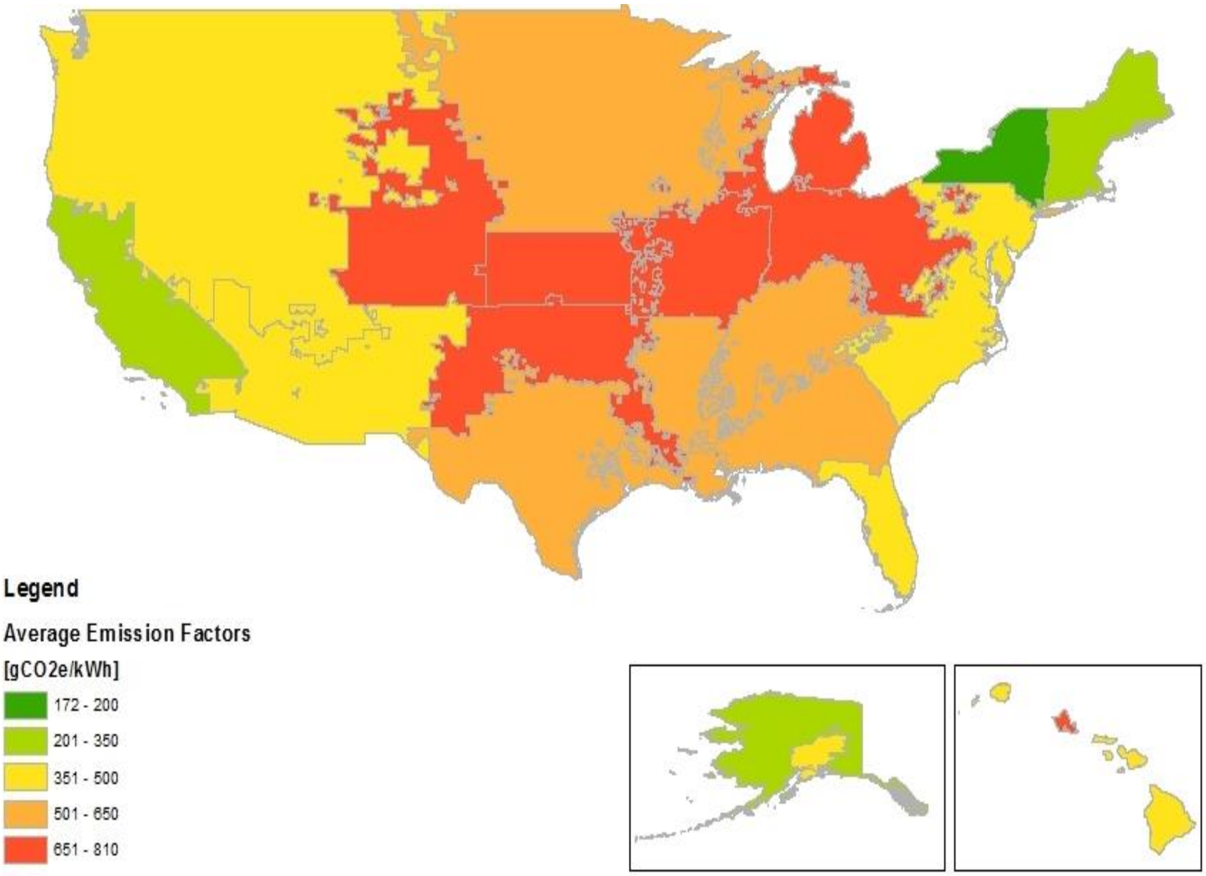


Source: EPA 2021g

eGRID = Emissions & Generation Resource Integrated Database. Ordered from region with lowest carbon dioxide equivalent emission rate grid mix to highest. Regional names are derived from NERC regional names: NYUP = NPCC Upstate NY; CAMX = WECC California; NEWE = NPCC New England; AKMS = ASCC Miscellaneous; NYCW = NPCC NYC/Westchester; SRVC = SERC Virginia/Carolina; RFCE = RFC East; NWPP = WECC Northwest; SRMV = SERC Mississippi Valley; FRCC = FRCC All; ERCT = Electric Reliability Council of Texas; SRTV = SERC Tennessee Valley; AZNM = WECC Southwest; SRSO = ERV South; SPSO = SPP South; RFCW = RFC West; SPNO = SPP North; MROW = MRO West; AKGD = ASCC Alaska Grid; HIMS = HICC Miscellaneous; RFCM = RFC Michigan; NYLI = NPSS long island; RMPA = WECC Rockies; MROE = MRO East; PRMS = Puerto Rico Miscellaneous; SRMW = SERC Midwest; HIOA = HICC Oahu

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 kWh relative to the least carbon-intensive subregion, as shown in Figure 6.2.3-9. Generally, AEFs and emissions associated with EV use-phase electricity consumption are lowest in the West, Northeast, and Alaska, and highest in the Central United States.

Figure 6.2.3-9. eGRID Subregion Average Emission Factors for Electricity (g CO_2e/kWh)

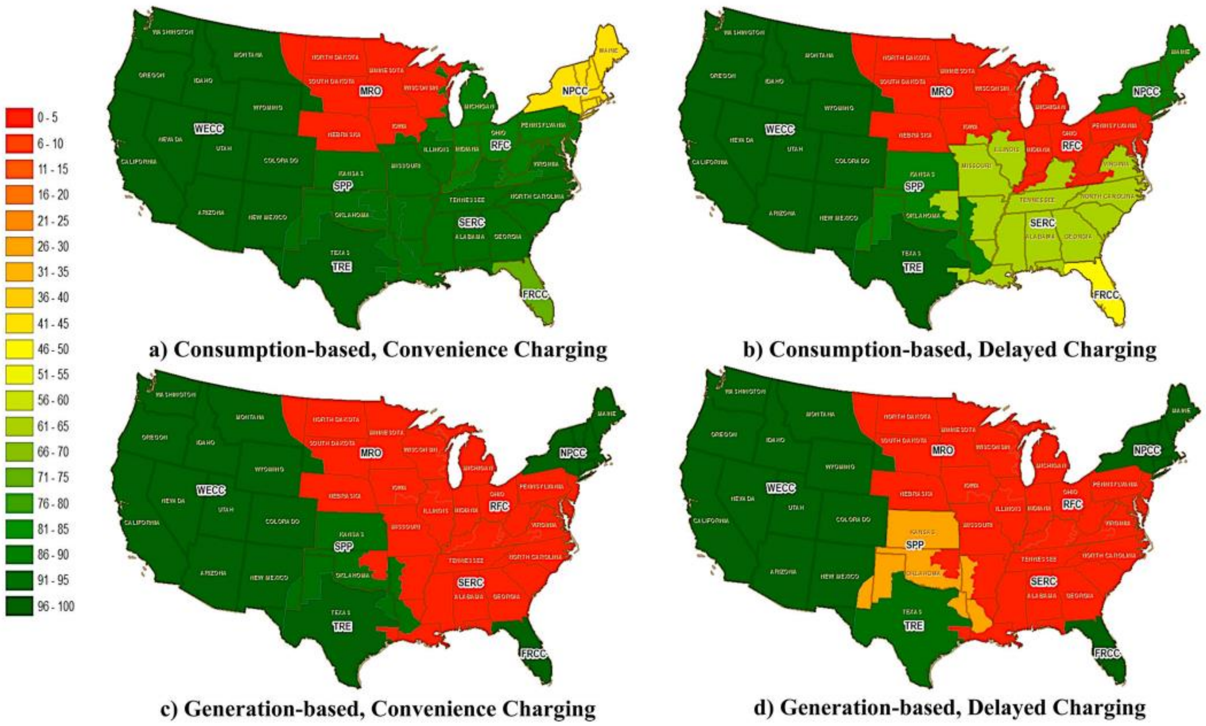


Source: EPA 2021h
eGRID = Emissions & Generation Resource Integrated Database; g CO_2e/kWh = grams of carbon dioxide equivalent per kilowatt –hour

An 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 kilograms [19.4 pounds] CO_2/day) and high carbon mix (93 percent coal, 26.4 kilograms [58.2 pounds] CO_2/day). A well-to-wheels study of BEVs in three Canadian regions with very different grid mixes found that the BEV emission intensity varied significantly between regions (Kamiya et al. 2019). However, even in regions with more carbon-intensive electricity, Kamiya et al. 2019 found that the well-to-wheels GHG emissions were lower for BEVs relative to gasoline-fueled ICE vehicles in all scenarios modeled, including short and long term. Each region offered emissions reductions—78 to 98 percent in British Columbia, 58 to 92 percent in Ontario, and 34 to 41 percent in Alberta (Kamiya et al. 2019).

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 ICE 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 ICE 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 ICE 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 6.2.3-10).

Figure 6.2.3-10. Probability that a BEV Emits CO_2 at a Lower Rate than a HEV or Internal Combustion Engine Vehicle



a) Consumption-based, Convenience Charging

b) Consumption-based, Delayed Charging

c) Generation-based, Convenience Charging

d) Generation-based, Delayed Charging

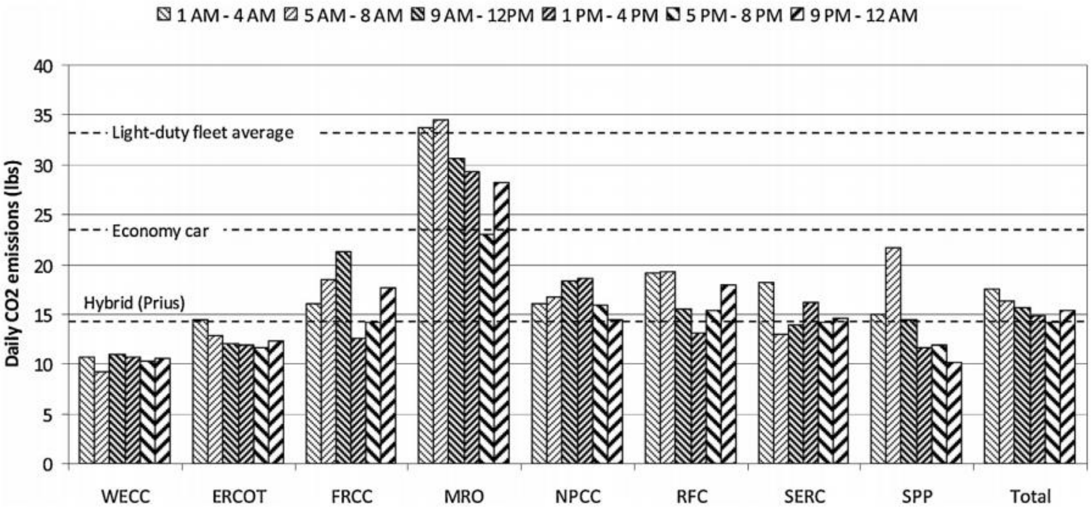
Source: Tamayao et al. 2015

Green indicates that the BEV is lower emitting than the gasoline vehicle (HEV or sales-weighted ICE 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

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 kWh). 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 kWh). 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 6.2.3-11 (Zivin et al. 2014). Under this study, the upper Midwest MRO region is also the only region where the average ICE economy car is less GHG-intensive than an EV.

Figure 6.2.3-11. 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; lbs = pounds; 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, sulfur oxides, and nitrogen oxide 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 ICE 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, nitrogen oxide, and sulfur oxide emissions substantially (Weis et al. 2016).

Kawamoto et al. (2019) assessed the relationship between driving distance and electricity mix in life-cycle emissions of EVs in comparison to ICE vehicles. The authors found that regional differences in the energy mix of electricity generation showed great significance in the overall LCA of an EV depending on the distance traveled throughout the vehicles' lifetime. In particular, regions with higher penetrations of renewables and/or lower carbon alternatives improved the LCA of EVs, such that a breakeven point with ICE vehicles—in terms of life-cycle emissions—would occur in the United States at approximately 60,000 kilometers (around 37,000 miles) (Kawamoto et al. 2019).

In summary, the studies cited in this section find that EV 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 ICE 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.[12] In comparing EV and HEV emissions, EVs emit less than HEVs in the West and Texas (the WECC and TRE/ERCOT NERC regions) and

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[12] Future electricity grid mixes could change and potentially raise the GHG intensity of regional grid mixes, which could affect this conclusion.

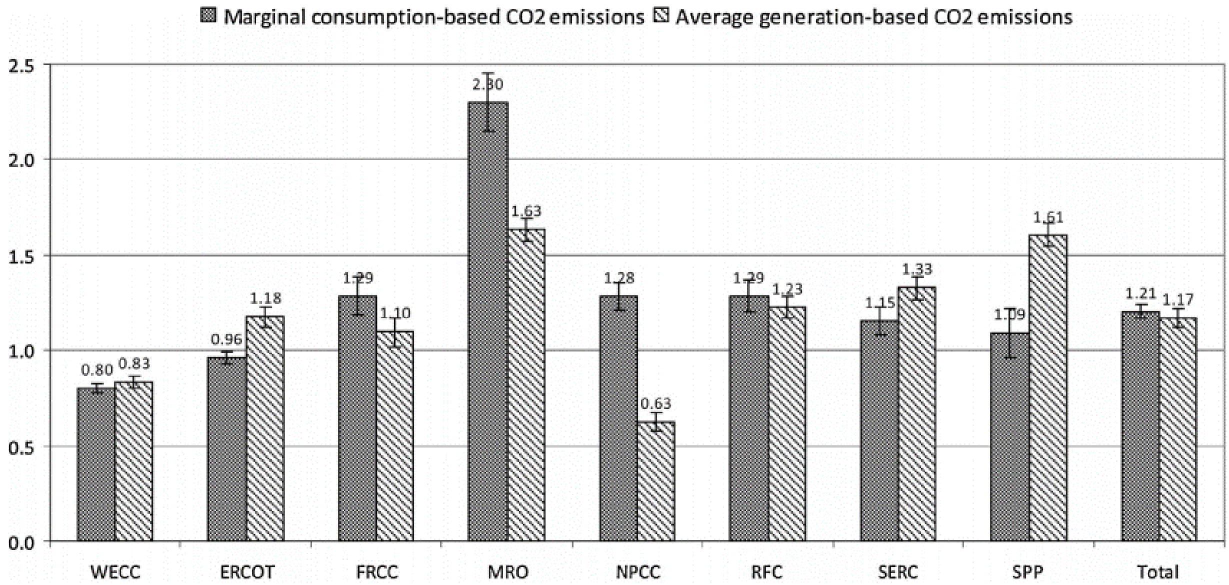
emit more in the upper Midwest (the MRO region). The results are mixed, varying based on emission factor estimation method and charging time, in the Northeast, the Southeast, and Central United States (the NPCC, FRCC, SPP, SERC, and RFC regions). Reducing grid mix carbon intensity reduces both GHG and criteria pollutant emissions for the EV use phase.

6.2.3.2 Marginal Grid Greenhouse Gas Intensity

MEFs discussed in Section 6.2.3.1, *Charging Location*, 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 6.2.3-12 (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 and 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 6.2.3-12. Marginal Emission Factors and 95 Percent Confidence Intervals versus Average Emission Factors by National Electricity Reliability Commission Region

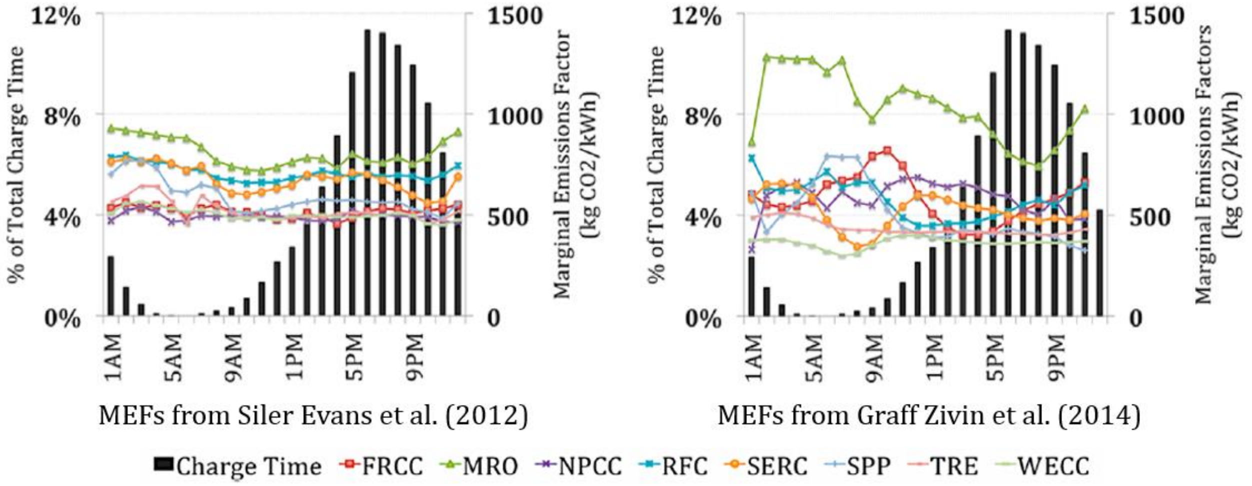


Source: Zivin et al. 2014

CO_2 = carbon dioxide; WECC = Western Electricity Coordinating Council; 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

MEFs vary throughout the day (Figure 6.2.3-13). 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 6.2.3-13) with diurnal MEF estimates for NERC regions (colored plots in Figure 6.2.3-13) 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 6.2.3-13. 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

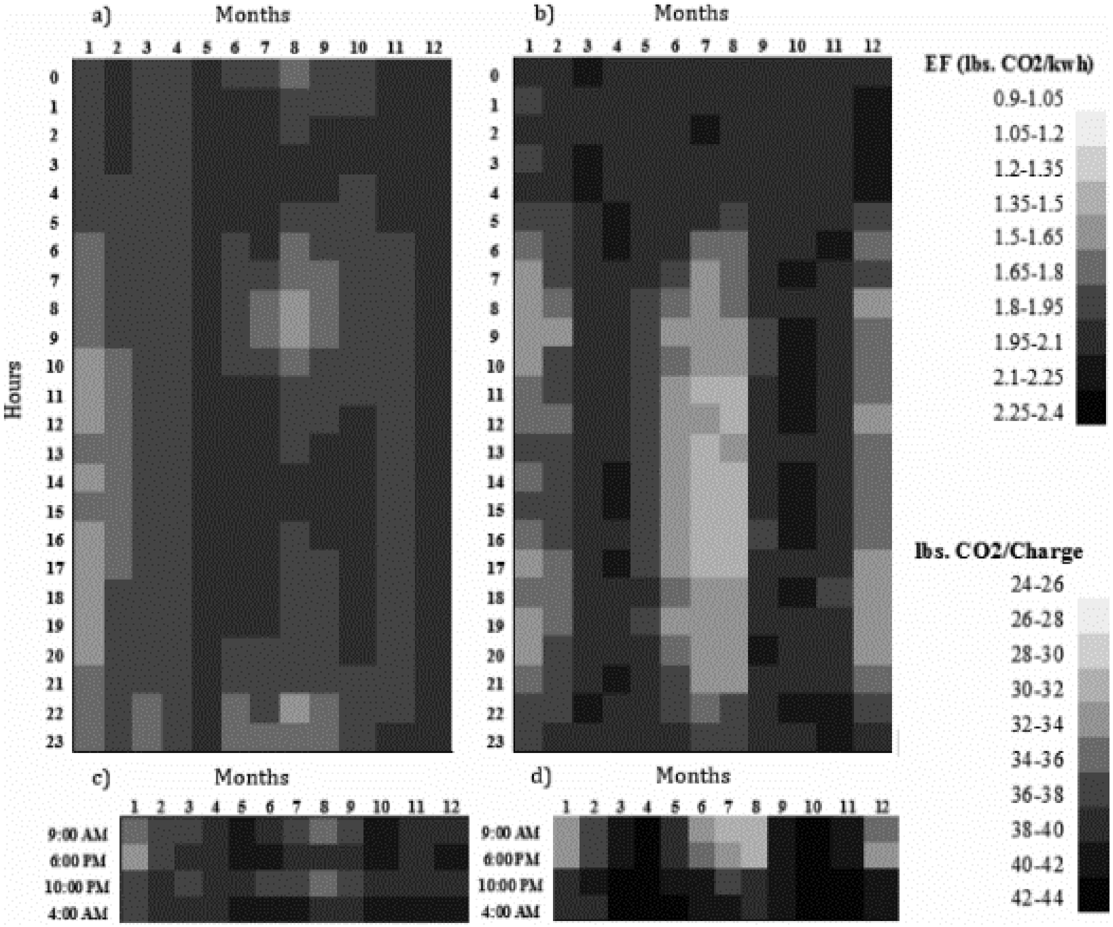
[b] Colored horizontal plots, right axis

[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; 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 6.2.3-14 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 6.2.3-14. 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[13] established the Renewable Fuel Standard, which was expanded by the Energy Independence and Security Act of 2007.[14] 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

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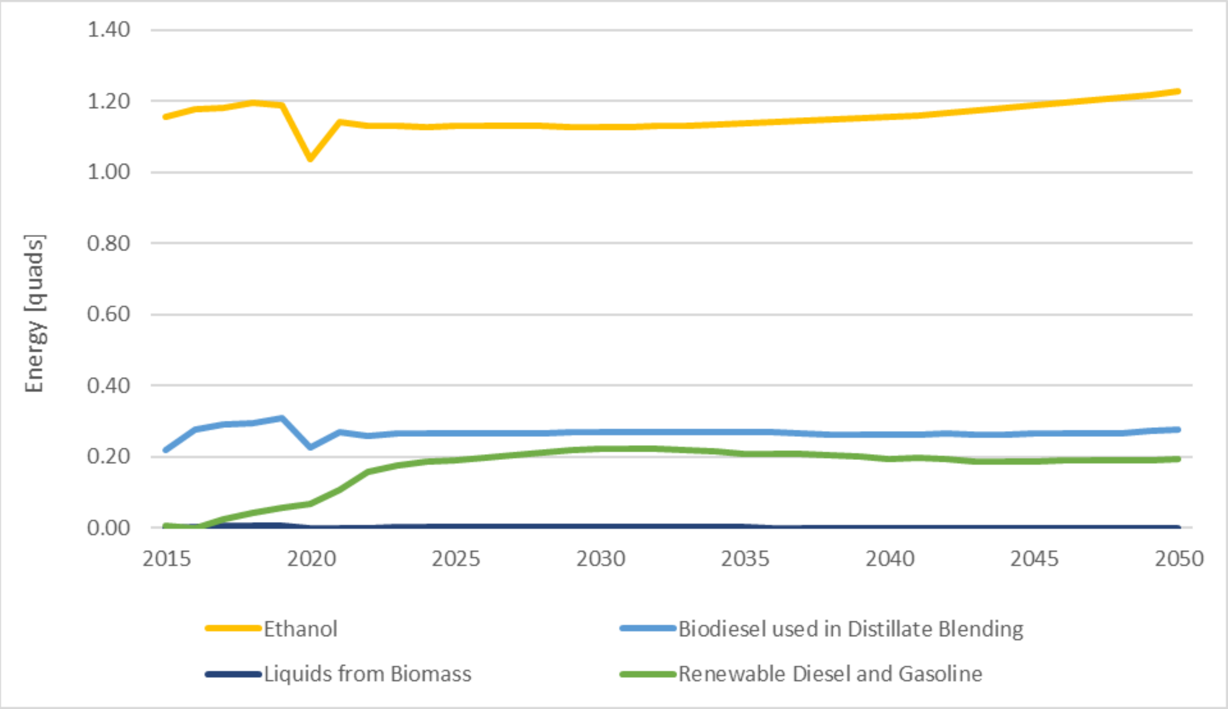
[13] Pub. L. No 109–58, 119 Stat. 594 (Aug. 8, 2005).

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

production of 36 billion gallons of total renewable fuel. The biofuels also must meet specific life-cycle GHG reduction targets relative to a 2005 petroleum baseline.

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 2021a

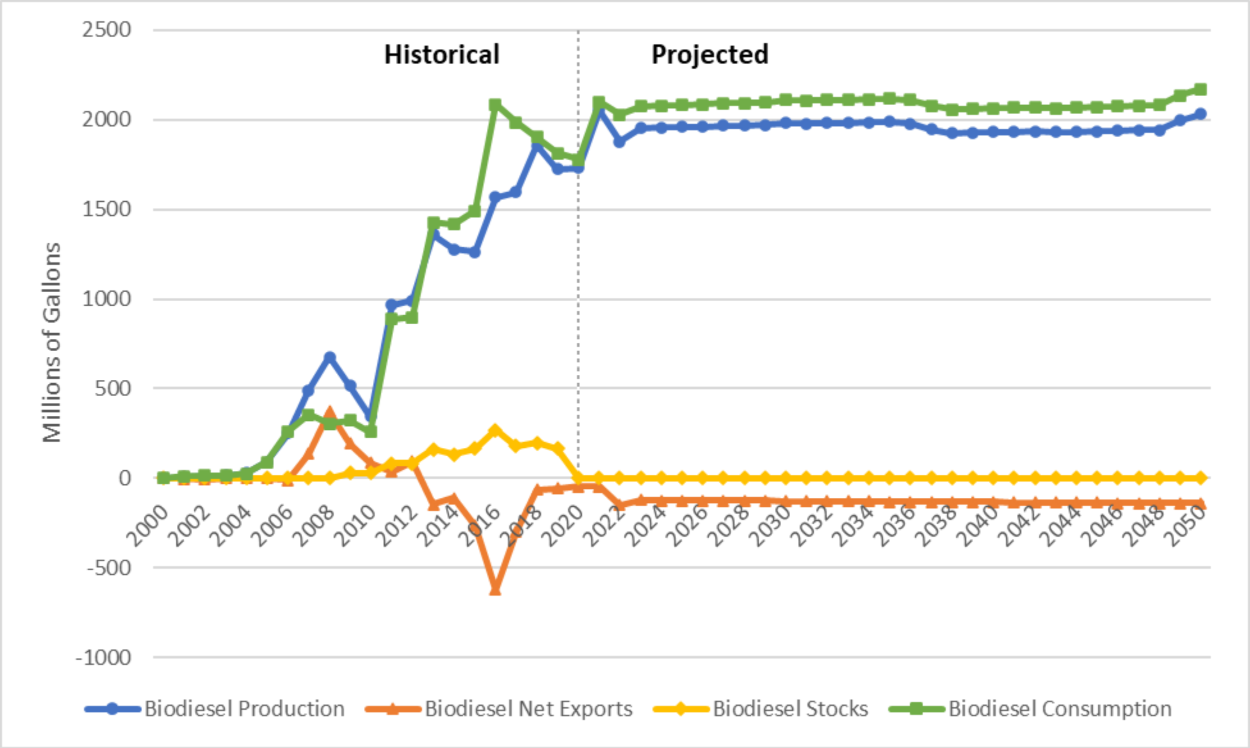
Given AEO 2021 (EIA 2021a) projections, the biofuel component of this literature synthesis focuses on ethanol and biodiesel. All diesel-powered passenger cars and light trucks are potential candidates for biodiesel blends.

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 2009). 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 2017). 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 increased significantly from 2005 through 2016, then leveled out through 2020. AEO 2021 projects that domestic production and consumption of biodiesel will remain at around 2,000 million gallons a year through

2050, as shown in the projected section of Figure 6.2.4-2 (EIA 2021a). Although production of biodiesel remains relatively steady, EIA projects that its market share will increase over this period as demand for non-petroleum-based fuels increases and the cost of petroleum-based diesel and gasoline rises.

Figure 6.2.4-2. Historical and Projected U.S. Biodiesel Production, Exports, Stocks, and Consumption



Source: EIA 2021a, 2021f

Biodiesel stocks refers to excess biodiesel that is stored for future use or export. The EIA projects that biodiesel stocks will remain negligible through 2050.

B20 and other lower-concentration biodiesel blends can be used in nearly all diesel equipment with few or no engine modifications (AFDC 2017). 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 2017). Because not all engines are compatible with higher-level blends, the NREL recommends contacting the engine manufacturer before using them (NREL 2009). 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).

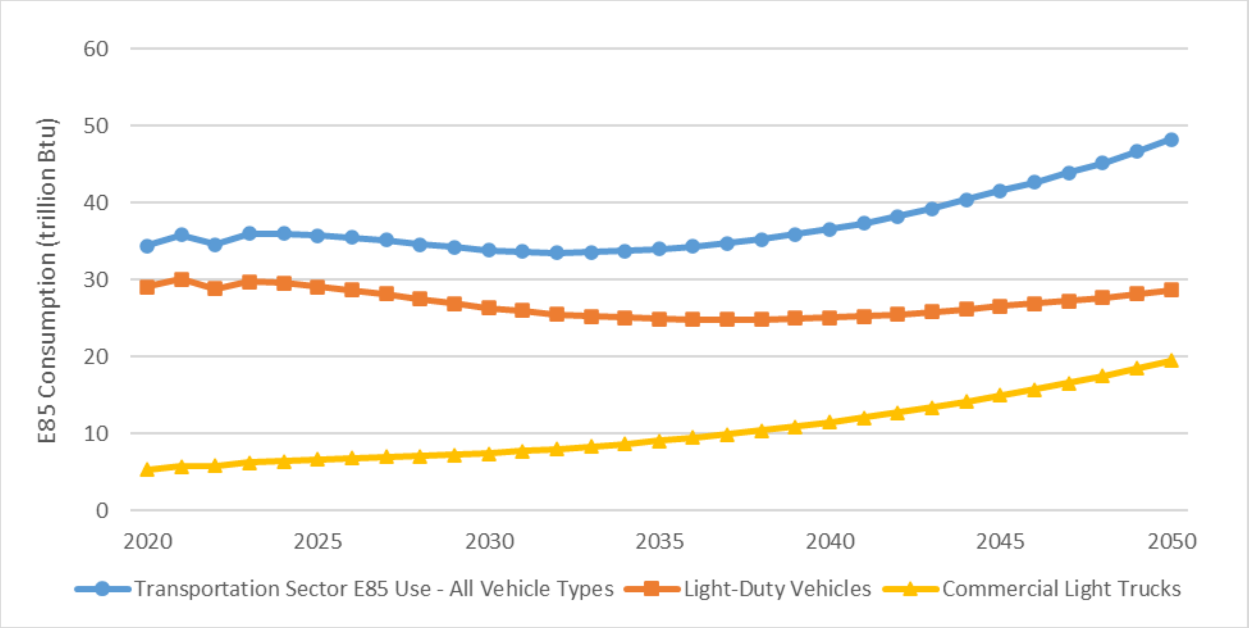
Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool shows that replacing one diesel passenger car with a comparable model running on B20 reduces GHG emissions from 3.6 to 3.1 metric tons CO_2e annually, and replacement with a B100 vehicle reduces GHG emissions to 1.4 metric tons CO_2e annually. Similarly, the GREET model estimates well-to-wheels emissions for petroleum diesel and B20 biodiesel at 450 and 395 grams of CO_2e per mile, respectively (ANL 2020b). These well-to-wheels emissions assume a soybean feedstock, which has lower life-cycle CO_2 emissions than algae feedstock. These estimates are consistent with an Argonne National Laboratory LCA that shows that GHG emissions can be decreased by 66 to 74 percent when using 100 percent biodiesel as a replacement for petroleum diesel (ANL 2020b; AFDC 2017).

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 (EIA 2021a). However, ethanol also can be produced from cellulosic feedstock 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 12 billion gallons per year (Rosenfeld et al. 2018; EIA 2021a). 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, are designed to be used primarily 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. To meet flexible fuel demands, fueling system equipment manufacturers have produced materials and products that are compatible with ethanol blends over E15 for fuel station infrastructure (DOE 2016a). Additionally, EPA approved a pilot program in Nebraska to study the use of E30 in conventional vehicles owned by the state, assessing impacts on vehicle performance, fuel economy, and emissions control systems (State of Nebraska 2018). As illustrated in Figure 6.2.4-3, E85 consumption by light-duty vehicles is projected to decrease slightly through 2038, then slowly climb back to current levels. E85 consumption will rise more markedly after a slight decrease through 2032, a change that is mostly driven by the increase of E85 use in commercial light trucks.

Figure 6.2.4-3. Projected E85 Consumption for Selected Vehicle Types



Source: EIA 2021a

Btu = British thermal units

Light-duty vehicles include passenger and fleet cars and trucks with a gross vehicle weight rating of 8,500 pounds or less (EIA 2018a).

The light truck category includes pickup trucks, minivans, sport-utility vehicles, and all other light-duty vehicles that are not classified as passenger cars (EIA 2017c).

Recent studies and LCA models have found that corn ethanol has declined in carbon intensity over time, revealing increased GHG emission savings relative to gasoline and other fossil fuels. This section summarizes these updates in ethanol LCA research that address improved modeling, technologies, and management practices through well-to-wheel life-cycle stages, including land-use change, farming, fuel production, supply-chain transportation, and end-use fuel efficiencies.

Wang et al. (2007) found that, depending on the energy source used during production, corn ethanol can reduce well-to-wheels GHG emissions by up to 52 percent compared to gasoline. Similarly, Canter et al. (2015) 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, ranging from 74 to 91 percent in reductions compared to gasoline (AFDC 2014; Morales et al. 2015; Canter et al. 2015). 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 409, 258, and 159 grams of CO_2e per mile, respectively (ANL 2020b). A study by the Oak Ridge National Laboratory, the NREL, 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).

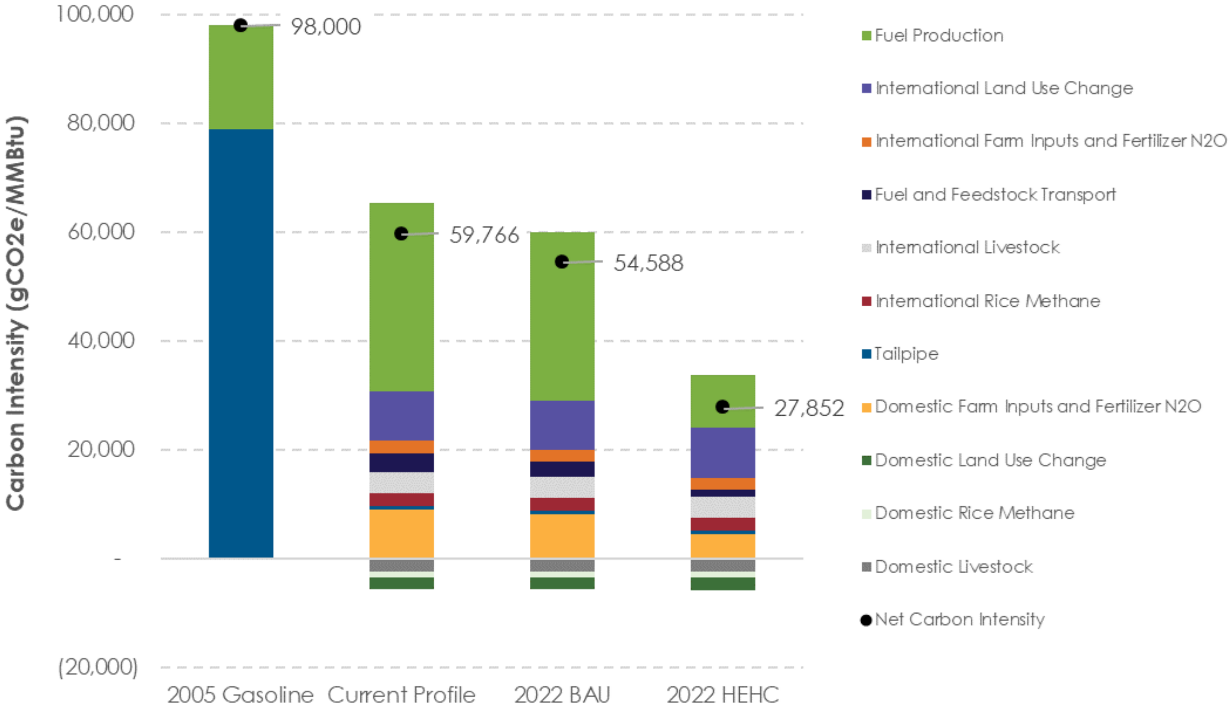
Table 6.2.4-1. Well-to-Wheels GHG Emissions Reductions in Vehicles Fueled by High-Octane Fuels with Different Ethanol Blending Levels Relative to Regular Gasoline (E10) Baseline Vehicles

	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
GHG = greenhouse gas; MPGGE = miles per gallon of gasoline-equivalent

Rosenfeld et al. (2018) estimated that, based on 2014 conditions, U.S. corn grain ethanol life-cycle GHG emissions are 59,766 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). The figure shows that vehicle use GHG emissions dominate the gasoline well-to-wheel life cycle, while they represent just a sliver of the ethanol vehicle life-cycle emissions profile. Other studies have produced similar results, including 60,000 g CO_2e/MMBtu (Canter et al. 2015) 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. 2015), 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 55 percent under a scenario with increased agricultural conservation and efficiency gains throughout the life cycle, making ethanol between 44 and 72 percent less GHG-intensive than gasoline (Rosenfeld et al. 2018).

Figure 6.2.4-4. GHG Emission Profiles of Gasoline and Corn Ethanol



Source: Rosenfeld et al. 2018

GHG = greenhouse gas; g CO_2e/MMBtu = grams of carbon dioxide equivalent per million British thermal units; N_2O = nitrous oxides

Current profile = pure corn ethanol life-cycle GHG profile in 2014

2022 BAU = business-as-usual projection of pure corn ethanol life-cycle GHG profile in 2022

2022 HEHC = high efficiency-high conservation projection of pure corn ethanol life-cycle GHG profile in 2022

As illustrated in Figure 6.2.4-4, the largest components of the Rosenfeld et al. (2018) corn ethanol life-cycle GHG profile for 2014 conditions ("current profile") include fuel production (58 percent, 34,518 g CO_2e/MMBtu), domestic farm inputs and fertilizer (15 percent, 9,065 g CO_2e/MMBtu), and international land use change (15 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 2010e), 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 between 9 and 53 percent from 2012 to 2022 (Boland and Unnasch 2014; Rosenfeld et al. 2018) because of improved technology and the development of new coproducts.

6.2.5 Hydrogen Fuel Cells

Fuel-cell vehicles are fueled by hydrogen that is converted to electricity via a fuel cell. While current light-duty fuel cell vehicle hydrogen consumption is less than 0.01 percent of total light-duty fuel consumption and current models (including the CAFE Model) project that it will remain less than 0.01 percent of light-duty fuel consumption through 2050 (EIA 2021a), fuel cells represent another potential alternative to carbon-intensive fuels, depending on the hydrogen production pathway. NHTSA's CAFE Model also shows that fuel cell use will stay low in future years—at less than 0.01 percent technology penetration rate in all alternatives in all future model years. 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, the GREET model estimates the well-to-wheel GHG emissions for a fuel-cell vehicle to be 95 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 92 percent of life-cycle emissions (ANL 2020b).

Numerous factors limit fuel-cell vehicle manufacture and consumer adoption, namely the cost and the lack of a hydrogen distribution infrastructure (NRC 2013a). Ongoing research and development are 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 2018). Recent studies have also determined that hydrogen fuel cells are a more efficient fuel source for large and heavy vehicles, where there are greater potential reductions in emissions—up to 20 percent of life-cycle GHG emissions—to offset the greater emissions from fuel cell production (Liu et al. 2018). In the future, increased use of renewable energy in hydrogen production is expected to help reduce upstream GHG emissions (Liu et al. 2018).

6.3 Materials and Technologies that Affect Vehicle Life-Cycle Emissions

Vehicle manufacturers have improved and will continue to improve fuel efficiency by reducing overall vehicle weight, reducing drag and friction, and by introducing new technologies that support alternative fuels. LCA studies have examined the GHG emissions impacts associated with the production, supply, and disposal of new materials to support these fuel efficiency improvements. LCAs have also compared these fuel efficiency benefits against potential increased emissions in upstream and downstream life-cycle stages from new materials. This section reviews LCA literature related to three categories of materials—aluminum and high-strength steel, plastics, and magnesium—and four broad categories of material joining techniques—laser welding, hydroforming, tailor-welded blanks (TWB), and aluminum casting and extrusion—that can improve passenger car and light truck fuel efficiency. A greater number of LCA studies have examined the effects of material substitution in vehicles. The studies to date suggest that changing vehicle mass using material substitution offers higher GHG emission reduction potential than changing vehicle mass by altering material joining techniques.

NHTSA’s CAFE Model estimates vehicle mass reduction at different increments of glider weight reduction in future vehicle model years. *Glider* refers to the vehicle curb weight excluding the powertrain weight. As shown in Table 6.3-1, the lower levels of mass reduction (no change, 5, and 7.5 percent reductions in glider weight) will see less technology penetration across all action alternatives relative to the No Action Alternative; however, the CAFE Model projects a substantial increase in higher levels of mass reduction (10 and 15 percent reductions in glider weight). For example, the penetration/use of technologies or materials that allow for a 15 percent reduction in glider weight are projected to increase across action alternatives as CAFE standard stringency increases, from 10 percent under No Action Alternative to 36 percent under Alternative 3. The life-cycle implications discussed in Section 6.3.1, *Vehicle Mass Reduction by Material Substitution*, and Section 6.3.2, *Vehicle Mass Reduction by Material Joining Techniques*, are relevant to the extent that manufacturers apply the technologies and materials discussed in these sections to meet the MY 2024–2026 CAFE standards.

Table 6.2.5-1. Mass Reduction Technology Penetration Rates for Model Year 2029

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Baseline Mass	10%	4%	2%	2%
Mass Reduction, Level 1 (5% Reduction in Glider Weight)	23%	21%	21%	15%
Mass Reduction, Level 2 (7.5% Reduction in Glider Weight)	20%	9%	7%	7%
Mass Reduction, Level 3 (10% Reduction in Glider Weight)	36%	42%	38%	40%
Mass Reduction, Level 4 (15% Reduction in Glider Weight)	10%	24%	33%	36%

6.3.1 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).

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 [62.1 miles] by 100 kilograms [220.5 pounds]), respectively). The authors used the GREET2 model for energy and emissions data and for modifying vehicle models to explore the substitution impacts.[15]

Material substitution ratios were obtained separately from a DOE report (DOE 2013b). 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

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[15] GREET2 is a module of Argonne National Laboratory's GREET model. GREET2 assesses life-cycle impacts from vehicle materials production and management, whereas GREET evaluates impacts from energy production and vehicle use.

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 6.3.1-1).

Figure 6.3.1-1. Breakeven Driving Distance for Different Material Substitution Pairs and Substitution Ratios

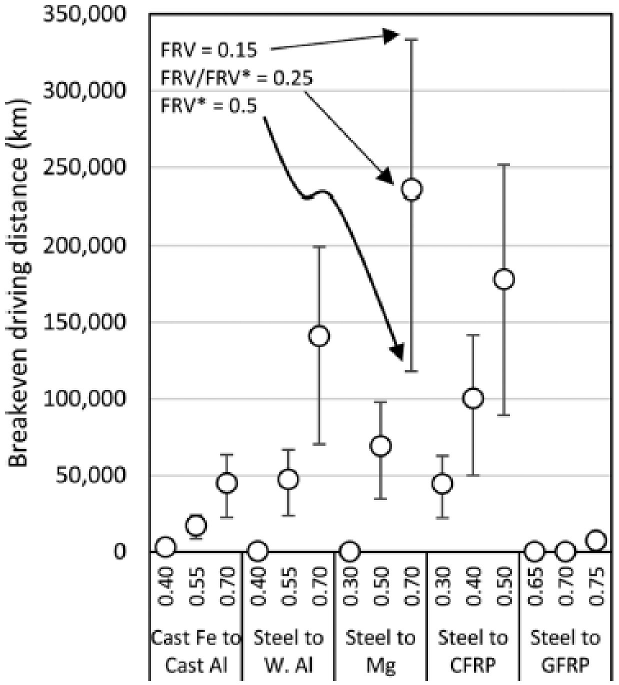

Figure 5. Breakeven driving distance for different material substitution pairs and substitution ratios, assuming different FRV/FRV* values.

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., ICE vehicles, HEVs, and BEVs). The study found that fuel reduction estimates varied significantly when reducing overall vehicle weight by 100 kilograms (220.5 pounds). 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).

6.3.1.1 Aluminum and High-Strength Steel

Automotive grade 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 and sometimes greater than 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. 2010a; Koffler and Provo 2012; Mohapatra and Das 2014).

NHTSA identified 23 studies[16] that examined the life-cycle impacts of substituting aluminum and/or high-strength steel for mild steel components in vehicles (Kim et al. 2010b; 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 Müller 2012; Shinde et al. 2016; Kelly et al. 2015; Das 2014; Modaresi et al. 2014; Raugei et al. 2015; Hardwick and Outteridge 2015; Sebastian and Thimons 2017; Milovanoff et al. 2019; Palazzo and Geyer 2019). 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. 2010b; 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 associated 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,[17] 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 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). Another study used a fleet-based life-cycle model to estimate the GHG emissions savings from

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[16] 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. (2010b), Geyer (2007, 2008), Dubreuil et al. (2010), Das (2014), Birat et al. (2003), Sebastian and Thimons 2017, and Milovanoff et al. (2019). Most of the studies reviewed have undergone peer review for publication in academic journals, although Sebastian and Thimons (2017) was not published in an academic journal. Certain studies noted where critical reviews were conducted in accordance with ISO 14044 standards on either the method (Geyer 2008), life-cycle inventory inputs (Dubreuil et al. 2010), or both (Sebastian and Thimons 2017), or where critical review was not performed (Bertram et al. 2009).

[17] LCA studies often use different assumptions for vehicle lifetime that can influence final results. For example, a study that expresses results per vehicle as a functional unit (e.g., kilograms CO_2e/vehicle) would have greater life-cycle emissions with a 10-year lifetime assumption than an 8-year assumption. Vehicle miles traveled assumptions over a vehicle's lifetime can also significantly impact results, which is why many vehicle LCA's express results per kilometer or mile as a functional unit.

lightweighting the U.S. light-duty fleet using aluminum or high-strength steel from 2016 to 2050. An aggressive aluminum lightweighting scenario led to cumulative life-cycle GHG emissions savings of 2.9 gigatons of CO_2e and annual emissions savings of 11 percent by 2050 (Milovanoff et al. 2019). 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 DOE 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 (802.5-pound) 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 [151,017 pounds] CO_2e) to the Mach I (57,600 kilograms [126,986 pounds] 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).

One study evaluated the life-cycle impact of two steel grades considered for the B-pillar in the Ford Fusion: a press-hardened boron steel design as used in previous models of the vehicle, and a hydroformed component made from a mix of dual phase steels (DP800 and DP1000, which are categorized by the study as advanced high-strength steels). The LCA showed that the new DP800/DP1000 B-pillar design achieved a lower environmental impact over the full life cycle of the vehicle, with a global warming potential that was 29 percent lower than the boron steel design. A 4-kilogram (8.8-pound) weight difference was achieved between the two designs, and accounts for the majority of the differential impacts. The assessment concluded that significant environmental impact improvements can be achieved through the increased use of advanced high-strength steels in the body structures of vehicles (Hardwick and Outteridge 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 depend heavily on the location of aluminum production and the share of secondary aluminum used (Kim et al. 2010b). Growing use of aluminum sheet in vehicles will result in significant growth of high-value aluminum scrap in the recycling market. A study conducted by Zhu et al. (2021) estimated that the Ford F-150, Super Duty, Expedition, and Lincoln Navigator alone account for around 1,200 kilotonnes (kt) of aluminum auto body sheet (ABS) within the 2020 U.S. light-duty vehicle fleet. This production is projected to result in approximately 125 kt per year of aluminum ABS scrap in 2035 and approximately 246 kt/year in 2050 if the current volumes of production are maintained. This increased volume of aluminum scrap presents an opportunity for vehicle manufacturers to increase the recycled content of vehicles and reduce the energy-intensity and GHG impacts of the material extraction and production phases.

LCA results are also sensitive to how energy and emissions savings from recycling end-of-life aluminum and high-strength steel vehicle components are allocated in a given study. Sebastian and Thimons (2017) found that substituting aluminum or high-strength steel for mild-steel sheet parts reduces the total life-cycle GHG emissions when using the avoided burden method to account for a credit from metals recycling "based on the premise that use of scrap offsets or substitutes the use of virgin materials." However, when only accounting for the effects of recycled materials in the manufacturing of vehicle components and not including a credit for avoided use of virgin materials, the study found that life-cycle GHG emissions from aluminum components exceeded those of both mild-steel and high-strength steel vehicles, while high-strength steel vehicles continued to show lower life-cycle GHG emissions compared to mild-steel (Sebastian and Thimons 2017). Similar results were shown in a study by Palazzo and Geyer (2019) examining the life-cycle GHG emissions from replacing steel with aluminum in production of North American vehicles. The authors noted that "technological limitations currently prevent recycling all of the incremental aluminum scrap back into the wrought components." The authors examined the impact on life-cycle GHG emissions for aluminum substitution scenarios when the aluminum displacement[18] rate falls below the one-to-one displacement assumed under the avoided burden method. The results show that lower aluminum displacement rates can significantly impact the breakeven time required for GHG emissions savings from vehicle use to exceed increased GHG emissions from aluminum production and end-of-life management. For scenarios where the aluminum displacement ratio was lower than 35 percent, the authors found that aluminum vehicles do not achieve GHG emissions savings across the vehicle life cycle (Palazzo and Geyer 2019).

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[19] (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

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[18] In this context, displacement is taking into account the benefits of aluminum recycling, thus the rate of aluminum being sourced from recycled materials (scrap and material markets). Substitution rate in this context is used to quantify the intensification of the use of aluminum in automotive parts.

[19] Open-loop recycling systems are characterized by recycled materials being converted into both new (raw) material, such as aluminum, and waste product. Materials recycled through this system are typically used for applications that vary from their former (pre-recycled) purpose, whereas a closed-loop system is characterized by manufactured products/parts recycled for use in the same type of product. Closed-loop systems are more often used in highly specialized industries, where parts are complex and expensive to break down, thus often designed with the closed-loop recycling process in mind. For aluminum ABS, scrap is not easily recycled into original aluminum ABS alloys without dilution of primary aluminum and addition of alloying elements (Zhu et al. 2021), thus making an entire closed-loop system challenging. However, emerging technologies (e.g., laser-induced breakdown spectroscopy, a focus laser pulse vaporizer) can help improve the process efficiency and accelerate the progress towards a closed-loop system.

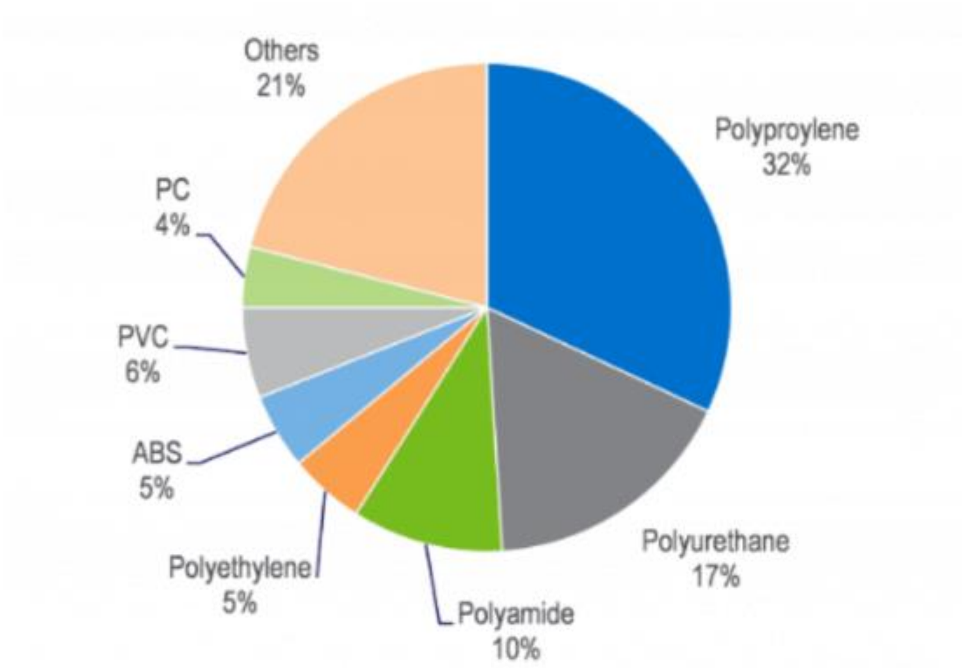
for a steel chassis resulted in net GHG savings under all recycling scenarios. The recycling scenarios ranged from *pessimistic*, where 75 percent of aluminum parts are open-loop recycled and 25 percent landfilled, to *optimistic*, where 90 percent of aluminum parts are closed-loop recycled (Raugei et 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).

6.3.1.2 Plastics and Polymer Composites

Plastics, also known as polymers, include thermosets, thermoplastics, and elastomers (Park et al. 2012). Most plastics are generally not as strong as metal with the exception of carbon fiber-reinforced plastics. As such, plastics are typically used for interior or exterior parts that do not have structural strength requirements, such as front and rear fascia, lighting, trim parts, or instrument panels (Park et al. 2012; Modi and Vadhavkar 2019). Polymer composites such as nanocomposites can, however, offer strength that is comparable to mild steel and thus can be used for body panels. Over 70 percent of the plastics used in a vehicle comes from four polymers: polypropylene, polyurethane, polyamides, and polyvinyl chloride, as shown in Figure 6.3.1-2 (Nexant 2019).

Figure 6.3.1-2. North America Plastics Consumption in the Automotive Sector in 2017



Source: Nexant 2019.
PC = polycarbonate; PVC = polyvinyl chloride; ABS = acrylonitrile butadiene styrene

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 2012c). 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).

Various types of reinforced polymer composites are in use or in development as substitutes for mild steel or aluminum, predominantly in vehicle body panels. Use of polymer composites as reinforcement in structural components is expected to increase with lower costs and advancements in processing technology (Modi and Vadhavkar 2019). These materials offer added tensile strength and weight-reduction potential compared to mild steel.[20] 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

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[20] 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).

are useful properties for automobile components such as body panels and casings for electronic equipment (Khanna and Bakshi 2009) and fuel filler pipes. However, commercialized carbon fiber nanotubes are often supplied in highly entangled tubes that results in lowering their overall performance. To address this issue, one recent study applied a chemical functionalization process to incorporate fiberglass into the carbon nanotubes. The results revealed that as low as 0.35 percentage by weight of fiberglass carbon fiber nanotubes could reduce fuel consumption by 16 percent and GHG emissions by 26 percent in addition to improving the strength of the panels by 60 percent (Subadra et al. 2020).

Twenty-one studies identified the life-cycle environmental impacts of substituting reinforced polymers or composites for aluminum or mild-steel components in vehicles (Tapper et al. 2020; Shanmugam et al. 2019; Dai et al. 2017; 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; Delogu et al. 2015; Witik et al. 2011; Mayyas et al. 2012; Kelly et al. 2015). Two studies examined the role of biocomposites or natural fibers in place of conventional synthetic materials (Barillari and Chini 2020; Roy et al. 2020). Two of the 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.
- Use of biocomposites or natural fiber composites as substitutes to conventional materials is gaining some traction in the automotive industry. One study found that the global warming potential can be reduced from 12.5 kilograms (27.6 pounds) CO_2e to 11.1 kilograms (24.5 pounds) CO_2e by substituting polypropylene reinforced with talc and colorant with polypropylene reinforced with biocarbon such as Miscanthus fiber (Roy et al. 2020). Another study reported that use of biopolymers in place of conventional plastic could theoretically result in up to 90 percent emissions

reduction, which amounts to 480 kilograms (1,058.2 pounds) of CO_2 savings for a mid-range car (Barillari and Chini 2020).

- EVs require additional considerations for the design and use of materials for under-the-hood applications and battery packs and offer opportunities for improved structural topologies. Furthermore, with higher EV market penetration, the demand for polycarbonates and polypropylene is expected to grow at a faster rate to offset the weight of batteries (Modi and Vadhavkar 2019).

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;[21] 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[22] energy required for carbon nanofiber polymer composites range from nearly 2 to 12 times greater than the energy requirements for steel[23] (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 associated with lower GHG emissions;[24] 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; Delogu et 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[25] (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 kilograms [163.2 pounds] CO_2e/part) (Koffler and Provo 2012).

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[21] 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.

[22] 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.

[23] Standard steel plate used in this study.

[24] 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).

[25] Including petroleum production, which refers to the upstream emissions associated with producing the petroleum that the vehicles consume.

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[26] 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 the material production stage of a vehicle's lifecycle instead of the use phase, unlike GHG emissions, where the use phase was the greatest source of emissions (Delogu et 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. 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 nitrogen oxide 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 (Raugei et al. 2015; Delogu et 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). One study demonstrated that the use of recycled carbon fiber components to produce composite materials used in vehicles offers the highest life-cycle

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[26] Includes four door panels, the hood, and the deck lid.

environmental benefit as compared to conventional and proposed lightweight materials (e.g., steel, aluminum, virgin carbon fiber) (Meng et al. 2017). 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.

6.3.1.3 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, magnesium is primarily used in the die casting process (almost 98 percent of magnesium-based structural applications) and is a key material to replace steel (Kumar et al. 2020b). Examples of vehicle body parts where magnesium has been incorporated for weight reduction purposes include transmission and front door castings (Ford), engine and drivetrain (BMW) (Kulkarni et al. 2018), instrument panel cross car beam (Park and Kwon 2015), and steering wheels, steering column, and airbag housing (Luo 2013). Thiagarajan et al. (2020) note in their case study that the potential increase in the use of magnesium in vehicle technology will be highly dependent on the question of whether established forming processes for aluminum and steel can be adapted to magnesium. 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; Kelly et al. 2015). Overall, the studies show the following trends.[27]

- Magnesium is more energy- and GHG-intensive to produce than steel or aluminum.

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[27] 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.

- 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).

One recent study evaluated the technical and environmental performance of a novel-developed magnesium alloy, reinforced with submicrometer-sized titanium carbide (TiC) particles, which is a ceramic material that is often used in wear-resistant applications. It was analyzed for use in automotive components. The AM60/TiC alloy (a 40 percent aluminum and 60 percent manganese alloy combined with TiC at 1 percent of total weight) was achieved through a high-temperature synthesis process. The study showed positive results in terms of material specifications (no presence of loose titanium or carbon particles, or secondary components), shape, and performance. The environmental analysis revealed the alloy had a lower life-cycle environmental impact for 70 percent of the indicators, compared to aluminum components (Ferreira et al. 2019).

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 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[28] 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 kilogram of magnesium (Ehrenberger 2013). Therefore, the degree of recycling can have a great impact on LCA results.

6.3.2 Vehicle Mass Reduction by Material Joining Techniques

Material joining techniques used in manufacturing vehicles and vehicle components discussed in this section improve fuel efficiency and reduce GHG emissions by reducing vehicle glider weight. Certain

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[28] SF_6 has a global warming potential of 23,500 according to the IPCC Fifth Assessment Report (AR5).

manufacturing techniques can also reduce the upstream waste generated and provide energy savings that along with the use phase benefits can further reduce the environmental impacts from across the vehicle life cycle.

6.3.2.1 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). Reducing overall material use avoids the environmental burden associated with a material's life cycle, including any inputs and outputs from raw material extraction, refining, shipping, processing, and production (Figure 6.1.1-1).

Afzal et al. (2020) conducted an LCA of three different welding processes on sheets of stainless steel. Friction stir welding, laser beam welding and gas tungsten arc welding process were compared for six environmental impact categories: acidification potential, abiotic depletion, eutrophication potential, global warming potential, photochemical ozone creation potential, and ozone depletion potential. Out of the three welding processes, laser beam welding was found to have the most environmental benefits, and friction stir welding the least. The study also concludes that with increasing sheet thickness, the friction stir welding is proportionally more detrimental to the environment (Afzal et al. 2020). Friction stir welding applications are limited in today's automotive industry; however, the technology facilitates multi-material solutions which Oak Ridge National Laboratory has identified as a high priority for automotive body lightweighting (Feng 2013). This LCA study has important auto industry implications, as stainless steel is currently being used in a variety of automobile parts, including car exhaust systems, chassis, suspension, and body and catalytic converter vehicle applications. The vast majority of welding that occurs in modern automobiles is spot welding.

Laser welding benefits include better stress distribution leading to higher stiffness at lower weight, smaller heat affected zones on the welded parts, and reduced flange sizes. Another study noted that this welding method has proven to be the most promising method for the joining of different materials whether they are similar or a dissimilar material category (Arulvizhi et al. 2019). Laser welding has achieved successful implementation by the automotive industry.

6.3.2.2 Hydroforming

Hydroforming is a metal fabricating and forming process that allows the shaping of metals through the use of a highly pressurized fluid. Hydroforming has been applied to steel and aluminum automobile parts and offers improved mechanical properties, including enhanced structural strength, stiffness, and surface finish. U.S. automotive manufacturers have been using hydroforming since before 2008 (Kocanda and Sadlowska 2008), and it is still being used today to reduce the weight of several automobile parts, such as shift beams, doors, and various frame components (Shinde et al. 2016).

There are two classifications used to describe hydroforming: sheet hydroforming and tube hydroforming. Sheet hydroforming uses one die and a sheet of metal that is driven into a die by high-pressure water on one side to form the sheet into the desired shape. Tube hydroforming involves the expansion of metal tubes into a desired shape by using two die halves that contain the raw tube. In comparison to the process of stamping two part halves and welding them together, hydroforming offers a seamless manufacturing process that increases parts' strength and results in a high-quality finish (free of joints).

As discussed in Section 6.3.1.1, *Aluminum and High-Strength Steel*, an LCA study by Hardwick and Outteridge 2015 examined a press-hardened boron steel design for a Ford Fusion vehicle compared to a as new design with a hydroformed component made with high-strength steel. The study found that the life-cycle GHG emissions were 29 percent lower for the vehicle with the new hydroformed design. Vehicle use phase contributed to the majority, or 93 percent, of the life-cycle GHG emissions due to the new design's lower vehicle weight and resized powertrain (Hardwick and Outteridge 2015).

Parts weight reduction is one of the main advantages of hydroforming, as illustrated by another study where 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). Other recent studies—Colpani et al. 2020 on tube hydroforming and Costin et al. 2018 on sheet metal hydroforming—also highlight the weight reduction benefits of the hydroforming process. They also discuss additional manufacturing advantages of the process including the reduction of the number of parts or joints needed, increased geometrical freedom (leading to enhanced topologies), and reduction of secondary operations and waste materials. Hydroforming can also be used as a tool to enable increased joint efficiencies between connecting structural members, as the technology allows for increased design creativity.

6.3.2.3 Tailor-Welded Blanks

TWBs are a weight-saving technology in which two or more metal sheets of different thickness, strength, and/or coating are joined together by laser welding so that the ensuing subassembly is lighter and has fewer 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 also improves corrosion behavior by eliminating overlapping joints. A recent study (Suresh et al. 2020) estimates that the TWB technology was introduced to the manufacturing of lightweight automotive body parts about 20 years ago, and that the production of TWB for vehicle components is growing at a rapid pace, with around 30 percent of components being manufactured by TWB technology alone.

One recent study (Suresh et al. 2020) focused on sustainability considerations in the LCA of the TWB technology and concluded that material savings of nearly 33 percent can be achieved through the punch load reduction (by 50 percent reduction) under warm forming conditions for the welded blanks. The study also discussed two recommendations to increase the sustainability impacts of the technology: (1) the use of thinner metal sheets and minimal weld lines, where possible, as it optimizes weight reduction, and (2) to integrate, where possible, opportunities to use scrap metal sheets as a part of the tailor-welded products, as using locally recycled metals (provided they comply with all applicable material requirements) represents a growing sustainability opportunity.

6.3.2.4 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 an extrusion die. 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).

Many studies highlight a growing need to consolidate the increasing demand for aluminum (including aluminum casting and extrusion products) with the expansion of recycled aluminum production (Smirnov et al. 2018). According to the Aluminum Association, the automotive industry is the largest market for aluminum casting and cast products make up more than half of the aluminum used in cars today (Aluminum Association 2021b). The Aluminum Extruders Council estimates that the average North American passenger car contained an average of 27 pounds of aluminum extrusion in 2012 and nearly 35 pounds per vehicle in 2020 (Aluminum Extruders Council 2021). They also project this number to grow to nearly 45 pounds by 2025. This projection emphasizes the sustainability opportunity presented by integrating recycled aluminum as a part of the supply chain for aluminum casting and extrusion products used in vehicle manufacturing. Doing this would decrease the environmental impact of the two technologies by reducing the operations (and emissions) related to sourcing new aluminum and by producing products that can themselves be recycled at the end of life of the vehicle.

6.3.3 Vehicle Batteries

Historically, battery manufacturers for passenger cars and light trucks have used lead-acid chemistries for ICE 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 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 lithium-ion batteries to stay charged longer (Notter et al. 2010). Lithium-ion batteries are an evolving technology. Researchers and manufacturers are continually developing new battery chemistries to increase energy density while reducing costs.

Lithium-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. 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 2013d).

LCA literature has focused on three cathode types: lithium manganese oxide (LMO), LFP, and MNC (Nealer and Hendrickson 2015). The manufacturing of lithium-ion batteries is an energy-intensive process, particularly with the coating and drying phases[29] as well as maintenance of the dry room conditions during cell assembly, as can be seen in Figure 6.3.3-1 for a battery cell lot. Significant

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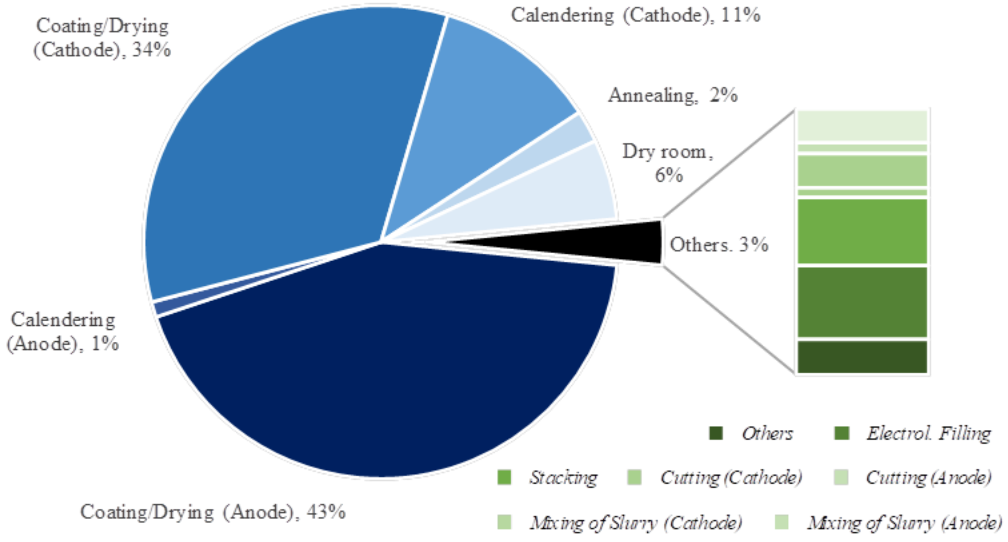
[29] The drying phase involves application of heat to remove the flammable solvent in the cathode after the coating process. Drying is an important step in the manufacture of Lithium-ion batteries as it helps ensure the stability of the lithium salts used as electrolytes under least humidity conditions. High humidity causes the lithium salts to react with water and produce hydrogen fluoride, leading to compromising the battery life.

efficiencies can be achieved by improving the material yield of the coating and drying phases and increasing the utilization area of the dry room (Wessel et al. 2021).

Figure 6.3.3-1. Proportional Energy Consumption per Process Step

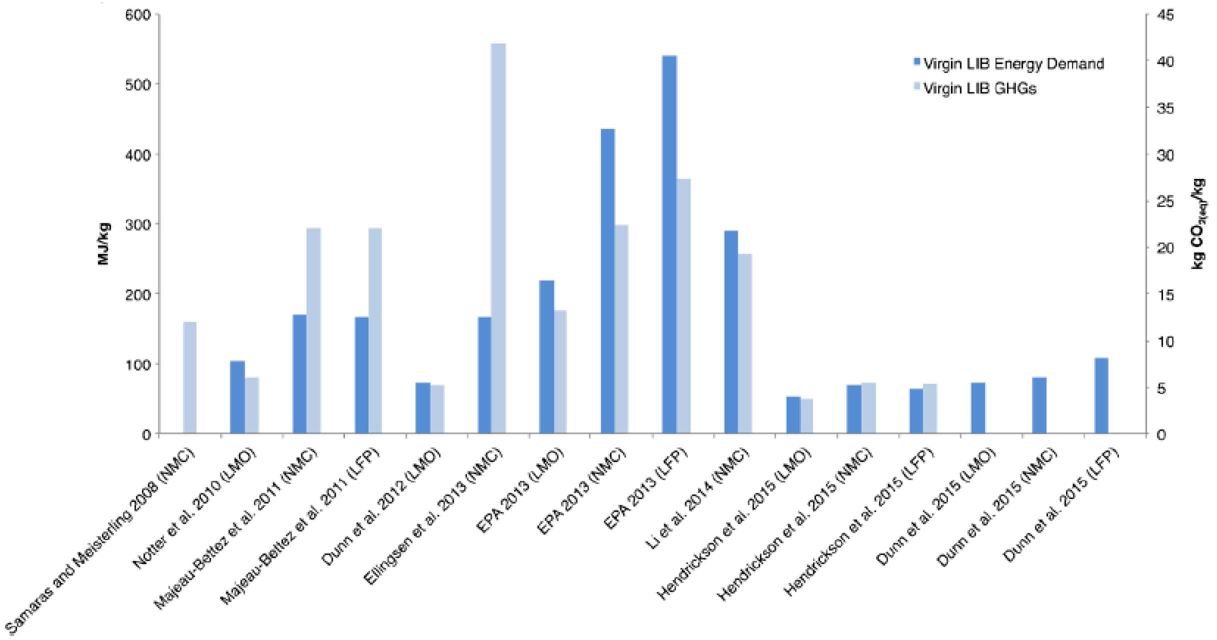


Source: Figure 3B from Wessel et al. 2021

A scan of life-cycle studies shows a wide variability of life-cycle emission results related to vehicle batteries. One study found that grid factor alone could account for 70 percent of the variability in life cycle results (Congressional Research Service 2020). Kawamoto et al. (2019) also noted the importance of the electricity mix of the battery production facility in addition to the use-phase electricity mix. When PHEVs and EVs are charged with a more renewable-based electricity grid mix, the vehicle use-phase GHG impacts decline, making the relative impact of the lithium-ion battery production process account for a greater share of the life-cycle emissions (Dunn et al. 2015). HEVs are not affected by grid mix variations during use, as the vehicle is not consuming grid electricity as a fuel. Estimates for the relative contribution of lithium-ion batteries on the vehicle life-cycle GHG impact 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 2013d) or almost 25 percent of total GHG emissions (Dunn et al. 2014; EPA 2013d; Hawkins et al. 2013). LCAs and LCA reviews have highlighted this, but focus on different drivers of results. Three articles focused on LCA scope and vehicle lifetime/mileage assumptions (Hawkins et al. 2012; Kawamoto et al. 2019; Held and Schücking 2019), while another study details battery design and specific LCA methods (Nealer and Hendrickson 2015). Detailed LCAs of EV lithium-ion battery production highlight specific materials in results (Notter et al. 2010; EPA 2013d; Li et al. 2014), while others closely analyze battery manufacturing and assembly processes as drivers of impacts (Ellingsen et al. 2014; Dunn et al. 2015; Dai et al. 2019).

Figure 6.3.3-2 shows the variations in LCA lithium-ion battery results for energy consumption and GHG emissions from a literature review for three common battery chemistries (LMO, LFP, and NMC) (Nealer and Hendrickson 2015). In addition to the studies cited in the figure, Kawamoto et al. (2019) found that GHG emissions from battery production were 160 kilograms (352.7 pounds) of CO_2 per kWh for NMC and 161 kilograms (354.9 pounds) of CO_2 per kWh for LFP, which is on the lower end of the range of results in Figure 6.3.3-2. Aichberger and Jungmeier (2020) reviewed 50 LCA studies published between 2005 and 2020 on lithium-ion batteries for EVs and found that the production of a battery pack had an emissions range of 70 to 175 kilograms (154.3 to 385.8 pounds) of CO_2e per kWh with a median of 120 kilograms (264.6 pounds) of CO_2e per kWh, depending on the battery pack capacity. The authors expect newer batteries to be in the lower range of emissions. Another study found that battery life-cycle GHG emissions have gone down substantially in 2 years—from 150 to 200 kilograms (330.7 to 440.9 pounds) of CO_2e per kWh battery capacity in 2017 to 61 to 106 kilograms (134.5 to 233.7 pounds) of CO_2e per kWh battery capacity in 2019 for NMC (Emilsson and Dahllöf 2019). Hoekstra (2019) points out that improving assumptions and methodologies within LCA studies of BEVs (e.g., taking into account large-scale production, extending battery lifetime, considering changes to electricity mix over the vehicle life) presents significant emission reduction potential.

Figure 6.3.3-2. GHG Emissions and Energy Consumption of Electric Vehicle Lithium-Ion Battery Production (per kilogram of battery)



Source: Nealer and Hendrickson 2015

GHG = greenhouse gas; MJ/kg = megajoule per kilogram; kg $CO_{2(eq)}$/kg = kilograms of carbon dioxide equivalent per kilogram; LIB = lithium-ion battery; NMC = lithium nickel manganese cobalt oxide; LMO = lithium manganese oxide; LFP = lithium iron phosphate

Beyond GHG emissions and energy consumption, the production of lithium-ion batteries from virgin materials can have adverse environmental impacts locally. Pollution of local resources can occur in the mining and processing stages of material development for battery cathodes and other components (Dunn et al. 2015; Congressional Research Service 2020). One study found that in comparison to ICE vehicles, the life cycle of BEVs, on average, could result in around 15 and 273 percent more particulate matter and sulfur dioxide emissions, respectively, primarily due to battery production and the electricity generation source used to charge the batteries (Congressional Research Service 2020).

NMC used in batteries currently dominate the U.S. and global automotive markets and are anticipated to continue to hold a large share in the foreseeable future (Kelly et al. 2020). One recent study found that in an MNC-dominated battery scenario,[30] the demand for the raw materials by 2050 will require significant expansion of existing supply chains in addition to potentially a need for additional resource exploration and/or mining. For instance, the global demand for lithium is anticipated to increase by 18 to 20 times, for cobalt by 17 to 19 times, for nickel by 28 to 31 times (Xu et al. 2020). Meeting the rising demand for these raw materials will require increased mining activities in relatively dry areas globally (Sakunai et al. 2021).

Lead-acid batteries (LABs) in ICE vehicles have negligible GHG emissions relative to the rest of the vehicle's life cycle (Hawkins et al. 2012). 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 2020).

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 lithium-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 lithium-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 2013d; Hendrickson et al. 2015). The recent literature review of 50 LCA studies on lithium-ion batteries for EVs found that recycling can reduce the life-cycle of GHG emissions by anywhere from 5 to 29 kilograms (11 to 63.9 pounds) of CO_2e per kWh with a median of 20 kilograms (44.1 pounds) of CO_2e per kWh (Aichberger et al. 2020).

LCAs of lithium-ion battery recycling have focused on three recycling technologies: pyrometallurgy, hydrometallurgy, and physical processes (Dunn et al. 2012; EPA 2013d; Hendrickson et al. 2015; Zwolinski and Tichkiewitch 2019; Xu et al. 2020). Pyrometallurgy uses a combination of smelting followed by leaching to recover slag and valuable metals. Yu et al. (2020) found that remanufacturing an NMC battery using the pyrometallurgical method could result in a nearly 5 percent reduction in GHG emissions. Hydrometallurgy uses chemical leaching, capable of recovering valuable metals and lithium. Closed-loop recycling can be set up with an initial pyrometallurgical followed by hydrometallurgical processing to convert the alloy into metal salts (Xu et al. 2020). With closed-loop recycling, the percentage of battery material demand that can be met with secondary material from battery recycling may reach anywhere between 20 and 70 percent during the 2040 to 2050 period, depending on the anticipated prevalent technology types (Xu et al. 2020). Sakunai et al. (2021) found that using the

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[30] The study assumes a global fleet penetration of EVs by 2050 of 50 percent in the Sustainable Development scenario.

closed-loop recycling method, GHG emissions and water consumption can be reduced by 4.5 and 13 percent, respectively, in nickel-supplying countries such as Indonesia.

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). Increasing lithium-ion battery recycling with pyrometallurgy could have adverse air pollution and human health impacts, depending on the location and implementation of the recycling technology (Hendrickson et al. 2015). A fourth alternative is direct recycling, which aims at maintaining chemical structures in the process of recovering the cathode materials. Direct recycling has the potential to be advantageous over other methods, both economically and environmentally; however, it is still in the early stages of development (Harper et al. 2019).

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 from second life uses of EVs, 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).

To the extent that future light-duty vehicle fleets include greater shares of EVs with lithium-ion batteries, such as those projected by the CAFE Model under some of the action alternatives (Table 6.3.3-1), a greater share of lithium-ion EVs would result in overall reduced life-cycle GHG impacts across the United States. For PHEVs and dedicated EVs, the impact would be more substantial in regions where the grid mixes are less carbon intensive; the grid mix would not affect the use phase for strong hybrid EVs because those vehicles are not plugged in and do not depend on electricity and charging stations for power. See Section 3.3 of NHTSA's TSD for detailed descriptions of the EV technologies included in the CAFE Model. The implications of the lithium-ion battery LCA considerations discussed in this section are more relevant for the action alternatives that reflect more stringent CAFE standards for which the CAFE Model projects a greater penetration of vehicle technologies involving lithium-ion batteries—reaching approximately 20 and 25 percent, respectively, in Alternatives 2 and 3 in MY 2029, as shown in Table 6.3.3-1.

Table 6.3.3-1. Technology Penetration Rates for Model Year 2029 for Vehicles Using Batteries

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Strong Hybrid EVs	**4.9%**	**6.8%**	**8.2%**	**9.7%**
SHEVP2: P2 Strong Hybrid/Electric Vehicle	0.7%	2.8%	2.8%	3.9%
SHEVPS: Power Split Strong Hybrid/Electric Vehicle	2.6%	2.0%	2.1%	1.8%
P2HCR1: Special P2 Strong Hybrid/Electric Vehicle with HCR1 Engine	1.7%	2.0%	3.2%	3.9%
PHEVs	**0.12%**	**0.32%**	**0.33%**	**0.73%**
PHEV20: 20-mile PHEV with HCR Engine	0.07%	0.26%	0.26%	0.53%
PHEV20T: 20-mile PHEV with Turbo Engine	0.05%	0.06%	0.06%	0.11%
PHEV20H: Special 20-mile PHEV with HCR Engine	0%	0%	0.01%	0.10%

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Dedicated EVs	**6.0%**	**7.7%**	**11%**	**14%**
BEV200: 200-mile EV	3.0%	3.6%	3.8%	3.9%
BEV300: 300-mile EV	2.7%	3.8%	7.0%	9.9%
BEV400: 400-mile EV	0.3%	0.3%	0.3%	0.3%
Total for Strong Hybrid EVs, PHEVs, and Dedicated EVs	11%	15%	20%	25%

For BEV200, BEV300, and BEV400, the number refers to the EV's mileage driving range.
PHEV = plug-in hybrid electric vehicle; EV = electric vehicle; BEV = battery electric vehicle

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, lithium-ion, fuel cell) where a cathode discharges energy to supply power. VRFBs are attractive for EV applications 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; Singh et al. 2021). 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 grams (0.63 to 0.74 ounce) CO_2e per kWh of electricity produced, depending on the number of wind turbines used. The overall energy storage system emissions ranged from 92 to 437 grams (3.25 to 15.41 ounces) CO_2e per 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 grams (0.88 to 1.94 ounces) CO_2e per kWh of surplus energy stored, varying by country (Sternberg and Bardow 2015). A more recent study indicated that the application of a novel three-dimensional detached serpentine flow field (i.e., a design offering continuous flow of a fluid in a fuel cell) can result in increases of approximately 4.2 and 3.2 percent in the voltage and energy efficiencies of VRFB cells, respectively (Sun et al. 2019).

6.3.5 Tires

Tires affect vehicle fuel economy through rolling resistance. Rolling resistance is the force that resists the movement of the tire. To overcome this resistance, the vehicle's engine converts the chemical energy in the fuel into mechanical energy, which is transmitted through the drivetrain to turn the wheels. 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; Trupia et al. 2017). EVs use far more of their energy input to power the wheels and to overcome rolling resistance than do gasoline ICE vehicles and hybrids, as shown in Table 6.3.5-1 (National Academies of Sciences, Engineering, and Medicine 2021). Another study estimates the energy loss for EVs due to rolling resistance at 25 to 35 percent (Gao et al. 2019). Across all light-duty vehicle types, some tests have shown that a 50 percent reduction in rolling resistance results in a 5 to 10 percent (National Academies of Sciences, Engineering, and Medicine 2021) to 15 percent reduction in fuel consumption (Świeczko-Żurek et al. 2017). Rolling resistance in large vehicles can account for nearly one third of fuel costs (Cannon 2019). Rolling resistance is also greatly affected by the physical design of tires, road conditions, and tire air pressure; an underinflated tire can consume over 10 percent more fuel due to increased rolling resistance than a tire inflated to the manufacturer's recommended pressure (Synák and Kalašová 2020).

Table 6.3.5-1. Percent of Energy Input for Powering Wheels and Overcoming Rolling Resistance

Vehicle Type	Percent of vehicle energy input that powers the wheels	Percent of vehicle energy input used to overcome rolling resistance
ICE vehicles	16–25%	4–7%
Hybrid vehicles	24–38%	6–11%
EVs	77–82%	22–23%

Source: National Academies of Science, Engineering, and Medicine 2021
ICE = internal combustion engine; EV = electric vehicle

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 2013a) 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 2013a). 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 2012a). 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, nitrogen oxides, 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).

EVs are thought to wear out tires faster than ICE vehicles because EVs have more powerful torque and rapid acceleration, and because the heavy batteries in some EVs make them heavier than an analogous ICE vehicle (Gao et al. 2019). The Organization for Economic Cooperation and Development reported that although lightweight EVs emit 11 to 13 percent less harmful particulate matter than ICE vehicles in the same vehicle class, heavier EVs with larger battery packs emit 3 to 8 percent more harmful particulate matter than equivalent ICE vehicles (Organisation for Economic Co-operation and Development 2020). Greater particulate matter emissions are a result of faster degradation of the wheel surface that can occur with higher torque or heavier vehicles, as well as those equipped with tires with higher rolling resistance. Tire companies are developing new designs specifically for EV tires that reduce rolling resistance as well as internal friction in order to accommodate the increased torque and weight of EVs (Tang et al. 2020). Early designs have reduced rolling resistance by nearly 20 percent compared to a conventional tire (Michelin North America 2021; The Goodyear Tire & Rubber Company 2018). The CAFE Model projects that 97 percent of the passenger car and light truck vehicle fleets will feature low-rolling-resistance tires (i.e., a 20 percent reduction in rolling resistance) in MY 2029 under all alternative scenarios. Because vehicles will be expending less energy to overcome rolling resistance and therefore consuming less fuel or electricity, if manufacturers elect to comply with CAFE standards by equipping new vehicles with low-rolling-resistance tires, this would translate into lower vehicle use GHG emissions.

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. These changes in environmental impacts are, therefore, proportional to the degree to which vehicle manufacturers use the various fuels, materials, and technologies in response to the alternatives under consideration. As discussed in Section 6.1, *Introduction*, NHTSA does not know how manufacturers will rely on the different technologies, materials, and fuel sources assessed in this chapter, and as a result, cannot quantitatively distinguish between alternatives.

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.

Table 6.4-1 presents a summary of the CAFE Model's projections of light-duty vehicle market penetration rates for different technologies discussed in this chapter that will contribute to lowering vehicle life-cycle GHG emissions, with the largest reductions in the use phase. The most stringent action alternative (Alternative 3) projects in MY 2029 twice as many strong hybrid EVs (i.e., 10 percent of the fleet vs. 5 percent under the No Action Alternative), about 2.5 times as many PHEVs and dedicated EVs (i.e., 15 percent of the fleet vs. 6 percent under the No Action Alternative), about 3.5 times the penetration of the highest level of mass reduction (i.e., 36 percent of the fleet vs. 10 percent under the No Action Alternative), and a similarly high level of low-rolling-resistance tires compared to the No Action Alternative (i.e., 97 percent for both). This suggests that the life-cycle GHG emissions benefit could roughly double for strong hybrid EVs, be about 2.5 times as high for PHEVs and dedicated EVs, and over 3.5 times as high for vehicles with a high level of mass reduction in MY 2029 across the range of action alternatives. For PHEVs and EVs, the emissions reduction benefit would be the most significant in the West, Northeast, and Alaska where the grid mixes include larger shares of hydropower, nuclear, natural gas, and renewables (Section 6.2.3.1, *Charging Location*). The mass reduction emissions reduction benefit could be met with the use of the technologies and materials discussed in this chapter.

Table 6.3.5-1. Summary of CAFE Model Technology Penetration Rates for Life-Cycle GHG Reducing Technologies in Model Year 2029 (Passenger Cars and Light Trucks)

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 3
Strong Hybrid EVs	5%	7%	8%	10%
PHEVs and Dedicated EVs	6%	8%	11%	15%
Mass Reduction, Level 4 (15% Reduction in Glider Weight)	10%	24%	33%	36%
Low-Rolling-Resistance Tires, Level 2 (20% Reduction)	97%	97%	97%	97%

EV = electric vehicle; PHEV = plug-in hybrid electric vehicle

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 3, *Energy*, 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 findings emerged from the LCA literature synthesis related to vehicle energy production and use:

- **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 unintentional seismic activity and increased water pollution.
- **Renewable energy.** Electricity will decline in carbon intensity as the share of renewable energy and natural gas in the electricity grid mix grow. For vehicles that run on grid electricity (PHEVs and BEVs), this will lower GHG emissions in the vehicle use phase. Emissions from the manufacturing and recycling of vehicle parts could also decline in locations using electric power with increasingly cleaner grid mixes.
- **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:

- **Lightweight materials.** Lightweight materials manufactured using aluminum, high-strength steel, plastics and composites, and magnesium require more energy to produce than similar conventional steel components, but offer overall life-cycle energy and emissions benefits through fuel efficiency improvements.
- **Weight-reducing technologies for vehicle manufacturing.** Weight-reducing manufacturing—such as hydroforming, laser welding, and aluminum casting—improves efficiencies in manufacturing and reduces overall vehicle weight, reducing impacts in the manufacturing and vehicle use phases.
- **Net environmental benefits of materials and technologies.** Upstream energy requirements for the manufacture of lightweight 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. Battery manufacture is an energy-intensive process; however, because BEVs have significantly lower vehicle use phase emissions, they have lower life-cycle emissions than ICE vehicles. Studies show recent declines in life-cycle GHG emissions from BEVs and point to significant emission reduction potential. Recent research has focused on battery recycling technologies, as new processes are being developed to mitigate concerns over increasing solid waste flows and to address the growing demand for lithium and other raw materials.
- **Tires:** Although EVs and hybrid EVs offer overall life-cycle GHG and energy benefits, the heavy weight of the batteries they carry can contribute to additional wear and tear on tires and thereby shorten tire life-span. EVs also expend a large share of their energy input to overcome rolling resistance. New designs are underway to reduce these impacts.
- **Further LCA research.** Scientific understanding of aerodynamic features, low-rolling-resistance tires, and other technologies is still evolving. More research is needed to assess the upstream and downstream impacts 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*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies*. 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, *Historic 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 final standards.

In this SEIS, NHTSA has not analyzed some resource areas because the action alternatives would have negligible or no impact on these resource areas (i.e., endangered species and Section 4(f)) or because they are discussed in other documents that are available for public review (i.e., safety impacts on human health). These resource areas are as follows:

- **Endangered Species Act (ESA).** NHTSA has concluded that consultation pursuant to Section 7(a)(2) of the ESA[1] is not required for this action. The agency's discussion of its responsibilities under the ESA are addressed in the preamble to the proposed rule in Section IX.D.6.
- **Section 4(f) Resources.** Section 4(f) (49 U.S.C. § 303/23 U.S.C. § 138) 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) resources, a Section 4(f) evaluation has not been prepared.
- **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 standards, NHTSA analyzed impacts from mass reduction, fleet turnover, and the rebound effect. NHTSA used statistical analyses of historical crash data and a fleet simulation study using 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 both the preamble to the proposed rule in Section III.H.3 and Chapter 5.3 of the Preliminary Regulatory Impact Analysis (PRIA).

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[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. This section focuses on the greatest sources of environmental impacts from land use and development that could result from NHTSA's Proposed Action. Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies*, also examines life-cycle environmental impacts related to electric vehicle (EV) and battery manufacturing, changes in which could also affect land use and development.

7.1.2 Environmental Consequences

Shifts toward more efficient, lighter vehicles, either because of general market trends, 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 Alternative 3 is the most stringent of the alternatives, it is likely that more lighter-weight materials would be used under this alternative, potentially leading to new mining sites, as discussed. Because the Proposed Action and alternatives are more stringent than the No Action Alternative, shifts toward lighter vehicles and the associated new mining activities seem likely under these alternatives.

Manufacturers could also incorporate a number of technologies for complying with more stringent standards, such as electrification. Electrification technologies may include 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). There could be additional land use impacts from these technologies due to mineral extraction for the batteries associated with electrification. See Section 6.2.3, *Electricity*, for a discussion of the environmental impacts associated with vehicle electrification, and Section 6.3.3, *Vehicle Batteries*, for additional information on the production and end-of-life management of vehicle batteries.

Additionally, the development of a network of EV charging or hydrogen fueling stations is necessary for the adoption of these vehicle types. Land use associated with charging points is estimated to be greater than the size of charging spaces and infrastructure alone; in addition to the charging point itself, dedicated parking spaces (10–15 per charging point) must be accessible and energy storage facilities may have to be installed to mitigate effects of high-demand charges such as from multiple simultaneous charges (Orsi 2021). However, impacts on land from development of networks of public charging points would be limited. Under a high-adoption scenario in which 40 percent of vehicles in the United States were battery electric vehicles, there would be an estimated 40 square miles of total land devoted to charging facilities (Orsi 2021).

The Proposed Action and alternatives are not anticipated to affect the production or use of biofuel technology in MY 2024–2026 light-duty vehicles in any predictable way. Depending on how manufacturers choose 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 (in 2020) caps the renewable fuel target at more than 20 billion gallons per year (EPA 2020n). 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 decreasing fuel costs per mile, higher fuel economy standards under the Proposed Action and alternatives could provide an incentive for increased driving, which could lead to higher VMT. In areas where the highway network, infrastructure availability, and housing market conditions allow, this could increase demand for low-density residential development beyond existing developed areas and decrease 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 2015). 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 and the rebound effect.

Under the Proposed Action and alternatives, fuel consumption is anticipated to decrease compared to the No Action Alternative, with decreases ranging from a total of 56 billion gasoline gallon equivalents (GGE) under Alternative 1 to 137 billion GGE under Alternative 3 from 2020 to 2050 (Chapter 3, *Energy*). This decrease in fuel consumption is likely to result in less oil extraction and refining. Because the decreased fuel consumption under the Proposed Action and alternatives represents a small percentage of total 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 Assessment Implications of Vehicle Energy, Materials, and Technologies*, also examines life-cycle environmental impacts of EV-related hazardous materials (e.g., lithium-ion batteries) and waste management practices. For hazardous waste impacts associated with EV-related hazardous materials, see Section 6.2.3, *Electricity*, 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 2017b).

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 2016a) and half of U.S. oil production (EIA 2016c). Oil supplies contained in low-permeability rocks, such as shale, can be accessed with hydraulic fracturing (EIA 2017d). 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 2017c).

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 2016b). A recent study analyzed the toxicity of certain chemicals in wastewater produced from hydraulic fracturing and found that, of 240 chemicals analyzed, 157 chemicals 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). The U.S. Geological Survey attributes induced earthquakes in the United States primarily to wastewater disposal, but attributes 2 percent of earthquakes in the state of Oklahoma to hydraulic fracturing operations and describes the largest earthquake known to be induced by hydraulic fracturing in the United States as a magnitude 4.0 earthquake in Texas in 2018 (USGS 2017, no date).

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 2000d; 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 2012d, 2016c).

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[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).

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 decrease in fuel production and combustion resulting from the Proposed Action and alternatives (Section 3.4, *Environmental Consequences*) could lead to a decrease 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 1995b). 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 1995b, 2017c). 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 1995b, 2003c). 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 2014b).[3] Spent sulfuric acid is by far the most commonly produced toxic substance; however, it is generally reclaimed rather than released or transferred for disposal (EPA 1995b). Because oil and gas extraction and refining are expected to decrease under the Proposed Action and alternatives, associated upstream emissions of volatile chemicals and other potentially dangerous substances are generally expected to decrease as well, compared to the No Action Alternative. The impact analysis in Chapter 4, *Air Quality*, includes emissions from extraction and refining. 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

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[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 2017d). 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 2017d). 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 2017d). 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 2017d).

freshwater ecosystems. Because the Proposed Action and alternatives have the potential to decrease overall petroleum extraction and refining levels due to increased fuel efficiency, the total number of hazardous material spills that result from extraction and refining may decrease 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 et al. 2013). The decrease in oil and gas extraction and refining that could occur under the Proposed Action and alternatives is also likely to result in an decrease 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 2012e, 2017d). Declines in the biodiversity of aquatic species and changes in terrestrial habitats have most likely had ripple effects on wildlife species that depend on these resources. Acid deposition contributes to the eutrophication of aquatic systems, which can ultimately result in the death of fish and aquatic animals (Lindberg 2007; EPA 2017d). The potential decrease in upstream fuel production and downstream fuel combustion resulting from the Proposed Action and alternatives could decrease pollutant emissions that cause acid deposition, compared to those emissions under the No Action Alternative. However, potential increases in electrical generation by fossil-fueled power plants due to EV charging could increase pollutant emissions that cause acid deposition, compared to those emissions under the No Action Alternative. In total, the Proposed Action and alternatives could increase or decrease pollutant emissions that cause acid deposition, depending on the action alternative and year, compared to those emissions under the No Action Alternative (Tables 4.2.1-1 and 4.2.1-3).

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 1995b). These solvents are used to clean metal and are used in the vehicle finishing process during assembly and painting (EPA 1995b). Between 2005 and 2015, quantities of chemical releases of these toxic substances used during motor vehicle manufacturing such as xylene, n-Butyl Alcohol, glycol ethers, and more have decreased substantially, with the exception of manganese and nickel (EPA 2020o). 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 (Occupational Safety and Health Administration 2016).

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) as a result of the implementation of the Proposed Action and alternatives. 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 Material Substitution,* and Section 6.3.2, *Vehicle Mass Reduction by Material Joining Techniques*, 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 final standards, including HEVs, electrified accessories, fully electric powertrains, 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, *Electricity*, 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 decrease in fuel production and consumption under the Proposed Action and alternatives could lead to a decrease 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 decreases in the associated environmental and health impacts from these substances. The Proposed Action and alternatives could also lead to the increased 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 EVs, this EIS does not quantify impacts related to waste produced during the refining process due to mass reduction or wastes associated with EV production and use. See Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies*, for a discussion of the environmental impacts associated with down-weighting and EV technologies.

7.3 Historic and Cultural Resources

7.3.1 Affected Environment

Section 106 of the National Historic Preservation Act of 1966[4] and its implementing regulations[5] require federal agencies to consider the effects of federally funded or approved undertakings having the potential to affect historic properties listed in or eligible for listing in the National Register of Historic Places (NRHP). Under Section 106, the lead federal agency must provide an opportunity for the State Historic Preservation Officer, affected Tribes, and other stakeholders to comment through a consultation process. The NRHP recognizes properties that are significant at the national, state, and local levels. According to NRHP guidelines, the quality of significance in American history, architecture, archaeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association, and that meet established significance criteria. A property may meet the NRHP significance criteria if it is associated with events that have made a significant contribution to the broad patterns of our history; is associated with the lives of persons significant in our past; embodies the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or yields, or may be likely to yield, information important in prehistory or history.

NHTSA addresses its obligations under the Section 106 process in Section IX.D.3 of the preamble to the proposed rule. The analysis in this section is intended to provide additional information in order to disclose impacts under NEPA.

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[4] 54 U.S.C. § 100101 et seq. (codified in 2014).

[5] 36 CFR Part 800.

7.3.2 Environmental Consequences

The corrosion of metals and the deterioration of paint and stone, as well as other historic materials, can be caused by both acid rain and the dry deposition of pollution (EPA 2017d). This damage can reduce the integrity of character-defining features that convey the significance of NRHP-listed or -eligible historic properties, such as buildings, statues, and cars, among others. Deposition of dry acidic compounds found in acid rain can also dirty historic buildings and structures, causing visual impacts and increased maintenance costs (EPA 2017d). 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 1995b).

The potential decrease in fuel production and combustion under the Proposed Action and alternatives could lead to a decrease in pollutant emissions that cause acid deposition compared to the No Action Alternative. A decrease in the emissions of such pollutants could result in a corresponding decrease in damage to historic properties caused by acid deposition. In terms of specific pollutant emissions, total SO_X emissions are anticipated to increase (except for Alternative 1 in 2035) under the Proposed Action and alternatives compared to the No Action Alternative, while total NO_X emissions would decrease slightly (except for all alternatives in 2025, and Alternative 3 in 2035) (Chapter 4, *Air Quality*, Table 4.2.1-3). Downstream (tailpipe) emissions of NO_X are projected to increase in 2025 and 2035, while tailpipe emissions of SO_X would decrease in 2025, 2035, and 2050. Upstream (refinery and power plant) emissions of NO_X are projected to decrease under Alternatives 1 and 2 but increase under Alternative 3 (except decrease under Alternative 3 in 2050). Upstream emissions of SO_X would increase, except under Alternative 1 in 2035 (Appendix A, *U.S. Passenger Car and Light Truck Results Reported Separately*, Tables A-2, A-3, A-4). This means that the impacts of the Proposed Action and alternatives would differ by location across the country. However, because NO_X and SO_X emissions that lead to 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 historic buildings and structures and the varying impact of a specific geographic location on any particular historic property (Striegel et al. 2003).

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. In 1981, EPA estimated that 19.3 million people in the United States were exposed to Day-Night Average Sound Levels (DNL) of 65 A-weighted decibels[6] (dBA) (EPA 1981). At DNL 65, approximately 14 percent of people exposed to this noise level would be highly annoyed (ANSI S12.9-2005/Part 4). Recent studies (Bureau of Transportation Statistics 2020) indicate that 6,367,715 people were exposed to 60 to 69 decibels (dBA, 24-hour equivalent sound level [L_{eq}]) of roadway noise. Even though the 24-hour L_{eq} and DNL metrics are slightly different from each other, this result shows that

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[6] A-weighted decibels, commonly used to describe environmental noise, express the relative loudness of sound to the human ear.

roadway noise exposure has dramatically decreased since the 1980s. 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 dBA (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). However, typical ranges of highway noise levels are much lower than hearing conservation thresholds such as those promulgated by the Occupational Safety and Health Administration. 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).

7.4.2 Environmental Consequences

More stringent fuel efficiency standards could increase overall VMT due to the rebound effect, resulting in potential increases 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 barriers, and the location of schools, residences, and other sensitive noise receptors all influence whether there would be noise impacts. While a truly local analysis (i.e., at the individual roadway level) is impractical for a nationwide EIS, NHTSA believes the potential noise impacts described below would apply to roadways and sensitive locations in general.

The Proposed Action and alternatives could lead to an increase in use of hybrid and electric technologies, depending on the methods manufacturers use to meet the new requirements, economic demands from consumers and manufacturers, and technological developments. An increased percentage of hybrid technologies under the Proposed Action and alternatives could result in decreased road noise compared to the No Action Alternative. However, tire-road interaction noise typically dominates over engine noise at highway vehicle speeds. Consequently, the introduction of more hybrid and EVs could have different effects depending on residential locations adjacent to highways versus secondary roads. 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*,[7] 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). A White House Environmental Justice Interagency Council established under EO 14008, *Tackling the Climate Crisis at Home and Abroad*, is expected to advise CEQ on ways to update EO 12898, including the expansion of environmental justice advice and recommendations. The White House Environmental Justice Interagency Council will advise on increasing environmental justice monitoring and enforcement.

The 2021 DOT Order 5610.2(c), *U.S. Department of Transportation Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[8] describes the process for DOT agencies to incorporate environmental justice principles in programs, policies, and activities. The DOT's Environmental Justice Strategy specifies that environmental justice and fair treatment of all people means that no population be forced to bear a disproportionate burden due to transportation decisions, programs, and policies. 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 U.S. Department of Health and Human Services (HHS) poverty guidelines. Low-income and minority populations may live in geographic proximity or be geographically dispersed/transient. In 2021, DOT 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 2019b, 2021).

7.5.1 Affected Environment

The affected environment for environmental justice is nationwide, with a focus on areas that could contain minority and low-income 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

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[7] Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations, 59 FR 7629 (Feb. 16, 1994).

[8] Department of Transportation Updated Environmental Justice Order 5610.2(c), (May 14, 2021).

areas, and urban areas that are subject to the heat island effect.[9] As part of the literature review conducted for this analysis, NHTSA did not locate any studies that specifically assessed disproportionate impacts on communities located near power generation, distribution facilities, or mining sites for vehicle materials.

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; Williams et al. 2020). 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, 2018a). 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.

7.5.1.1 Proximity to Oil Production and Refining

Numerous studies have found that some environmental hazards are more prevalent in areas where minority and low-income populations represent a higher proportion of the population compared with the general population. For example, Mohai et al. 2009 found that survey respondents who were black and, to a lesser degree, had lower income levels, were significantly more likely to live within 1 mile of an industrial facility listed in the EPA's 1987 Toxic Release Inventory national database.

Ringquist 2005 conducted a meta-analysis of 49 environmental equity studies and concluded that evidence of race-based environmental inequities is statistically significant (although the average magnitude of these inequities is small), while evidence supporting the existence of income-based environmental inequities is substantially weaker. Considering poverty-based class effects, Ringquist 2005 found an inverse relationship between environmental risk and poverty, concluding that environmental risks are less likely to be located in areas of extreme poverty. However, individual studies may reach contradictory conclusions in relation to race- and income-based inequities across a range of environmental risks. Therefore, the meta-analysis also sought to examine the reasons why conclusions vary across studies of environmental inequity. Possible explanations for why studies reach contrary conclusions include variability in the source of potential environmental risk that the study considers (e.g., the type of facility or the associated level of pollution or risk); variability in the methodology applied to aggregate demographic data and to define the comparison population; and the degree to which statistical models control for other variables that may explain the distribution of potential environmental risk.

To test whether there are disparate impacts from hazardous industrial facilities on racial/ethnic minorities, the disadvantaged, the working class, and manufacturing workers, Sicotte and Swanson (2007) tested the relationship between hazard scores of Philadelphia-area facilities in EPA's Risk-Screening Environmental Indicators database and the demographics of populations near those facilities using multivariate regression. This study concludes that racial/ethnic minorities, the most

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[9] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas. See Section 8.6.5.2, *Sectoral Impacts of Climate Change*, under *Urban Areas*, for further discussion of the heat island effect.

socioeconomically disadvantaged, and those employed in manufacturing suffer a disparate impact from the highest-hazard facilities (primarily manufacturing plants).

Other commissioned reports and case studies (UCC 2007; NAACP and CATF 2017; Ash et al. 2009; Kay and Katz 2012) provide additional evidence of the presence of low-income and minority populations near industrial facilities and of racial or socioeconomic disparities in exposure to environmental risk, although these sources were not published in peer-reviewed scientific journals.

Few studies address disproportionate exposure to environmental risk associated with oil refineries specifically. O'Rourke and Connolly 2003 find the populations surrounding oil refineries are more often minorities, finding "56 percent of people living within three miles of [oil] refineries in the United States are minorities – almost double the national average." Graham et al. 1999 examined whether findings of environmental inequity varied between coke production plants and oil refineries, both of which are significant sources of air pollution. This study concluded that census tracts near coke plants had a disproportionate share of poor and nonwhite residents, and that existing inequities were primarily economic in nature. However, the findings for oil refineries did not strongly support an environmental inequity hypothesis. A more recent study of environmental justice in the oil refinery industry (Carpenter and Wagner 2019) found evidence of environmental injustice as a result of unemployment levels in areas around refineries and, to a slightly lesser extent, as a result of income inequality. This study did not test for race-based environmental inequities.

Overall, the body of scientific literature points to disproportionate representation of minority and low-income populations in proximity to a range of industrial, manufacturing, and hazardous waste facilities that are stationary sources of air pollution, although results of individual studies may vary. While the scientific literature specific to oil refineries is limited, disproportionate exposure of minority and low-income populations to air pollution from oil refineries is suggested by other broader studies of racial and socioeconomic disparities in proximity to industrial facilities generally.

7.5.1.2 Proximity to High-Traffic Roadways and Air Pollution

Studies have consistently demonstrated a disproportionate prevalence of minority and low-income populations that are living near mobile sources of pollutants and therefore are exposed to higher concentrations of criteria air pollutants in multiple locations across the United States (Hajat et al. 2013). 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, 2011). In California, studies demonstrate that minorities and low-income populations are disproportionately likely to live near a major roadway or in areas of high traffic density compared to the general population (Carlson 2018; Gunier et al. 2003), and on average African American, Latino, and Asian Californians are exposed to more particulate matter 2.5 microns or less in diameter (PM2.5) pollution from vehicles than white Californians (Reichmuth 2019). A study of traffic, air pollution, and socio-economic status inside and outside the Minneapolis-St. Paul metropolitan area similarly found that populations on the lower end of the socioeconomic spectrum and minorities are disproportionately exposed to traffic and air pollution and at higher risk for adverse health outcomes (Pratt et al. 2015). Near-road exposure to vehicle emissions can cause or exacerbate health conditions such as asthma (Carlson 2018; Gunier et al. 2003; Meng et al. 2008; Khreis et al. 2017). Kweon et al. (2016) demonstrate that students at schools in Michigan closer to major highways had a higher risk of respiratory and neurological disease and were more likely to fail to meet state educational standards, after controlling for other variables. In general, studies such as these demonstrate trends in specific locations in the United States that may be indicative of broader national trends.

Studies at the national level also demonstrate a correlation between minority and low-income 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[10] children were disproportionately located within 250 meters (273 yards) of a major roadway.

In analyzing the 2009 American Housing Survey (AHS), the focus was on whether or not a housing unit was located within 300 feet of a “4-or-more lane highway, railroad, or airport.”[11] The study analyzed whether there were differences between households in such locations in comparison to those in locations more than 300 feet from where these transportation facilities (Bailey 2011). The study also looked at other variables, such as land use category, region of country, and housing type. Homes with a nonwhite householder were found to be 22 to 34 percent more likely to be located within 300 feet of these large transportation facilities than homes with white householders. Homes with a Hispanic householder were 17 to 33 percent more likely to be located within 300 feet of these large transportation facilities than homes with non-Hispanic householders. Households near large transportation facilities were, on average, lower in income and educational attainment, more likely to be a rental property, and more likely to be located in an urban area compared with households more distant from transportation facilities.

In examining schools near major roadways, the Common Core of Data from the U.S. Department of Education, which includes information on all public elementary and secondary schools and school districts nationwide, was examined.[12] To determine school proximities to major roadways, a geographic information system (GIS) to map each school and roadways based on the U.S. Census’s TIGER roadway file was used (Pedde and Bailey 2011). Minority students were found to be overrepresented at schools within 200 meters of the largest roadways, and schools within 200 meters of the largest roadways also had higher-than-expected numbers of students eligible for free or reduced-price lunches. For example, Black students represent 22 percent of students at schools located within 200 meters of a primary road, whereas Black students represent 17 percent of students in all U.S. schools. Hispanic students represent 30 percent of students at schools located within 200 meters of a primary road, whereas Hispanic students represent 22 percent of students in all U.S. schools. Overall, there is substantial evidence that the population who lives or attends school near major roadways are more likely to be minority or low income.

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[10] 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.

[11] This variable primarily represents roadway proximity. According to the Central Intelligence Agency’s World Factbook, in 2010, the United States had 6,506,204 km of roadways, 224,792 km of railways, and 15,079 airports. Highways, thus, represent the overwhelming majority of transportation facilities described by this factor in the AHS.

[12] http://nces.ed.gov/ccd/.

7.5.1.3 Disproportionate Health Effects of Air Pollution

Lower-positioned socioeconomic groups are differentially exposed to air pollution and differentially vulnerable to effects of exposure (O’Neill et al. 2003; Nardone et al. 2018a). Studies show that in multiple California cities, historically redlined census tracts (residential areas systematically graded as hazardous for foreclosure risk according to race) in California are associated with high particle emissions and asthma rates (Nardone et al. 2020). Nationwide, studies conducted between 2013 and 2017 show racial disparities in asthma risk, due in part to air pollution exposure (Nardone et al. 2018b).

Reports from HHS show 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 health care quality (HHS 2003, 2013, 2017). Other studies show that low socioeconomic position can modify the health effects of air pollution, with higher effects observed in groups with lower socioeconomic position (O’Neill et al. 2003; Finkelstein et al. 2003).

7.5.1.4 Distributed Benefits of Electric Vehicles

EV adoption is increasing and the proposed rule may reinforce that trend. EVs provide a range of benefits, some of which are realized by the owner of the vehicle, such as maintenance and fuel savings, and others—environmental, health, and economic development benefits—which are realized by broader society. Studies show that benefits are not equally distributed among society.

Realization of participant benefits by vehicle owners depends on market access, including air quality benefits to low-income communities living close to air pollution hotspots such as freeways (Muehlegger and Rapson 2018). Muehlegger and Rapson (2018) found that price discrimination and market access are not limiting new EV adoption among low-income consumers and minority ethnic groups. However, a 2020 Consumer Reports analysis shows that EVs typically have a higher purchase price over gasoline-powered vehicles (Consumer Reports 2020). These higher upfront costs are typically offset by savings over the life of the vehicle, saving the typical driver between $6,000 and $10,000 over the life of the vehicle in comparison to comparable gasoline-powered vehicles, but higher upfront costs can present a barrier to market entry for lower-income populations. Increasingly, incentives programs are targeted at low-income individuals and there are new state and national goals to reduce internal combustion engines; resulting uptake of EV could further improve prospects for realization of participant benefits to low-income, disadvantaged groups (Muehlegger and Rapson 2018).

Ability to charge an EV at home or work is another important differential socioeconomic factor related to EV access and ownership. While the charging network is expanding nationwide, access to charging at multifamily residential complexes can be challenging or limited due to owner-renter billing dynamics, electrical service access, and shared parking (DOE 2021a).

Environmental benefits from EV adoption can be quantified in terms of air pollution damages from driving EVs which range from -$0.30 to $0.81 per person (Holland et al. 2019). The distribution of benefits realized by sub-populations vary by demographic patterns across county and census block groups, patterns of pollutant dispersal, location of vehicle use, and location of power sources used for EV charging. In comparison to gasoline-powered vehicles, benefits from EV are significantly more equitably distributed across a wider range of individuals.

However, environmental benefits tend to decrease with income (Holland et al. 2019). Holland et al. (2019) define environmental benefits as “the differences in air pollution damages between driving an electric vehicle and driving the foregone gasoline vehicle." While individuals earning an annual household income of more than $65,000 receive positive environmental benefits from EV adoption, individuals with an income below this threshold do not receive the value of environmental benefits. Benefits from changing from a gasoline vehicle to an EV are realized above the $65,000 threshold because the pollution damages associated with driving gasoline vehicles are higher among higher-income populations, resulting in a positive net benefit when comparing against the relatively equitable EV pollution damages. Benefits from EV adoption are highest in dense urban areas and where the grid is not primarily coal powered, but in these areas, families with higher incomes are more likely to benefit. Benefits are higher in dense urban areas because pollution damages from gasoline vehicles are higher in dense urban areas; they stand to gain more from EV adoption. Furthermore, on average, Holland et al. show that economic pollution damages—i.e., benefits—from EV adoption are realized for Asian and Hispanic populations, but not for white and Black populations because Hispanic and Asian populations are more dense in the West and EVs are generally more environmentally beneficial in the West where penetration of EVs is higher.

Another study sought to monetize health benefits, showing that driving an EV over the course of 10 years results in an estimated value of $1,686 (Malmgren 2016). It is not clear how these benefits are distributed across society, but access to ownership will play a key role in realizing these participant-level benefits. Given that low-income and non-white populations are disproportionately exposed to traffic density (Rowangould 2013), and thus, some types of air pollution, these benefits may be greater among those populations.

EV adoption may result in job losses in the oil industry (Malmgren 2016). However, jobs may be created in the auto industry for manufacturing, research and development, installation, and maintenance of supply equipment. It is not clear how job creation versus job loss will affect disadvantaged communities.

7.5.1.5 Differential Vulnerabilities to Climate Change

Climate change is disproportionately affecting people and communities (GCRP 2018a). Across all climate risks, low-income communities, some communities of color, and those facing discrimination are disproportionately affected by climate events (Roth 2018).

Communities overburdened by poor environmental quality experience increased climate risk due to a combination of sensitivity and exposure (GCRP 2014, 2018a). Urban populations experiencing inequities and health issues have greater susceptibility to climate change (GCRP 2018a). Some communities of color facing cumulative exposure to multiple pollutants also live in areas prone to climate risk (GCRP 2018a).

Urban areas are also subject to the most substantial temperature increases because of the compounding effects of climate change and the urban heat island effect (Knowlton et al. 2011; GCRP 2018a; EPA 2018d). 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; Harlan and Ruddell 2011; GCRP 2014).

Indigenous people in the United States face increased health disparities, such as high rates of diabetes, that cause increased sensitivity to extreme heat and air pollution (GCRP 2018a). See Section 8.6.5.2, *Sectoral Impacts of Climate Change*, under *Human Health* and *Human Security*, for additional discussion of health and societal impacts of climate change on indigenous communities.

Together, this information indicates that climate impacts such as increasing temperatures disproportionately affect minority and low-income populations because of socioeconomic circumstances, histories of discrimination, and inequity. Furthermore, high temperatures can exacerbate poor air quality, further compounding the risk to overburdened communities. Finally, health-related sensitivities in low-income and minority populations increase risk of damaging impacts from poor air quality under climate change underscoring the potential benefits of improving air quality to communities overburdened by poor environmental quality.

7.5.2 Environmental Consequences

The potential decrease in fuel production and consumption projected as a result of the Proposed Action and alternatives compared to the No Action Alternative could lead to a decrease in upstream emissions of criteria and toxic air pollutants due to reduced extraction, refining, and transportation of fuel. As shown in Table 4.2.1-2 and Table 4.2.2-2, total upstream emissions of CO, NO_X, and PM2.5 in 2035 are projected to decrease under Alternatives 1 and 2 but increase under Alternative 3, compared to the No Action Alternative. Upstream emissions of sulfur dioxide (SO_2) in 2035 are projected to decrease under Alternative 1 but increase under Alternatives 2 and 3, compared to the No Action Alternative. Upstream emissions of VOC in 2035 are projected to decrease under all action alternatives compared to the No Action Alternative. Upstream emissions of toxic air pollutants in 2035 are projected to decrease 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 emissions of the Proposed Action and alternatives. As noted, a correlation between proximity to oil refineries and the prevalence of minority and low-income populations is suggested in the scientific literature. However, the magnitude of the change in emissions relative to the baseline is 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, total downstream (tailpipe) emissions of CO in 2035 are projected to increase under Alternative 1 but decrease under Alternatives 2 and 3, compared to the No Action Alternative. Tailpipe emissions of NO_X and VOC in 2035 are projected to increase under all action alternatives compared to the No Action Alternative. Tailpipe emissions of PM2.5 and SO_2 in 2035 are projected to decrease under all action alternatives compared to the No Action Alternative (except increase slightly for PM2.5 under Alternative 1). Tailpipe emissions of acetaldehyde, benzene, diesel particulate matter, and formaldehyde in 2035 are projected to increase under all action alternatives compared to the No Action Alternative. Tailpipe emissions of acrolein and 1,3-butadiene in 2035 are projected to increase under Alternative 1 but decrease under Alternatives 2 and 3 compared to the No Action Alternative. To the extent that minority and low-income populations disproportionately live or attend schools near major roadways, these populations may be more likely to be adversely affected by the Proposed Action and alternatives. However, the change in the level of exposure would be small in comparison to the existing conditions in these areas.

As discussed in Chapter 4, *Air Quality* and Chapter 9, *Mitigation*, differences in air quality parameters 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 VMT from the rebound effect. Other CAFE Model inputs and assumptions, which are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and at length in the proposed rule preamble, Technical Support Document, and PRIA issued concurrently with this Draft SEIS, including the rate at which new vehicles are sold, will also affect these estimates. However, as discussed in Chapter 4, *Air Quality*, these impacts are small in relation to total criteria emissions impacts during this period.

As also reported in Chapter 4, *Air Quality*, projected changes in both upstream and downstream emissions of criteria and toxic air pollutants are mixed with emissions of some pollutants remaining constant or increasing and emissions of some pollutants decreasing. These increases are associated with both upstream and downstream sources and, therefore, may disproportionately affect minority and low-income populations that reside in proximity to these sources. However, the magnitude of the change in emissions relative to the No Action Alternative is minor and would not be characterized as high and adverse.

As described in Chapter 5*, Greenhouse Gas Emissions and Climate Change*, the Proposed Action and alternatives are projected to decrease carbon dioxide (CO_2) emissions from passenger cars and light trucks by 5 to 10 percent by 2100, 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 minor rather than high and adverse. Compared to the annual U.S. CO_2 emissions of 7,193 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) from all sources by the end of the century projected by the Global Climate Change Assessment Model (GCAM) Reference scenario (Thomson et al. 2011), the Proposed Action and alternatives are projected to reduce annual U.S. CO_2 emissions by 0.8 to 1.6 percent in 2100. Compared to annual global CO_2 emissions, the Proposed Action and alternatives would represent an even smaller percentage increase and ultimately, by 2100, are projected to result in percentage decreases in global mean surface temperature, atmospheric CO_2 concentrations, and sea level, and increases in ocean pH, ranging from less than 0.01 percent to 0.10 percent (Table 5.4.2-2). Any impacts of this rulemaking on low-income and minority communities would be attenuated by a lengthy causal chain; but if one could attempt to draw those links, the changes to climate values would be very small and incremental compared to the expected changes associated with the emissions trajectories in the GCAM Reference scenario.

Adverse health impacts are projected to decrease nationwide under each of the action alternatives (except Alternatives 2 and 3 in 2025, which show increases for some impact metrics) compared to the No Action Alternative (Table 4.2.3-1). The increases in 2025 would be primarily the result of increases in emissions of NO_X, PM2.5, and SO_2. The projected decreases in adverse health impacts in 2035 under the action alternatives compared to the No Action Alternative would range from 1.3 percent (under Alternative 1) to 2.2 percent (under Alternative 3).

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 rulemaking would set standards nationwide, and although minority and low-income populations may experience some disproportionate effects or face inequities in receiving some benefits, 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 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

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[1] 40 CFR § 1508.8(a) (2019).

[2] 40 CFR § 1508.8(b) (2019).

[3] 40 CFR § 1508.7 (2019).

reasonable ability of NHTSA to model or describe fuel consumption and emissions for the light-duty vehicle sector.

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 SEIS. 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 2021 Annual Energy Outlook (AEO), which includes assumptions and projections relating to fuel prices. The CAFE Model also uses "upstream" process emission factors generated by Argonne National Laboratory's Greenhouse Gases, Emissions, and Energy Use in Transportation (GREET) model, which incorporates U.S. air pollutant emissions regulations applicable to upstream processes, as well as tailpipe emission factors generated using the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) model, which reflects U.S. regulations impacting vehicular emissions of criteria pollutants. 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 (EVs) 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 (2021 through 2100) that could contribute to global GHG emissions and climate change. Instead, examples of some known actions that contribute to the underlying emissions scenario provide a national and an international perspective.

8.3 Energy

8.3.1 Scope of Analysis

The timeframe for this cumulative energy impact analysis extends from 2020 through 2050, and the geographic area 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*. In addition, this analysis of cumulative energy impacts builds on the discussion of the life-cycle impacts of EVs presented in Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies*.

8.3.2 Analysis Methods

NHTSA's EIS for the MY 2017–2025 CAFE standards, 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 SEIS, improvements by manufacturers, including over-compliance with CAFE standards and ongoing fuel economy improvements, are incorporated in the CAFE Model outputs and are included in Chapter 3, *Energy*.

For this SEIS, NHTSA has taken a fresh look at its analytical approach regarding the cumulative impacts of the Proposed Action and alternatives on energy. NHTSA models different scenarios involving different fuel consumption rates that will have an effect on future energy production and use in the CAFE Model, and the results of this analysis are presented in Chapters 4.6 and 6.6.2 of the Preliminary Regulatory Impact Analysis (PRIA) issued with the proposed rule. This section focuses on market trends related to EVs and future driving demand, which may provide additional insights about the future and could affect energy use beyond the impacts identified in Chapter 3, *Energy* and Chapter 6, *Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies*.

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 domestic and global policies and market trends that may affect U.S. energy production and use.

In the near term, market trends following the COVID-19 pandemic and domestic policies responding to a more fuel-efficient fleet, like vehicle miles traveled (VMT) taxes, may affect passenger travel and energy use. In addition, recent policies on oil and gas exploration may lower GHG emissions associated with light-duty vehicle gasoline and diesel use; however, gasoline and diesel fuels are still estimated to represent 97 percent of light-duty vehicle fuel consumption in 2050. On the other hand, global EV market trends may influence U.S. light-duty vehicle fuel consumption by lowering the cost of EVs and EV batteries over time, which could increase the market share for EVs in the United States beyond what is currently accounted for in the CAFE Model's technology cost and learning rate estimates. Similarly, as EVs become more popular, technological advancements are expected to make EVs even more efficient compared to internal combustion engine (ICE) vehicles. As consumers adopt more EVs, concurrent changes in the grid mix used to charge those vehicles would also affect their total energy use.

Section 8.3.3.1, *Changes in Passenger Travel*, describes how a VMT tax and market trends could affect VMT and energy use. Section 8.3.3.2, *Oil and Gas Exploration*, describes Executive Orders (EOs) that may lower GHG emissions from oil and gas production. Section 8.3.3.3, *Global Electric Vehicle Market Projections*, explains how the global EV market trends may affect U.S. light-duty vehicle fuel consumption from 2020 through 2050, including how 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 8.3.3.4, *Electric Vehicle Fuel Economy*, describes how an increase in U.S. EV sales could have an impact on fuel use due to higher EV fuel economy at slower speeds in congested traffic. Finally, Section 8.3.3.5, *Changes in Electric Grid Mix*, describes how ongoing changes towards a cleaner grid mix would be used to power EVs.

8.3.3.1 Changes in Passenger Travel

Market trends following the COVID-19 pandemic and domestic policies responding to a more fuel-efficient fleet may affect passenger travel and energy use. Several states, including Oregon and Utah, have begun experimenting with a VMT tax, and several other states, federal legislators, and the Federal Highway Administration (FHWA) have expressed interest in the policy (Washington Post 2021). A VMT tax would supplement or replace revenue generated by fuel taxes, which states typically rely on to fund highway and road maintenance and would be assessed on the basis of individual drivers’ VMT. Replacing a fuel tax with a VMT tax would make travel more expensive for fuel-efficient vehicles and thus may reduce the expected VMT for such vehicles and result in purchasers buying relatively less fuel-efficient vehicles.

Additionally, there is some evidence indicating that passenger travel and commuting habits following the COVID-19 pandemic may result in national travel-related energy consumption reductions compared to pre-pandemic conditions. A study by KPMG predicted that COVID-19 could result in a long-term VMT reduction of 270 billion miles per year for light vehicles as commute- and shopping-related VMT habits change (KPMG 2020). Similarly, a Bureau of Transportation Statistics analysis predicts that passenger VMT will continue to lag behind 2019 levels by 3.3 percent in 2024, even after a projected COVID-19 recovery phase extending to the summer of 2022 (Polzin and Choi 2021). With economic and other inputs that have been updated in light of the COVID-19 pandemic, the current CAFE Model analysis shows the U.S. light-duty vehicle market quickly recovering to annual level of about 16–17 million units (varying over time and between regulatory alternatives), and shows light-duty vehicle VMT also quickly recovering and then slowly declining from about 3.5 trillion miles in 2040 to about 3.3 trillion miles by 2050 (also varying somewhat between regulatory alternatives).

8.3.3.2 Oil and Gas Exploration

Despite projected growth in EV sales, the AEO 2021 forecasts that gasoline and diesel will still represent 97 percent of light-duty vehicle fuel consumption in 2050. Section 6.2.1, *Diesel and Gasoline*, provides background on GHG emissions from the extraction, refining, supply, and combustion of gasoline and diesel from different types of petroleum supply. In particular, Section 6.2.1 shows that well-to-tank GHG emissions for gasoline and diesel from oil sands petroleum is more than twice as high as the U.S. average GHG emissions for all gasoline and diesel. EO 13990 revoked the Keystone XL Pipeline permit, which is expected to reduce U.S. use of oil sands petroleum. EO 13990 also directed EPA to consider proposing new regulations to establish comprehensive standards of performance and emission guidelines for methane and volatile organic compound emissions from existing operations in the oil and gas sector, including the exploration and production, transmission, processing, and storage segments. These actions will lower GHG emissions associated with light-duty vehicle gasoline and diesel use.

8.3.3.3 Global Electric Vehicle Market Projections

The International Energy Agency (IEA) Global EV Outlook 2021 (IEA 2021) reports that global plug-in electric vehicle (PEV) sales—including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—increased by 41 percent in 2020, despite a decline in total world light-duty vehicle sales. Almost 3 million PEVs were sold in 2020, accounting for 4.6 percent of all light-duty vehicle sales. The global PEV stock reached 10 million, up 43 percent over 2019, and now accounts for 1 percent of the world light-duty vehicle stock. BEVs accounted for two-thirds of new PEV sales and two-thirds of the PEV stock in 2020. The IEA notes that increasing PEV sales in 2020 were supported by pre-pandemic regulations (e.g., carbon dioxide [CO_2] standards),[4] additional PEV incentives enacted during the economic downturn, an increasing number of EV models for sale, and continuing declines in battery costs.

In its baseline forecast, the IEA 2021 expects that global PEV sales will reach almost 15 million in 2025 and surpass 25 million vehicles in 2030, accounting for 10 percent of global light-duty vehicle sales in 2025 and 15 percent in 2030. In this baseline forecast, the PEV share of light-duty vehicle sales in 2030 is expected to reach 35 percent in China, 40 percent in Europe, and 15 percent in the United States (IEA 2021). One major uncertainty associated with PEV forecasts is when the cost of PEVs will be competitive with ICE vehicles (without PEV subsidies). The discussion of battery cost learning curves in Chapter 3.3.5 of NHTSA's Technical Support Document (TSD) provides additional discussion that readers may consult on this issue.

While most PEV charging is done at home and at work, the IEA also reports progress in expanding the number of publicly accessible EV charging stations. Publicly accessible chargers reached 1.3 million units in 2020, of which 30 percent are fast chargers. The number of public chargers increased by 45 percent in 2020 after increasing by 85 percent in 2019. The availability of publicly accessible EV charging stations may have additional impacts on EV market share.

8.3.3.4 Electric Vehicle Fuel Economy

In addition to increasing overall light-duty vehicle fuel economy due to the higher miles-per-gallon equivalent (MPGe) for PEVs, 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, hybrid electric vehicles (HEVs) achieve better highway miles per gallon (mpg) than ICEs, and BEVs achieve much higher highway MPGe. The gap in city mpg is especially high when comparing an EV to an ICE vehicle because regenerative braking recharges batteries during the frequent stops associated with city driving. 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 vehicle mpg falls anywhere from 10 to 60 percent at speeds below 20 mph, which means that EPA city mpg ratings[5] may overstate mpg for ICE vehicles used by drivers with daily commutes in congested stop-and-go traffic (Davis and Boundy 2021).

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[4] In Europe, for example, the 2020 surge in PEV sales was associated with stringent new 2020 EUCO_2 emissions standards and with many European governments increasing subsidies for PEVs as part of economic stimulus efforts.

[5] The EPA city drive cycle test is one component of the EPA fuel economy ratings.

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. Data from FHWA shows that metro areas with the worst commuter traffic congestion (highest TTIs) have a much higher concentration of EV registrations per 1,000 population (FHWA 2017).

8.3.3.5 Changes in Electric Grid Mix

Forecast growth in EV sales through 2050 will coincide with ongoing changes in electricity generation used to power EVs. These changes include increased generation efficiency and an increasing share of electricity from renewable power sources, resulting in a cleaner grid mix.

The efficiency of electric power plants is often measured by *heat rate*, which is the amount of energy (British thermal units [Btu]) used to generate one kilowatt-hour (kWh) of electricity. Power plants with lower heat rates are more efficient because they produce more electricity (kWh) per Btu of power generation source fuel.[6] From 2009 to 2019, the average operating heat rate for coal power plants increased from 10,414 to 10,551 Btu/kWh, as the average heat rate for natural gas power plants fell from 8,160 to 7,732 Btu/kWh.[7] One major factor in efficiency gains for natural gas power plants is the increasing share of gas-fired electricity produced by combined-cycle systems that are more efficient than simple-cycle systems (steam turbines, gas turbines, and ICEs). In 2015, combined-cycle plants operated at an average heat rate of 7,340 Btu/kWh, while simple-cycle generators operated at an average heat rate of 9,788 Btu/kWh.[8] Over time, as more combined-cycle units have been installed and older simple-cycle units are retired, the average efficiency of natural gas power plants will continue to increase.

Efficiency gains for natural gas power plants have also been a major factor in making coal-fired plants less competitive with gas-fired plants. From 2011 to 2020, the power-generating capacity of U.S. coal power plants fell by 29 percent, while the generating capacity of U.S. combined-cycle natural gas power plants increased by 30 percent. Despite older, less-efficient coal plants being retired, U.S. coal plants still struggle to compete with combined-cycle natural gas power plants, resulting in lower capacity factors (capacity utilization) for coal plants and higher capacity factors for natural gas power plants. In 2011, the average capacity factor was 62.8 percent for coal plants and 44.3 percent for natural gas plants. In 2020, the average capacity factor was 40.2 percent for coal plants and 56.6 percent for combined-cycle natural gas power plants.[9] Coal plant capacity factors are lower in the spring and autumn when overall power demand is lower, with some coal plant operators now evaluating plans to run plants on a seasonal basis, when higher electricity demand allows for steadier operation.[10]

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[6] https://www.eia.gov/tools/faqs/faq.php?id=107&t=3

[7] https://www.eia.gov/electricity/annual/html/epa_08_01.html

[8] https://www.eia.gov/todayinenergy/detail.php?id=32572

[9] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a

[10] https://www.eia.gov/todayinenergy/detail.php?id=44976

Section 6.2.3, *Electricity*, provides more background on the shift from coal to natural gas power generation over the last decade, and the recent and projected shift to renewable power generation. Section 6.2.3 notes that EIA projects large gains in solar and wind generating capacity, and decreases in coal-fired generation, through 2050. This projected increase in renewable energy sources in the electricity grid mix will further lower the GHG (and air quality) emissions associated with electricity consumption, including emissions associated with future BEV use.

The EIA also reports that more utility-scale battery storage systems are being installed to increase grid reliability and reduce dependence on fossil fuels.[11] From 2010 through 2018, the power capacity of U.S. utility-scale battery storage systems increased from 59 megawatts to 869 megawatts, and average costs per unit of utility-scale battery storage capacity decreased 61 percent between 2015 and 2017. Pairing battery storage systems with renewable energy power generation is increasingly common as the cost of energy storage continues to fall. The number of solar and wind generation sites co-located with battery storage systems grew from 19 in 2016 to 53 in 2019. This trend is expected to continue, with another 56 sites pairing renewable energy and battery storage expected to come online by the end of 2023.[12] Pairing battery storage with renewable energy power generation means that stored solar power can be used when the sun is not shining, and stored wind power can be used when the wind is not blowing.

The EIA forecast for battery storage is sensitive to its forecast for renewable energy costs. Under the AEO 2021 Reference case, the EIA forecasts that 59 gigawatts of battery storage will serve the power grid in 2050, but its Low Renewables Cost case (which assumes a 40 percent reduction in renewable power and energy storage costs compared with the Reference case) forecasts that 167 gigawatts of battery storage will serve the grid in 2050.[13] Under the Low Renewables Cost case, solar and wind generation replace more coal, nuclear, and natural gas power generation, further lowering the emissions associated with electricity consumption, including emissions associated with future BEV use.

8.3.4 Cumulative Impacts on Energy

In the near term, changes in passenger travel have the potential to lower the energy use of the U.S. light-duty vehicle fleet. In addition, policies addressing oil and gas exploration would likely further lower those energy impacts. As EV adoption spurs further decline in the cost of EVs to consumers beyond what is projected in the CAFE Model, the market share of EVs could also continue to increase. In addition, technological advancements make it likely that EVs could become even more efficient compared to ICE vehicles. Trends in where and how PEVs are driven would provide additional energy benefits: EVs are likely to be used more intensively in congested traffic, where regenerative braking further increases EV fuel economy compared to ICE vehicles. Finally, as the market share of EVs increases, changes in the electric grid mix have the likelihood to lower the emissions impacts of EVs, as more renewable energy is expected to come online. All of these potential cumulative actions would further reduce U.S. petroleum consumption and slightly increase U.S. electricity consumption.

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[11] https://www.eia.gov/todayinenergy/detail.php?id=44696#

[12] https://www.eia.gov/todayinenergy/detail.php?id=43775

[13] https://www.eia.gov/todayinenergy/detail.php?id=47276#

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.

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 (Davis and Boundy 2021; EPA 2021a). 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 emissions 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 (EPA 2021a) 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 emissions 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 are expected to affect U.S. emissions and could result in future increases or decreases in emissions. Potential changes in federal regulation of 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

Beyond reducing domestic gasoline consumption, the proposed standards affect energy supply and use by decreasing domestic petroleum production and refining while also increasing electricity generation for PHEVs and BEVs. Overall emissions of any specific criteria and toxic air pollutant could decrease in some years and increase in others, depending on the balance of changes in tailpipe and upstream emissions. 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, the cheap, abundant supply of natural gas, and decreasing costs of solar and wind energy development. As fuel use in the light-duty transportation sector decreases, upstream energy use associated with feedstock extraction and refining, distribution, and storage could decrease proportionally, thereby decreasing emissions associated with that upstream energy use (although such decreases could be dampened by suppliers' participation in the global markets for petroleum and petroleum products). Upstream emissions associated with sources other than energy use also could decrease. For example, decreases in oil and gas development would decrease emissions from associated processes such as hydraulic fracturing. Changes in other federal rules that affect the oil and gas industry, such as the Bureau of Land Management's methane waste prevention regulations (43 CFR 3160 and 3170), would affect the size of these emissions changes.

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 capacity in different combinations depending on the varying demand for electricity. As a result, overall emission rates from the power plant fleet (i.e., electric grid mix) are different during hours of peak electrical demand, when peakload power plants are operating, and off-peak hours, when predominantly baseload power plants are operating. Charging EVs during these off-peak hours is generally advantageous in terms of grid reliability and electricity generation costs. The CAFE Model accounts for increased electricity generation to charge PHEVs and BEVs by scaling up the energy required in the rule's upstream emission inventories.

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 would lead to higher total emissions from EV charging.

Annual Energy Outlook forecasts of power generation used in the CAFE Model account for existing legislation and other regulatory actions that affect power plant emissions. 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 and population exposure. Higher emissions in a geographic area would be expected to lead to an increase in overall health impacts in that area, while lower emissions would be expected to lead to a decrease in health impacts in that area, compared to conditions in the absence of cumulative impacts. Population distribution varies geographically, and as a result, a given amount of emissions would have greater health impacts in an area with greater population than in an area with less population. The level of population exposure in an area also is affected by the meteorological and topographical conditions in that area because these factors affect the dispersion and transport of emissions in the atmosphere. In addition, populations living or working near roadways could experience relatively greater exposure to tailpipe emissions, while populations living or working near upstream facilities (e.g., refineries) could experience relatively greater exposure to upstream emissions. An individual geographic area could experience either an increase or decrease in cumulative impacts under the proposed standards, depending on the relative magnitudes of effects from tailpipe versus upstream emissions that would affect that area.

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 2040 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 Reasonably 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 Reasonably Foreseeable Future Actions* (energy) and 8.4.3, *Other Past, Present, and Reasonably Foreseeable Future Actions* (air quality).

8.5.4 Cumulative Impacts on Other Resources

8.5.4.1 Land Use and Development

Chapter 4.4.1 of the PRIA and Chapter 4.4.3 of the TSD provide a discussion of VMT forecast. These sections detail that travel demand will recover rapidly from 2020’s unprecedented decline, then increase through 2040 before declining gradually through 2050. Trends in electrification could be important insofar as the availability of convenient residential and workplace charging could both depend on and influence development.

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.

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 projected increases resulting 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. Reduced fuel costs per mile 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 Implications of Vehicle Energy, Materials, and Technologies*, and Chapter 7, *Other Impacts*, for additional discussions of the waste impacts associated with EV usage.

8.5.4.3 Historic 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 per mile 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, increased driving associated with reduced fuel costs could result in 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 are associated with the Proposed Action and alternatives. Direct land disturbance resulting from oil exploration and extraction is expected to decrease as well as decreases 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. With the revocation of EO 13783, *Promoting Energy Independence and Economic Growth,* decreased oil extraction and refining could be expected, as well as decreased vehicle operation due to increased fuel prices. Given these decreases, minority and low-income populations may experience fewer impacts resulting from these activities, but again, only to the extent that such populations are present near emissions sources. As noted in Chapter 7, *Other Impacts*, a body of scientific literature signals disproportionate exposure of low-income and minority populations to poor air quality and proximity of minority and low-income populations to industrial, manufacturing, and hazardous waste facilities. Depending on communities' locations, energy sources, and other factors influencing distribution of air quality benefits, implementation of the Proposed Action and alternatives could help to reduce disproportionate pollution impacts on overburdened communities and, as such, are not 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 (GCRP 2018a). Because minority and low-income populations may be disproportionately exposed to climate hazards (Ebi et al. 2018), depend on infrastructure that may be affected by climate change (Gowda et al. 2018), and have fewer resources to manage these impacts (Jacobs et al. 2018), these populations are disproportionately affected by climate change compared to the overall population. Although the action alternatives would reduce the potential increase in CO_2 concentrations and temperature under the cumulative impact analysis, the reductions would be a small fraction of the total increase in CO_2 concentrations and global mean surface temperature that is anticipated to occur. 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 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 2040 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 1) the global emissions scenario used for the main cumulative analysis is the Global Climate Change Assessment Model (GCAM) 6.0 scenario, and 2) multiple global emissions scenarios are modeled 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 GCAM6.0 scenario as a reference case global emissions scenario that assumes a moderate level of global actions to address climate change. NHTSA chose the GCAM6.0 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 GCAMReference baseline scenario used in the direct and indirect analysis. For the cumulative analysis, the GCAM6.0 scenario serves as a reference scenario against which the climate impacts of the Proposed Action and alternatives can be measured. The GCAM6.0 scenario is the GCAM representation of a scenario that yields a radiative forcing of approximately 6.0 watts per square meter in the year 2100.

To evaluate the sensitivity of the results to a reasonable range of alternative emissions scenarios, NHTSA also used the Representative Concentration Pathways (RCP) 4.5 scenario and the GCAMReference 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.[14] The GCAMReference scenario is the GCAM representation of a radiative forcing of 7.0 watts per square meter.

The GCAM6.0 scenario is the GCAM representation of the radiative forcing target (6.0 watts per square meter) of the RCP scenarios developed by the MiniCAM model of the Joint Global Change Research Institute. The GCAM6.0 scenario assumes a moderate level of global GHG reductions. It is based on a set of assumptions about drivers such as population, technology, socioeconomic changes, and global climate policies that correspond to stabilization, by 2100, of total radiative forcing and associated CO_2 concentrations at roughly 678 parts per million (ppm). More specifically, GCAM6.0 is a scenario that incorporates declines in overall energy use, including fossil fuel use, as compared to the reference case. In addition, GCAM6.0 includes increases in renewable energy and nuclear energy. 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 GCAM6.0 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 GCAM6.0 represents a reasonable proxy for the past, present, and 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 compared to the No Action Alternative was calculated. This change was then applied to the GCAM6.0 scenario to generate modified global-scale emissions scenarios, which show the impact of

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[14] 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).

the Proposed Action and alternatives on the global emissions path. For example, emissions from passenger cars and light trucks in the United States in 2040 under the No Action Alternative are estimated to be 1,215 million metric tons of carbon dioxide (MMTCO$_2$); emissions in 2040 under Alternative 3 are estimated to be 1,093 MMTCO$_2$. The difference of 123 MMTCO$_2$ represents the decrease in cumulative emissions projected to result from Alternative 3.[15] Cumulative global CO$_2$ emissions for the GCAM6.0 scenario in 2040 are estimated to be 49,034 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 3 are, therefore, estimated to be 123 MMTCO$_2$ less than this reference level or 48,911 MMTCO$_2$ in 2040 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 GCAM6.0 (687 ppm in 2100), RCP4.5 (544 ppm in 2100), and GCAMReference scenario (789 ppm in 2100).

8.6.3 Other Past, Present, and Reasonably Foreseeable Future Actions

NHTSA chose the GCAM6.0 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 that will affect GHG emissions. Global and domestic actions to reduce GHG emissions 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 effects associated with these actions, policies, or programs when taken together (and NHTSA does not attempt to do so), collectively they illustrate an existing and continuing trend of U.S. and global awareness, emphasis, and efforts toward substantial GHG reductions. Therefore, a scenario that accounts for moderate reductions in the rate of global GHG emissions, such as the GCAM6.0 scenario, can be considered reasonably foreseeable under NEPA.

8.6.3.1 United States: Regional and State Actions

The following actions in the United States are already underway or reasonably foreseeable.

- **Regional Greenhouse Gas Initiative (RGGI).** Launched on January 1, 2009, RGGI was the first mandatory, market-based effort in the United States to reduce GHG emissions (RGGI 2009). The initiative now includes the following 11 Northeast and Mid-Atlantic States: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont,

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[15] The reduction in U.S. CO$_2$ emissions in 2040 under the Proposed Action and alternatives compared to the No Action Alternative ranges from 50 MMTCO$_2$ (Alternative 1) to 123 MMTCO$_2$ (Alternative 3). Differences may not calculate exactly due to rounding.

and Virginia.[16] Initially, RGGI states 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, RGGI states lowered the regional emissions cap to 91 $MMTCO_2$ for 2014. The RGGI CO_2 cap then declined 2.5 percent per year from 2015 through 2020 (RGGI 2021). RGGI states plan to reduce the overall cap by 30 percent between 2020 and 2030 (RGGI 2021). The proposed changes include an 11-state cap of 119.8 $MMTCO_2$ in 2021, which will decline to 86.9 $MMTCO_2$ in 2030 (RGGI 2021).

- **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 $MMTCO_2e$ (California Air Resources Board [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 EV 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).[17] Each of these measures is a known commitment or already underway or required. 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 by 82 $MMTCO_2e$ by 2030 relative to a business-as-usual scenario (CARB 2017).
- **U.S. Climate Alliance.** Twenty-five U.S. governors have committed to reduce GHG emissions in their respective jurisdictions consistent with the goals of the Paris Agreement. Alliance members have committed to implement policies that will reduce emissions at least 50 to 52 percent below 2005 levels by 2030 and achieve overall net-zero emissions as soon as practicable and before 2050 (U.S. Climate Alliance 2021). In 2005, emissions from Alliance members totaled approximately 2.8 gigatons of CO_2 (Gt) (EIA 2018b, 2018c). From 2005 to 2018, Alliance members reduced emissions by 14 percent (U.S. Climate Alliance 2021). Based on policies in place in June 2018, Alliance members are projected to achieve combined emissions reductions of 18 to 25 percent below 2005 levels by 2025 (U.S. Climate Alliance 2019).
- **Zero Emission Vehicle (ZEV) Mandates.** In March 2012, California Governor Jerry Brown issued an EO establishing several milestones on a path toward 1.5 million ZEVs in California by the year 2025 (California Office of the Governor 2013). Since 2013, California has created three ZEV action plans for obtaining this goal and introducing new goals; most recently with the goal of 5 million ZEVs by 2030 (California Governor's Office of Business and Economic Development 2021). In addition to these goals, California has issued several mandates with more details on California's ZEV plans of

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[16] 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, and the state officially rejoined in 2019. Virginia joined RGGI in July 2020. On October 3, 2019, Pennsylvania Governor Tom Wolf issued an executive order instructing the state's Department of Environmental Protection to join RGGI; however, as of April 2021, the state has not yet officially joined.

[17] In September 2019, NHTSA issued a final rule that established regulatory text explicitly preempting state and local laws relating to fuel economy standards established under the Energy Policy and Conservation Act (EPCA). As part of that action, EPA also withdrew the waiver it had previously provided to California for that State's GHG and ZEV programs under section 209 of the Clean Air Act. The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Part One: One National Program; Final Rule, 84 FR 51310 (Sept. 27, 2019).

action. In 2015, the state updated the California Code of Regulations (CCR) at 13 CCR § 1962.2, which regulated the minimum ZEV credit percentage requirements for passenger cars, light-duty trucks, and medium-duty vehicles for MY 2018 and later. In 2018, this ZEV minimum percentage requirement was 4.5 percent, increasing to 22.5 percent for MY 2025 and beyond. In September 2020, California Governor Gavin Newsom established through EO (EO N-79-20), new targets for ZEVs including, 100 percent of in-state sales of new passenger vehicles and drayage trucks to be zero-emission by 2035, with medium- and heavy-duty vehicles to follow in 2045 (California Governor's Office of Business and Economic Development 2021). As of 2020, 13 states (the "Section 177" states[18]), making up more than one-third of total new car sales in the United States, have either adopted identical ZEV mandates to California's or ones with variations (Larson 2019).

- **CARB Framework Agreement.** In September 2019, the federal government revoked the federal Clean Air Act waiver for California that allows California to set more rigorous vehicle GHG emissions standards. Litigation is still ongoing for the official revocation of the waiver (CARB 2019a). In August 2020, California formalized bilateral agreements with six automakers to continue its emissions reduction framework developed in 2019 (CARB 2019b). These six automakers are BMW (of America), Ford, Honda, Volkswagen (of America), Audi, and Volvo. The framework agreement continues annual reductions of light-duty vehicle GHG emissions through MY 2026 under approximately the same rates as the standards set during the Obama administration (CARB 2020). The states that have previously adopted these California standards (the same 13 that adopted the ZEV mandates) have also supported California's GHG vehicle framework agreements.

8.6.3.2 United States: Federal Actions

The following federal actions are already underway or reasonably foreseeable:

- **Proposed Rule to Repeal the SAFE Vehicles Part One Final Rule.** On January 20, 2021, President Biden issued EO 13990, *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*,[19] which directed NHTSA to consider publishing for notice and comment by April 2021 a proposed rule suspending, revising, or rescinding the SAFE Vehicles Part One Final Rule, which declared that certain types of state regulation (in particular, California's ZEV mandates and regulation of vehicle GHG emissions) were preempted due to a perceived irreconcilable conflict with NHTSA's fuel economy standards.[20] Pursuant to EO 13990, on April 22, 2021, NHTSA announced a proposed rule to repeal the SAFE Vehicles Part One Final Rule.[21] Relatedly, on April 28, 2021, EPA published a notice that it is reconsidering the 2019 EPA withdrawal of the waiver of preemption for California's ZEV mandate and GHG emissions standards.[22] If NHTSA finalizes its rule and EPA reinstates California's Clean Air Act waiver, then California and the Section 177 states will be permitted to move forward with their vehicle GHG regulations, in which case new passenger cars and light trucks sold in those states would have to meet these standards. The CAFE Model accounts

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[18] *Section 177 states* refers to the states that have adopted California's criteria pollutant and GHG emissions regulations under Section 177 of the Clean Air Act (42 U.S.C. § 7507).

[19] Executive Order 13990, Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis, 86 FR 7037 (Jan. 25, 2021).

[20] *The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Part One: One National Program; Withdrawal of Waiver; Final Rule*, 84 FR 51310 (Sept. 27, 2019).

[21] *Corporate Average Fuel Economy (CAFE) Preemption; Notice of Proposed Rulemaking*, 86 FR 25980 (May 12, 2021).

[22] *California State Motor Vehicle Pollution Control Standards; Advanced Clean Car Program; Reconsideration of a Previous Withdrawal of a Waiver of Preemption; Opportunity for Public Hearing and Public Comment*, 86 FR 22421 (Apr. 28, 2021).

for the GHG emissions reductions that would result from these state regulations, as described in Chapter 2.3 of the TSD.

- **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 CO_2 emissions for passenger cars and light trucks, as described in Chapter 1, *Purpose and Need for the 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). Since the implementation of this joint rule, 10 of the 14 largest vehicle manufacturers selling cars in the U.S. market have made improvements to both fuel economy and CO_2 emissions. Between 2012 and 2019, the industry decreased CO_2 emissions by 21 gallons per mile and increased fuel economy by 1.3 mpg (EPA 2020p).
- **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 CO_2 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 CO_2 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 combined standards were projected to reduce CO_2 emissions by approximately 270 $MMTCO_2e$ over the lifetime 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 2018–2027.** In August 2016, NHTSA and EPA published the Phase 2 joint final rule to reduce fuel consumption and GHG emissions from heavy-duty vehicles. As with the Phase 1 standards, the Phase 2 fuel consumption and CO_2 standards apply to highway vehicles and engines that are not regulated by the light-duty vehicle CAFE and CO_2 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 and 8 tractors (combination heavy-haul tractors), Classes 2 through 8 vocational vehicles (buses and work trucks), and Classes 2b and 3 heavy-duty pickups and vans (large pickup trucks and vans). The combined standards were projected to reduce GHG emissions by approximately 1,100 $MMTCO_2e$ over the lifetime of vehicles sold during MYs 2018–2027 (NHTSA 2016a).
- **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 2015b).[23] The increased use of renewable fuels over 30 years, given a zero percent discount rate, is projected to reduce GHG emissions by 4,500 $MMTCO_2e$.

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[23] https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based.

- **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 2014). The program has avoided more than 3,000 $MMTCO_2$, and is expected to reduce GHG emissions by 7,900 $MMTCO_2e$ annually by 2030 (DOE 2016b).
- **Final rule to redefine terms under Department of Energy (DOE) lighting efficiency standards.** In 2007, the EISA directed DOE to conduct a rulemaking on efficiency standards for general service lamps (GSLs) and other incandescent lamps. In January 2017, DOE issued a final rule that revised and expanded the definition for GSL to include a broader range of incandescent lightbulbs, including those used for decorative and less-common purposes than general lighting (EPA 2017e). In February 2019, DOE issued a notice of proposed rulemaking to rescind the 2017 amendments, arguing that the definition revisions were not lawful according to the 2007 rulemaking directive (EPA 2019d). The rule to rescind the amendments was finalized in September 2019. The energy savings potential of the 2017 standards was estimated to be 27 quadrillion BTUs for lamps shipped between 2020 and 2049 (Kantner et al. 2017). The proposal had the potential to reduce GHG emissions by 540 $MMTCO_2e$ by 2030 (Kantner et al. 2017). In May 2021, DOE announced that it is re-evaluating its determination from 2019—that the Secretary of Energy was not required to implement the statutory backstop requirement for GSLs– possibly reinstating the 2017 revision (DOE 2021b).
- **Revisions to the Methane New Source Performance Standards Rule.** In 2016, the New Source Performance Standards (NSPS) rule that targets controlling CH_4 leaks from oil and gas operations on public lands was finalized. In 2020, EPA issued two final rules that amended the 2016 NSPS. The first, published on September 14, 2020, finalized policy amendments to remove oil and gas transmission and storage operations and associated CH_4 emission limits under the oil and natural gas sector NSPS ("policy amendments final rule").[24] The second, published on September 15, 2020, finalized technical amendments that lowered leak mitigation requirements for compressor stations in the oil and gas industry and eliminated leak mitigation requirements for the industry's low-production wells, among other changes ("technical amendments final rule").[25] In June 2021, President Biden signed a Senate joint resolution to disapprove (repeal) the policy amendments final rule.[26] In accordance with the Biden administration's direction in EO 13990, the EPA intends to reconsider the technical amendments final rule.[27] If the technical amendments final rule remains in place, CH_4 emissions can be expected to increase by 10 $MMTCO_2e$ by 2030.[28]
- **Proposal to Revise the Regulations on Ozone-Depleting Substance (ODS) Substitute Refrigerants Extension.** In 2016, EPA finalized a rule that updated the Clean Air Act Section 608 rule regulating ODS emissions reductions during appliance maintenance and leak repairs to also include substitute refrigerants such as hydrofluorocarbons (HFCs), specifically, the appliance maintenance and leak

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[24] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources Review; Final Rule*, 85 FR 57018 (Sept. 14, 2020).

[25] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Source Reconsideration; Final Rule*, 85 FR 57398 (Sept. 15, 2020).

[26] Pub. L. No. 117-23, S.J.Res.14 (June 30, 2021).

[27] Spring 2021 Unified Agenda of Regulatory and Deregulatory Actions, RIN 2060-AV16. Available at: https://www.reginfo.gov/public/do/eAgendaMain (last accessed June 22, 2021).

[28] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Source Reconsideration; Final Rule*, 85 FR 57398, 57434 (Sept. 15, 2020).

repair provisions. The rule also listed provisions to lower the threshold for which leaks to repair and required periodic leak inspections for equipment leaking above the threshold, repair verification tests, and record the disposal of appliances containing more than 5 and less than 50 pounds of refrigerants (EPA 2016d). In August 2017, EPA announced that it would revisit the 2016 rule's extension to include more refrigerants (HFCs), specifically, the appliance maintenance and leak repair provisions. In October 2018, a proposed rule was issued to withdraw the extension and additional provisions, arguing whether the agency held the statutory authority to extend the regulations initially (EPA 2018e). On December 27, 2020, the American Innovation and Manufacturing Act was enacted by Congress. The Act directs EPA to address the environmental impact of HFCs by phasing down production and consumption, maximizing reclamation and minimizing releases from equipment, and facilitating the transition to next-generation technologies through sector-based restrictions. This action is expected to reduce GHG emissions by 4,700 $MMTCO_2$ from 2022 to 2050 (EPA 2021i).

- **United States and the Paris Agreement.** On April 22, 2021, President Biden submitted a Nationally Determined Contribution to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat, with a target for the United States to achieve a 50 to 52 percent reduction in economy-wide net GHG pollution from 2005 levels by 2030. This target was submitted under the Paris Agreement, which entered into force on November 4, 2016. The United States formally withdrew from the Paris Agreement in November 2020, but then officially rejoined in February 2021. The Paris Agreement's goal is to limit global average temperature increase to well below 2°C (3.6°F) above preindustrial levels and pursue efforts to limit the increase to 1.5°C (2.7°F).

8.6.3.3 International Actions

The following international actions are already underway or reasonably foreseeable:

- **UNFCCC and the annual Conference of the Parties.** 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 an agreement to extend the imminently expiring Kyoto Protocol. The Second Commitment Period took effect on January 1, 2013, ran through December 2020, and required parties to reduce emissions by at least 18 percent below 1990 levels by 2020, a metric that was on pace to be exceeded, although data is not yet available (UNFCCC 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 degrees Fahrenheit [°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 May 2021, 191 countries, including the United States, comprising over 97 percent of global GHG emissions had ratified, accepted, or approved the Paris Agreement (WRI 2021; UNFCCC 2021). 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.

- **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 2018). The aim of the system is to help European Union member states achieve compliance with their commitments under the Kyoto Protocol (European Union 2015). 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 2015) and covers about 10,000 energy-intensive installations across the European Union. This represents 40 percent of Europe's emissions of CO_2 (European Union 2018). 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 2018). To achieve climate neutrality in the EU by 2050, the EU Emissions Trading System is under review with the aim to both expand the scope of coverage, but also update its target by reducing GHGs to at least 55 percent below 1990 levels by 2030 (European Union 2020). Installations covered by the Emissions Trading System reduced emissions by about 35 percent between 2005 and 2019 (European Union n.d.).
- **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 2015 prevailing standard (ICCT 2015). Similarly, China has implemented fuel economy standards, based on the Worldwide harmonized Light-duty Test Cycle instead of the previously used New European Driving Cycle. In December 2019, China set new standards for passenger vehicles produced or imported to an average target of 59 mpg.

- **China EV Targets.** China has established a program that effectively sets quotas for PEVs and fuel cell electric vehicles (FCVs), under which PEVs and FCVs were expected to make up at least 10 percent of each automaker's sales in China in 2019, and 12 percent in 2020 (ICCT 2021). Subsequent targets under Phase 2 of this policy will require these vehicles to make up 18 percent of total sales by 2023. 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.
- **Other International GHG mitigation efforts.** There are many nations adopting other national actions, such as cap-and-trade programs, to reduce GHG vehicle emissions. Some efforts from large emitters include:
  - In January 2021, China launched its new national emissions trading scheme, which allows market emitters to buy, sell, and/or trade emissions credits (ICAP 2021). These new plans build upon existing cap-and-trade efforts launched in December 2017. The updates include goals of a reduction in carbon emissions per unit of gross domestic product by 18 percent compared to the 2020 levels within the next 5 years, a peak of emissions before 2030, and carbon neutrality by 2060 (ICAP 2021).
  - Officially launched in 2017, India currently has a similar cap-and-trade program, which has been cited as the first program to include particulate matter (PM) aerosols within its emissions trading scheme program (University of Chicago 2019). As of 2019, India has also pledged to reduce emissions intensity by 33 to 35 percent compared to 2005 levels (Timperley 2019).
  - To date, many other countries have adopted a national cap-and-trade program including, but not limited to, Mexico, Australia, Colombia, Chile, New Zealand, South Korea, Japan, and nearly all the nations within the European Union (Plumber and Popovich 2019).

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.

The Model for the Assessment of Greenhouse-Gas Induced Climate Change (MAGICC) 6 scenario 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., RCP2.6 [low], RCP4.5 [medium], RCP6.0 [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 reduce the projected increase in CO_2 concentrations and temperature, but the reductions 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 687.29 ppm under the No Action Alternative to 686.55 ppm under Alternative 3. 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 lead to small differences in climate effects. Compared with projected total global CO_2 emissions of 4,044,005 $MMTCO_2$ from all sources from 2021 to 2100 under GCAM6.0, the incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.10 (Alternative 1) and 0.21 (Alternative 3) percent by 2100.

Table 8.6.4-1. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise, and Ocean pH by Alternative [a]

Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [b]			Sea-Level Rise (cm) [b]			Ocean pH [c]		
	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	472.51	545.85	686.94	1.215	1.810	2.836	22.16	35.14	70.19	8.4150	8.3610	8.2725
Alt. 2	472.48	545.76	686.73	1.215	1.809	2.835	22.16	35.14	70.17	8.4150	8.3610	8.2726
Alt. 3	472.45	545.67	686.55	1.215	1.809	2.834	22.16	35.14	70.15	8.4150	8.3611	8.2727
Reductions Under Alternatives												
Alt. 1	0.05	0.15	0.35	0.000	0.001	0.002	0.00	0.01	0.03	-0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.56	0.000	0.001	0.003	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 3	0.11	0.33	0.74	0.001	0.002	0.003	0.00	0.02	0.07	-0.0001	-0.0002	-0.0004

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 less than zero but more 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 reductions 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 reductions of CO_2 concentrations under the range of action alternatives compared to the No Action Alternative. As shown in Figure 8.6.4-2, the reduction in CO_2 concentrations by 2100 under Alternative 3 compared to the No Action Alternative is more than twice that of Alternative 1 compared to the No Action Alternative.

Figure 8.6.4-1. Atmospheric Carbon Dioxide Concentrations by Alternative

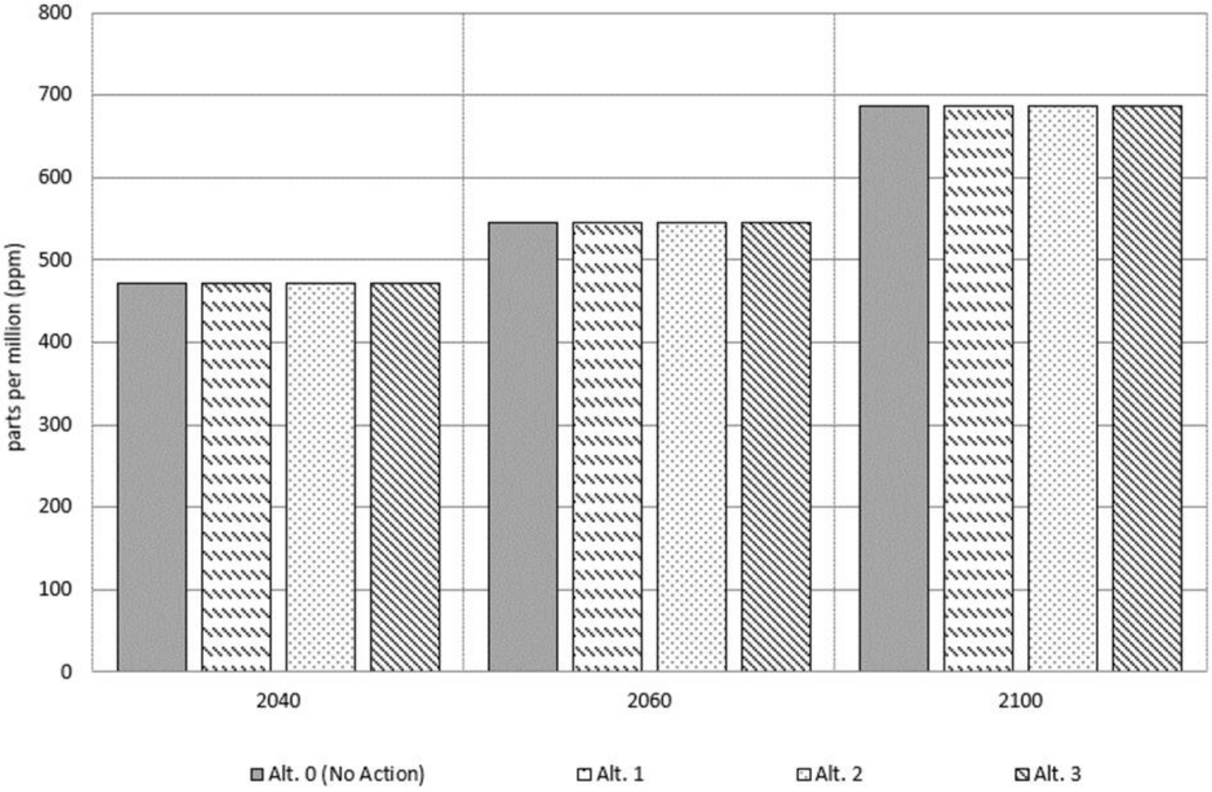
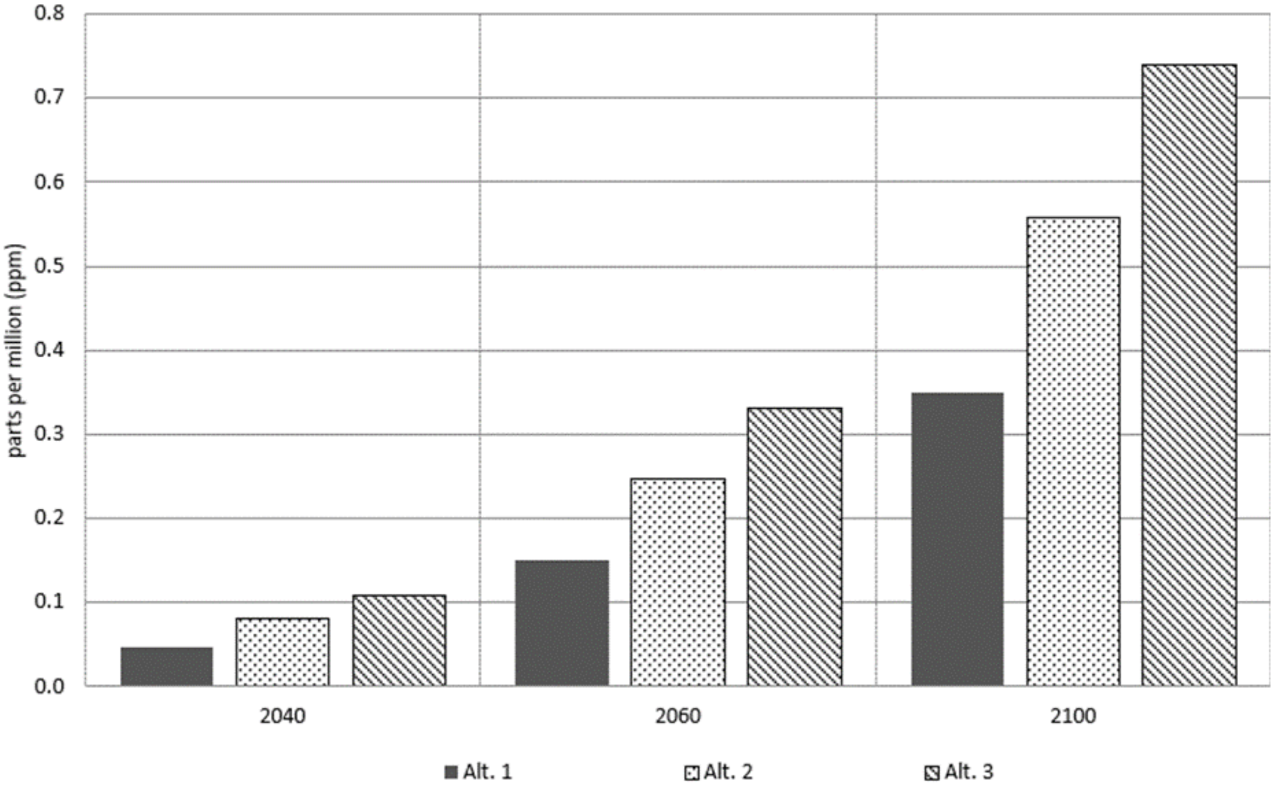


Figure 8.6.4-2. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative



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 moderate global success in reducing 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.[29] The differences among alternatives are small (Figure 8.6.4-3). For example, in 2100, the decrease in temperature under the action alternatives would range from approximately 0.002°C (0.003°F) under Alternative 1 to 0.003°C (0.006°F) under Alternative 3. 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 reduce the changes in regional temperatures roughly in proportion to the reduction in global mean surface temperature. Regional changes to warming and seasonal temperatures as described in the IPCC Fifth Assessment Report are summarized in Table 5.4.2-3.

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[29] 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

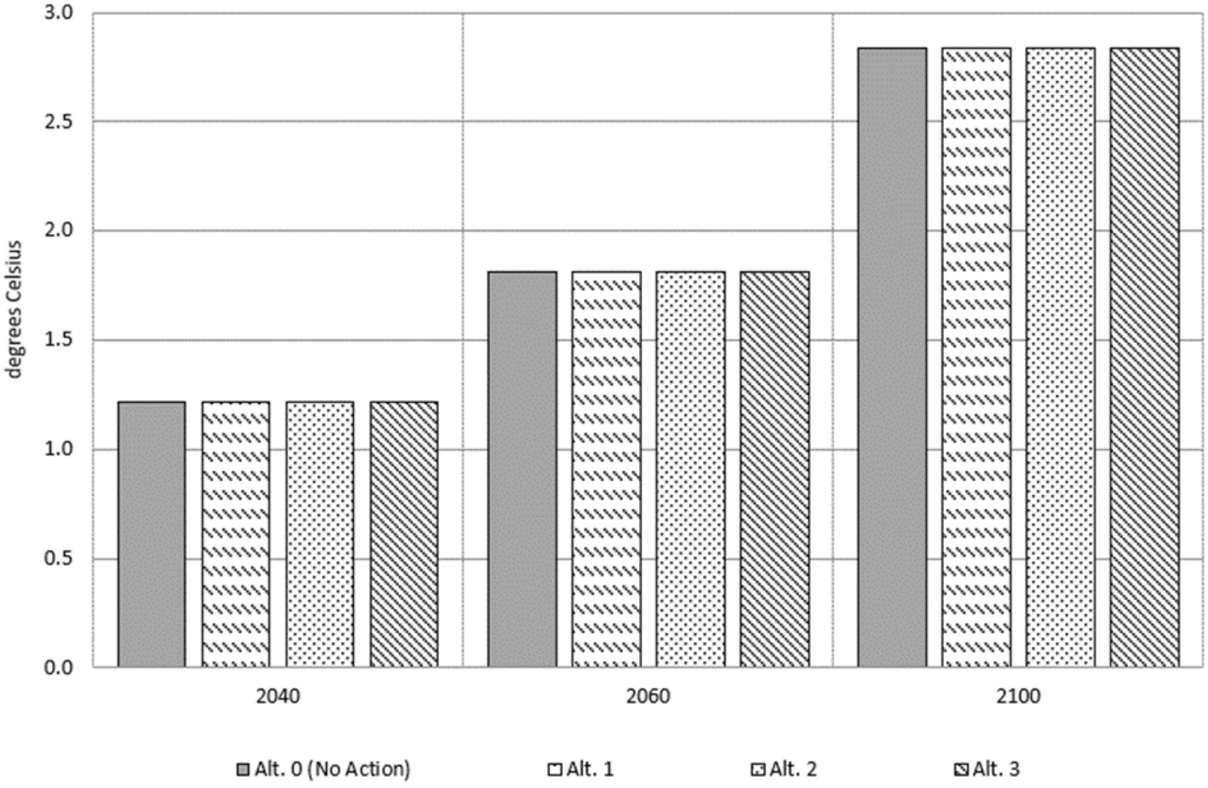
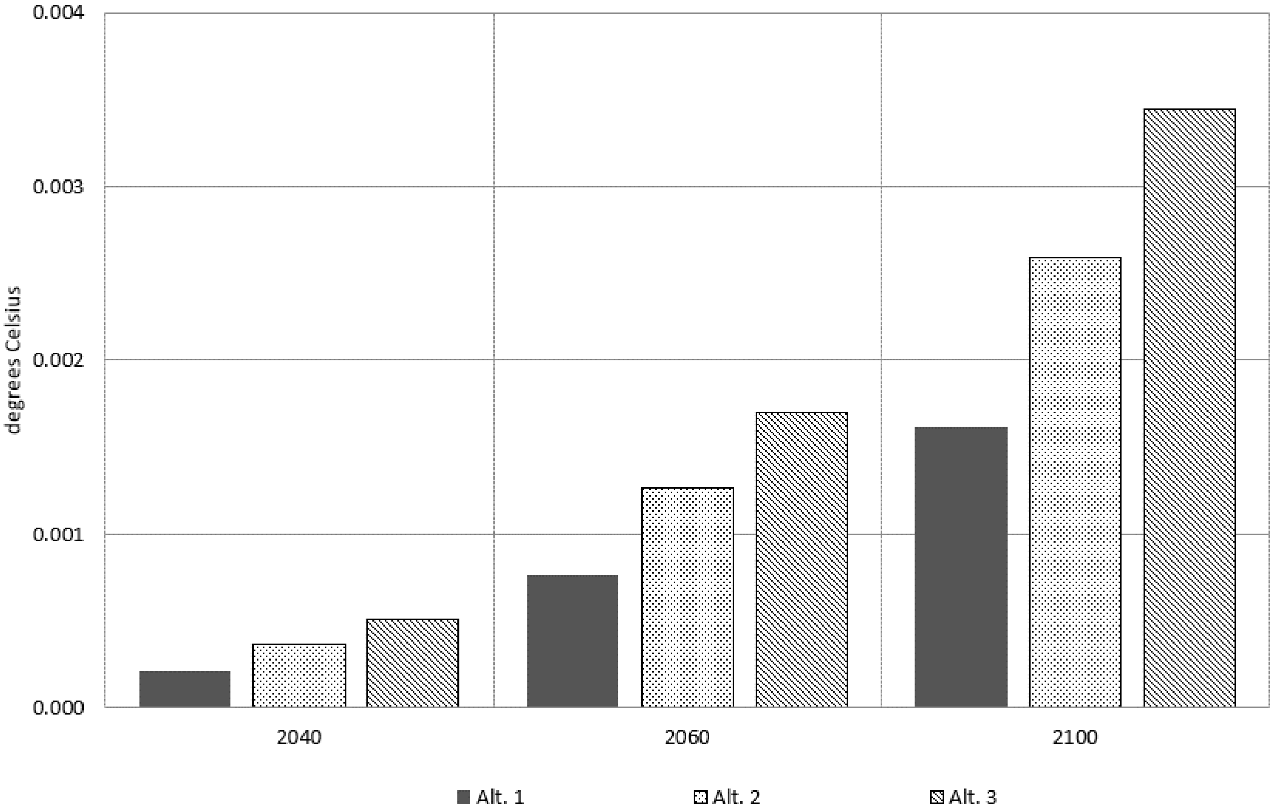


Figure 8.6.4-4. Reductions in Global Mean Surface Temperature Compared to the No Action Alternative



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 5.4.2.2, *Climate Change Attributes, 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 reduce temperatures slightly compared to the No Action Alternative, they also would reduce predicted increases in precipitation slightly; however, as shown in Table 8.6.4-2, the reduction would be less than 0.01 percent in most instances.

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			
Alternative 0 (No Action)	1.216	1.810	2.838
Alternative 1	1.215	1.810	2.836
Alternative 2	1.215	1.809	2.835
Alternative 3	1.215	1.809	2.834
Reductions in Global Temperature (°C) Compared to the No Action Alternative [b]			
Alternative 1	0.000	0.001	0.002
Alternative 2	0.000	0.001	0.003
Alternative 3	0.001	0.002	0.003
Global Mean Precipitation Increase (%)			
Alternative 0 (No Action)	2.04%	3.04%	4.77%
Alternative 1	2.04%	3.04%	4.76%
Alternative 2	2.04%	3.04%	4.76%
Alternative 3	2.04%	3.04%	4.76%
Reductions in Global Mean Precipitation Increase Compared to the No Action Alternative [c]			
Alternative 1	0.00%	0.00%	0.00%
Alternative 2	0.00%	0.00%	0.00%
Alternative 3	0.00%	0.00%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

[c] The reduction 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 reduce regional changes in precipitation roughly in proportion to the reductions in global mean precipitation. Regional changes to precipitation as described by the IPCC Fifth Assessment Report are summarized in Table 5.4.2-6.

Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.4.2.2, *Climate Change Attributes*, under *Sea-Level Rise*. Table 8.6.4-1 presents the cumulative impact on sea-level rise from each alternative and show sea-level rise in 2100 ranging from 70.22 centimeters (27.65 inches) under the No Action Alternative to 70.15 centimeters (27.62 inches) under Alternative 3, for a maximum decrease of 0.07 centimeter (0.03 inch) by 2100.

Ocean pH

Table 8.6.4-1 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative. Ocean pH under the alternatives ranges from 8.2723 under the No Action Alternative to 8.2727 under Alternative 3, for a maximum increase in pH of 0.0004 by 2100.

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 3. 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	454.00	494.74	509.86	0.618	0.858	1.039	31.56	8.3866
	2.0	457.25	500.76	521.54	0.793	1.113	1.387	40.77	8.3781
	2.5	460.19	506.30	532.80	0.951	1.351	1.728	50.31	8.3701
	3.0	462.84	511.42	543.61	1.097	1.572	2.057	60.01	8.3625
	4.5	469.40	524.57	573.37	1.463	2.151	2.975	89.21	8.3423
	6.0	474.44	535.15	599.59	1.751	2.625	3.794	117.55	8.3252
Alt. 2	1.5	453.97	494.65	509.69	0.618	0.858	1.038	31.55	8.3868
	2.0	457.22	500.67	521.36	0.792	1.113	1.387	40.76	8.3783
	2.5	460.15	506.21	532.62	0.951	1.350	1.727	50.29	8.3702
	3.0	462.80	511.33	543.42	1.097	1.572	2.056	59.99	8.3626
	4.5	469.36	524.47	573.17	1.463	2.150	2.974	89.18	8.3424
	6.0	474.41	535.06	599.38	1.751	2.625	3.792	117.50	8.3253
Alt. 3	1.5	453.94	494.57	509.53	0.618	0.857	1.037	31.54	8.3869
	2.0	457.19	500.58	521.21	0.792	1.112	1.386	40.75	8.3784
	2.5	460.13	506.13	532.45	0.951	1.350	1.726	50.27	8.3703
	3.0	462.77	511.25	543.26	1.096	1.571	2.055	59.97	8.3628
	4.5	469.33	524.39	572.99	1.463	2.149	2.972	89.15	8.3425
	6.0	474.38	534.97	599.19	1.751	2.624	3.790	117.46	8.3254

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
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.05	0.14	0.29	0.000	0.001	0.001	0.02	-0.0002
	2.0	0.05	0.15	0.30	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.05	0.15	0.31	0.000	0.001	0.002	0.03	-0.0002
	3.0	0.05	0.15	0.32	0.000	0.001	0.002	0.04	-0.0002
	4.5	0.05	0.15	0.34	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.05	0.15	0.36	0.000	0.001	0.003	0.07	-0.0002
Reductions Under Alternative 2 Compared to the No Action Alternative									
Alt. 2	1.5	0.08	0.24	0.47	0.000	0.001	0.002	0.03	-0.0003
	2.0	0.08	0.24	0.48	0.000	0.001	0.002	0.04	-0.0003
	2.5	0.08	0.24	0.50	0.000	0.001	0.003	0.05	-0.0004
	3.0	0.08	0.24	0.51	0.000	0.001	0.003	0.06	-0.0004
	4.5	0.08	0.25	0.55	0.000	0.002	0.004	0.09	-0.0004
	6.0	0.08	0.25	0.58	0.000	0.002	0.005	0.12	-0.0004
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.11	0.32	0.62	0.000	0.001	0.002	0.03	-0.0005
	2.0	0.11	0.32	0.64	0.000	0.001	0.003	0.05	-0.0005
	2.5	0.11	0.32	0.66	0.000	0.002	0.003	0.06	-0.0005
	3.0	0.11	0.32	0.68	0.001	0.002	0.004	0.08	-0.0005
	4.5	0.11	0.33	0.72	0.001	0.002	0.005	0.12	-0.0005
	6.0	0.11	0.34	0.77	0.001	0.003	0.006	0.16	-0.0005

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 reductions under higher emissions scenarios can lead to larger reductions in CO_2 concentrations in later years. Under higher emissions scenarios, anthropogenic emissions levels exceed global emissions sinks (e.g., plants, oceans, and soils) by a greater extent. As a result, emissions reductions under higher emissions scenarios are avoiding more of the anthropogenic emissions that are otherwise expected to stay in the atmosphere (are not removed by sinks) and contribute to higher CO_2 concentrations. The use of different climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from 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 3 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, the action alternatives would have the greatest impact on CO_2 concentration in the global emissions scenario with the highest CO_2 emissions (GCAMReference scenario), and the least impact in the scenario with the lowest CO_2 emissions (RCP4.5). The total range of the impact of Alternative 3 on CO_2 concentrations in 2100 is roughly 0.68 to 0.77 ppm across all three global emissions scenarios. Alternative 3, using the GCAM6.0 scenario and a 3.0°C (5.4°F) climate sensitivity, would have a 0.74 ppm decrease compared to Alternative 1, which would have a 0.35 ppm decrease in 2100.

Table 8.6.4-4. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for GCAM6.0[a] 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	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	463.28	527.58	643.12	0.694	1.004	1.505	36.93	8.2982
	2.0	466.69	534.18	658.39	0.885	1.294	1.970	47.81	8.2890
	2.5	469.75	540.26	672.99	1.058	1.561	2.413	58.94	8.2805
	3.0	472.51	545.85	686.94	1.215	1.810	2.836	70.19	8.2725
	4.5	479.34	560.22	725.17	1.611	2.455	3.996	103.74	8.2512
	6.0	484.58	571.80	758.96	1.920	2.983	5.034	136.29	8.2331
Alt. 2	1.5	463.25	527.49	642.93	0.694	1.004	1.505	36.92	8.2983
	2.0	466.66	534.09	658.19	0.885	1.293	1.969	47.79	8.2892
	2.5	469.72	540.16	672.78	1.058	1.561	2.413	58.93	8.2806
	3.0	472.48	545.76	686.73	1.215	1.809	2.835	70.17	8.2726
	4.5	479.30	560.12	724.95	1.611	2.454	3.995	103.71	8.2513
	6.0	484.54	571.70	758.74	1.920	2.982	5.033	136.25	8.2332
Alt. 3	1.5	463.22	527.41	642.77	0.694	1.004	1.504	36.91	8.2984
	2.0	466.63	534.01	658.02	0.885	1.293	1.969	47.78	8.2893
	2.5	469.69	540.08	672.61	1.058	1.561	2.412	58.91	8.2807
	3.0	472.45	545.67	686.55	1.215	1.809	2.834	70.15	8.2727
	4.5	479.28	560.03	724.76	1.611	2.453	3.993	103.68	8.2514
	6.0	484.51	571.61	758.53	1.920	2.982	5.031	136.21	8.2334

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
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.05	0.15	0.32	0.000	0.000	0.001	0.02	-0.0002
	2.0	0.05	0.15	0.33	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.05	0.15	0.34	0.000	0.001	0.001	0.03	-0.0002
	3.0	0.05	0.15	0.35	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.05	0.15	0.37	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.05	0.16	0.40	0.000	0.001	0.003	0.07	-0.0002
Reductions Under Alternative 2 Compared to the No Action Alternative									
Alt. 2	1.5	0.08	0.24	0.51	0.000	0.001	0.001	0.02	-0.0003
	2.0	0.08	0.24	0.53	0.000	0.001	0.002	0.03	-0.0003
	2.5	0.08	0.24	0.54	0.000	0.001	0.002	0.04	-0.0003
	3.0	0.08	0.25	0.56	0.000	0.001	0.003	0.05	-0.0003
	4.5	0.08	0.25	0.59	0.000	0.002	0.003	0.08	-0.0003
	6.0	0.08	0.26	0.63	0.000	0.002	0.004	0.11	-0.0003
Reductions Under Alternative 3 compared to the No Action Alternative									
Alt. 3	1.5	0.11	0.32	0.68	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.11	0.33	0.70	0.000	0.001	0.003	0.05	-0.0004
	2.5	0.11	0.33	0.72	0.000	0.002	0.003	0.06	-0.0004
	3.0	0.11	0.33	0.74	0.001	0.002	0.003	0.07	-0.0004
	4.5	0.11	0.34	0.79	0.001	0.002	0.005	0.11	-0.0004
	6.0	0.11	0.34	0.83	0.001	0.002	0.006	0.15	-0.0004

Notes:

[a] Sea-level rise results are based on the regression analysis described in Section 5.3.3, *Methods for Estimating Climate Effects*, using GCAM6.0.

[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 GCAMReference 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
		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	469.56	545.95	737.14	0.741	1.128	1.889	41.03	8.2447
	2.0	473.04	552.94	755.14	0.941	1.445	2.450	52.72	8.2351
	2.5	476.17	559.37	772.33	1.122	1.738	2.980	64.50	8.2262
	3.0	478.99	565.29	788.74	1.287	2.007	3.483	76.25	8.2178
	4.5	485.95	580.47	833.90	1.699	2.706	4.866	110.89	8.1954
	6.0	491.29	592.72	874.45	2.019	3.278	6.168	144.64	8.1761
Alt. 2	1.5	469.53	545.85	736.95	0.740	1.127	1.889	41.02	8.2448
	2.0	473.01	552.85	754.94	0.941	1.445	2.449	52.71	8.2352
	2.5	476.14	559.27	772.12	1.122	1.737	2.979	64.48	8.2263
	3.0	478.96	565.19	788.52	1.287	2.007	3.482	76.23	8.2179
	4.5	485.92	580.37	833.65	1.698	2.705	4.865	110.86	8.1955
	6.0	491.26	592.61	874.21	2.019	3.277	6.167	144.59	8.1763
Alt. 3	1.5	469.50	545.77	736.77	0.740	1.127	1.888	41.01	8.2449
	2.0	472.98	552.76	754.76	0.941	1.445	2.449	52.70	8.2353
	2.5	476.11	559.19	771.94	1.122	1.737	2.978	64.47	8.2264
	3.0	478.93	565.11	788.33	1.287	2.007	3.481	76.22	8.2180
	4.5	485.89	580.28	833.45	1.698	2.705	4.864	110.83	8.1956
	6.0	491.23	592.53	873.98	2.019	3.277	6.165	144.56	8.1764
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.05	0.15	0.34	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.05	0.15	0.35	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.05	0.15	0.36	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.05	0.15	0.37	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.05	0.16	0.37	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.05	0.16	0.43	0.000	0.001	0.003	0.06	-0.0002

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
		2040	2060	2100	2040	2060	2100	2100	2100
Reductions Under Alternative 2 Compared to the No Action Alternative									
Alt. 2	1.5	0.08	0.24	0.54	0.000	0.001	0.001	0.02	-0.0003
	2.0	0.08	0.25	0.55	0.000	0.001	0.002	0.03	-0.0003
	2.5	0.08	0.25	0.57	0.000	0.001	0.002	0.04	-0.0003
	3.0	0.08	0.25	0.58	0.000	0.001	0.002	0.05	-0.0003
	4.5	0.08	0.25	0.62	0.000	0.002	0.003	0.08	-0.0003
	6.0	0.08	0.26	0.67	0.000	0.002	0.005	0.11	-0.0003
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.11	0.32	0.71	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.11	0.33	0.73	0.000	0.001	0.002	0.04	-0.0004
	2.5	0.11	0.33	0.75	0.000	0.001	0.003	0.05	-0.0004
	3.0	0.11	0.33	0.77	0.001	0.002	0.003	0.06	-0.0004
	4.5	0.11	0.34	0.83	0.001	0.002	0.004	0.10	-0.0004
	6.0	0.11	0.35	0.91	0.001	0.002	0.006	0.14	-0.0004

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; CO_2 = 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. When using modeling using the GCAMReference scenario (the scenario with the highest global emissions of GHGs), Alternative 3 has a greater reduction in global mean surface temperature than when modeled under RCP4.5 (the scenario with lowest global emissions). 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 reduction in emissions yields a greater reduction in radiative forcing and global mean surface temperature.

The sensitivity of simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 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 each alternative than it would be under scenarios with higher climate sensitivities. Conversely, scenarios with higher climate sensitivities have higher sea-level rise; the increase of sea-level rise would be higher under the action alternatives than it would be under scenarios with lower climate sensitivities. Higher global GHG emissions scenarios have higher sea-level rise, but the impact of the action alternatives 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 the action alternatives 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 is low, and less than 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 decrease the growth in GHG emissions as discussed in Section 5.4 and Section 8.6.4, they alone would not prevent climate change. Instead, the action alternatives would reduce 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. Similarly, to the extent the action alternatives would result in reductions in projected increases in global CO_2 concentrations, this rulemaking would also reduce the impact of climate change across resources and the risk of crossing atmospheric CO_2 concentration thresholds that trigger abrupt changes in Earth's systems—thresholds known as "tipping points." NHTSA's assumption is that reductions in climate effects relating to temperature, precipitation, sea level, and ocean pH would decrease 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.[30] 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 benefits of reducing GHG emissions would result in reducing 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.

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[30] 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.

NHTSA's analysis draws largely from recent studies and reports, including the IPCC *Fifth Assessment Report* (IPCC 2013a, 2013b, 2014a, 2014b, 2014d), the IPCC *Special Study: Global Warming of 1.5° C* (IPCC 2018), the IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC 2019a), the IPCC *Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (IPCC 2019b), and the Global Climate Research Program (GCRP) *National Climate Assessment* (NCA) *Reports* (GCRP 2014, 2017, 2018a). 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 in the IPCC Framework*). This approach provides a consistent method to define confidence levels and percent probability of a projected 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 (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 2014b). 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 2014b; GCRP 2014, 2018a).

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 2014d).

Detected trends in streamflow and runoff are generally consistent with observed regional changes in precipitation and temperature (IPCC 2014b). Globally, in regions with seasonal snow storage, warming has led to earlier occurrence of the maximum streamflows from snowmelt during the spring and increased winter streamflows because more winter precipitation falls as rain instead of snow (IPCC 2014b citing Clow 2010, Korhonen and Kuusisto 2010, and Tan et al. 2011). These reduced snow-to-rain ratios are leading to significant differences between the timing of water supply and demand (*medium confidence)*. In particular, warming temperatures and reduced snowpack are decreasing surface and groundwater availability in much of the western United States (U.S. Bureau of Reclamation 2021). Changes in the timing of flows and temperatures of freshwater bodies *likely* impact local wildlife populations through phenological and distribution/range shifts (*high confidence*) (GCRP 2018a). 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 2014d).

The number and intensity of very heavy precipitation events have been increasing significantly across most of the United States (U.S. Bureau of Reclamation 2011). 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 2011; 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 2011, 2016). There is *medium confidence* that global warming of 1.5°C would lead to a lesser expansion of the area with significant increases in runoff than under a 2°C increase (IPCC 2018).

The risk faced from heavy precipitation and flooding events is compounded by aging water infrastructure such as dams and levees across the United States. The scope of the nation's exposure to this risk has not yet been fully identified; however, the estimated reconstruction and maintenance costs for the totality of American water infrastructure is estimated in the trillions of dollars (GCRP 2018a). It can be said with *high confidence* that extreme precipitation events are projected to increase in a warming climate, and that our deteriorating water infrastructure compounds the risk climate change poses to our society (*high confidence*).

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 evapotranspiration (i.e., agricultural droughts) (GCRP 2017). This increased evapotranspiration has also increased the need for human use of water in many areas. Over the past three decades, efficiency gains in irrigation methods have generally kept pace with this increased usage; however, without further improvements in this area, future human demand could outpace supply in many regions (GCRP 2018a). In fact, due to limitations on surface water storage and trading of water across basins and usages, certain U.S. aquifers have experienced significant depletion (GCRP 2018a citing Russo et al. 2017).

Globally, meteorological and agricultural droughts have become more frequent since 1950 in some regions, including southern Europe and western Africa (IPCC 2014b citing Seneviratne et al. 2012). Drought hazards are projected to be less severe at 1.5°C of warming compared to 2°C (IPCC 2018 citing Smirnov et al. 2016, Sun et al. 2017, Arnell et al. 2018, and Liu et al. 2018; IPCC 2019b).

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 2015c). 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 2016e 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 2014b 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 2014b citing Allen et al. 2010b, Crosbie et al. 2013b, Ng et al. 2010, and 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 2016; GCRP 2017). These effects are of particular concern in Hawaii and U.S. territories in the Caribbean and Pacific, threatening previously dependable and safe water supplies. The freshwater supplies in these same areas also face increased potential for contamination from increasingly frequent extreme weather events that damage freshwater infrastructure (GCRP 2018a).

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. Changes in the amount of water flow in surface water bodies due to climate change presents chronic problems, such as increased cost of water treatment and greater risk to public health due to pollutant concentrations (GCRP 2018a). Positive reported impacts include reductions in the risk of eutrophication when nutrients were flushed from lakes and estuaries by more frequent storms and hurricanes (IPCC 2014b citing Paerl and Huisman 2008). For rivers, all reported impacts on water quality are negative, and surface water quality as a whole is declining as water temperature increases (*high confidence*) (GCRP 2018a). Studies of impacts on groundwater quality are limited and mostly report elevated concentrations of fecal coliforms during the rainy season or after extreme rain events (IPCC 2014b citing Auld et al. 2004, Curriero et al. 2001, Jean et al. 2006, Seidu et al. 2013, and Tumwine et al. 2002, 2003).

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 2015d; Abt Associates 2016). Water conservation and demand management are also being promoted as important nonstructural, low-regrets approaches for managing water supply.

However, the Fourth National Climate Assessment states that management of surface water and groundwater sources across federal agencies has been hampered by a lack of coordination, creating inefficiencies in the response to climate change. 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

The impacts of climate change on terrestrial and freshwater ecosystems have been observed at a variety of scales, including individuals (e.g., changes in genetics and physical characteristics), populations (e.g., changes in timing of life cycle events), and species (e.g., changes in geographic range) (GCRP 2018a citing Scheffers et al. 2016). Several reviews of climate change impacts on ecosystem services indicate that 59 to 82 percent of ecosystem services have experienced impacts from climate change (Runting et al. 2016, Scheffers et al. 2016).

Recent global satellite and ground-based data have identified phenology[31] shifts, including earlier spring events such as breeding, budding, flowering, and migration, which have been observed in hundreds of plant and animal species (IPCC 2014b citing Menzel et al. 2006, Cleland et al. 2007, Parmesan 2007,

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[31] Phenology refers to the relative timing of species' life-cycle events.

Primack et al. 2009, Cook et al. 2012a, and Peñuelas et al. 2013). In particular, migratory species that rely on one primary food source are particularly vulnerable to climate change due to phenological mismatch (GCRP 2018a citing Both et al. 2010, Mayor et al. 2017, and Ohlberger et al. 2014). 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 2016f citing Schwartz et al. 2013). Phenological mismatches that result in unfavorable breeding conditions could cause significant negative impacts on species' breeding processes (GCRP 2014 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). In some ecosystems, higher trophic levels may be more sensitive to climate change than lower trophic levels, which can affect the energy demands and mortality rates of prey, affect overall ecosystem functioning, and alter energy and nutrient flow (GCRP 2018a citing Laws and Joern 2013, McCluney and Sabo 2016, Verdeny-Vilalta and Moya-Laraño 2014, Miller et al. 2014, and Zander et al. 2017).

Species respond to stressors such as climate change by phenotypic[32] or genotypic[33] modifications, migrations, or extinction (IPCC 2014b citing Dawson et al. 2011, Bellard et al. 2012, Peñuelas et al. 2013). Changes in morphology[34] 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 2014b). Climate change has led to range contractions in almost half of studied terrestrial animals and plants in North America (GCRP 2018a citing Wiens 2016). 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, and Stralberg et al. 2009). A recent study suggests that species redistribution is linked to reduced terrestrial productivity, impacts on marine community assembly, and threats to the health of freshwater systems from toxic algal blooms (Pecl et al. 2017).

IPCC concluded with *high confidence* that climate change will exacerbate the extinction risk for terrestrial and freshwater species over the 21st century (IPCC 2014b). A recent study suggests that local extinctions related to climate change are already widespread, with 47 percent of 976 species reviewed having experienced climate-related local extinctions (Wiens 2016). However, there is low agreement on the proportion of current species that are at risk from climate-related extinctions (ranging from 1 to 50 percent) (IPCC 2014b). 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, and McIsaac et al. 2002).

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[32] Referring to an organism's observable traits, such as color or size.

[33] Referring to an organism's genetic makeup.

[34] Referring to an organism's structural or anatomical features (e.g., egg size, wing shape, or even of the organism as a whole).

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.

Climate change may result in more uniform population structures, leading to increased competition and potentially resulting in extinctions (GCRP 2018a citing Ohlberger et al. 2014 and Lancaster et al. 2017). For example, extreme weather events can benefit invasive species by decreasing native communities' resistance and by occasionally putting native species at a competitive disadvantage (GCRP 2018a citing Diez et al. 2012, Kats et al. 2013, Tinsley et al. 2015, and Wolf et al. 2016).

Diverse observations suggest that global terrestrial primary production increased over the latter 20th and early 21st centuries due to a combination of the fertilizing effect of increasing atmospheric CO_2, nutrient additions from human activities, longer growing seasons, and forest regrowth (GCRP 2018a citing Campbell et al. 2017, Graven et al. 2013, Wenzel et al. 2016, Zhu et al. 2016, and Domke et al. 2018). Conversely, in areas experiencing extended drought (such as the western United States in 2014), water stress results in decreased tree growth (IPCC 2014b). 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. 2011). Within a few decades, it is possible that changes in temperature and precipitation patterns will exceed nitrogen and CO_2 as key drivers of ecosystem productivity (IPCC 2014b).

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. 2004 and 2006, 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[35] begin with initial changes in a biological system (for example, the introduction of a new predatory animal species to the system due to changes in climate that are favorable to the newly introduced species), which are then amplified by positive feedback loops and can lead to cascading effects throughout the system. The point at which the system can no longer retain stability is a threshold known as a tipping point. Changes in such situations are often long-lasting and hard to roll back; managing these conditions is often very difficult (IPCC 2014b citing Leadley et al. 2010). Leadley et al. (2010) evaluated the potential tipping point mechanisms and their impacts on biodiversity and ecosystem services for several ecosystems. Examples include warming tundra that will reduce albedo, providing a warming feedback that will result in further thawing of tundra; and the large-scale changes

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[35] An ecological tipping point is described by IPCC (2014b), in reference to the potential for Amazonian ecosystem shifts, as "a large-scale, climate-driven, self-reinforcing transition" of one ecosystem into another type.

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 2014b citing Girardin and Mudelsee 2008, Macias and Johnson 2008, Kasischke et al. 2010, Turetsky et al. 2011, Mann et al. 2012, and 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 2014b citing Bond-Lamberty et al. 2007, Goetz et al. 2007, Welp et al. 2007, Euskirchen et al. 2009, Randerson et al. 2006, Jin et al. 2012, and O'Halloran et al. 2012).

Limiting warming to 2.7°F (1.5°C) compared to 3.6°F (2°C) may benefit terrestrial and wetland ecosystems through avoidance or reduction of changes, such as biome transformation, species range losses, and increased extinction risks (all *high confidence*) (IPCC 2018 citing Hoegh-Guldberg et al. 2018).

Adaptation

In the context of natural resource management, adaptation is about managing changes (GCRP 2014 citing Staudinger et al. 2012, Link et al. 2010, and West et al. 2009). The ability or inability of ecosystems to adapt to change is referred to as adaptive capacity. There could be notable regional differences in the adaptive capacity of ecosystems, and adaptive capacity is moderated by anthropogenic influences and capabilities. The ultimate impact of climate change on ecosystems depends on the speed and extent to which these systems can adapt to a changing climate. 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, and Schwartz et al. 2012). EPA (2016g) 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 2018 NCA report indicates the effectiveness of existing adaptation strategies and approaches may be significantly reduced in the face of a changing climate (GCRP 2018a).

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 2014b).

In general, global ocean surface temperatures have risen at an average rate of 1.3°F ± 0.1°F (0.7°C ± 0.08°C) per century and have risen at a higher rate from 2000 to 2016 than from 1950 to 2016 (GCRP 2018a citing Jewett and Romanou 2017; 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; Cheng et al. 2019). 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 globally live in the Low Elevation Coastal Zone (IPCC 2014b citing McGranahan et al. 2007), with approximately 270 million people exposed to the 1-in-100-year extreme sea level (Jongman et al. 2012). Globally, there has been a net migration to coastal areas, largely in flood- and cyclone-prone regions, increasing the number of individuals at risk (IPCC 2014b citing de Sherbinin et al. 2011). Without adaptation, hundreds of millions of people may be displaced due to episodic localized flooding associated with storm surge and coastal flooding and land loss from sea-level rise by 2100, with the majority from eastern, southeastern, and southern Asia (Jongman et al. 2012; GCRP 2018a).

Even under the RCP2.6 low emissions scenario, the frequency, depth, and extent of high tide and more-severe and damaging coastal flooding in the United States are projected to increase rapidly over the coming decades (GCRP 2018a). In the United States, 133.2 million people live in coastal zone counties (GCRP 2018a citing Kildow et al. 2016), and analysis indicates that 4.2 million Americans could be at risk under a scenario of 3 feet of sea-level rise, and 13.1 million people under 6 feet of sea-level rise, which could drive mass migration and societal disruption (Hauer 2017; Hauer et al. 2016).[36] New high-resolution digital elevation models improve estimates of potential future population exposure to sea-level rise. For example, assuming sea-level rise projections under RCP8.5, these new models reveal that up to 630 million people live on land that could be exposed to annual coastal flood levels in 2100 (Kulp and Strauss 2019). Such increases in sea-level rise and annual flooding present dramatic risks to coastal communities. 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).

Coastal inundation and flooding are the product of both long-term sea-level rise and dynamic short-term processes such as storm surge, erosion, and ocean tides (GCRP 2018a; Barnard et al. 2019). Climate change is expected to exacerbate all of these coastal processes, potentially altering coastal life and disrupting coast-dependent economic drivers and activities and services, some of which—such as transportation and energy infrastructure, and water resources—are particularly sensitive to these changes. (GCRP 2014; IPCC 2014b citing Handmer et al. 2012, Horton et al. 2010, Hanson and Nicholls 2012, and Aerts et al. 2013). Increased sea surface temperature and ocean heat content are projected to facilitate additional tropical storm activity and increase the probability of high rainfall tropical cyclones

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[36] The NOAA Sea Level Rise visualization tool shows inundation footprints associated with different sea-level rise simulations along the continental U.S. coast (NOAA, Office for Coastal Management, DigitalCoast, Sea Level Rise Viewer, https://coast.noaa.gov/digitalcoast/tools/slr.html). This and other tools can be used to understand and assess risks from sea-level rise.

(Trenberth et al. 2018; Emanuel 2017). In turn, extreme storms can erode or remove sand dunes and other land elevations, exposing them to inundation and further change (GCRP 2014). 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). For instance, major marine heat wave events along the Northeast Coast of the United States in 2012 and the entire West Coast in 2014 through 2016 caused ocean temperatures to increase greater than 2°C above the normal range, a level similar to average conditions expected later this century under future climate scenarios (GCRP 2017). These events caused changes in the coastal ecosystems, including the appearance of warm-water species, increased mortality of marine mammals, and an unprecedented harmful algal bloom, all of which contributed to economic stress for the fisheries in these regions.

Species with narrow physiological tolerance to change, low genetic diversity, specific resource requirements, or weak competitive abilities will be particularly vulnerable to climate change (GCRP 2014 citing Dawson et al. 2011 and Feder 2010). For example, during the end-Permian mass extinction, a change in ocean pH of approximately 0.3, which is consistent with current projections for pH changes over the next 100 years, resulted in a loss of approximately 90 percent of known species (NRC 2013b). Under the RCP8.5 scenario, the Atlantic, Pacific, and Indian Oceans are projected to see a 15 to 30 percent decrease in total marine animal biomass by 2100. Meanwhile, polar oceans are projected to see a 20 to 80 percent decrease (Bryndum-Buchholz et al. 2018). Overall, projected shifts in fish and species distribution and decreases in their population due to climate change pose risks to income, food security and livelihoods of marine-based communities (IPCC 2019a).

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, and Hughes et al. 2010). There are already 25 coral species listed under the Endangered Species Act (NOAA 2021). Further, IPCC projects that when average global warming reaches 1.3°C above pre-industrial levels, tropical coral reefs are *virtually certain* to experience high risks of impacts, such as frequent mass mortalities, and at 2°C, most available evidence (*high agreement, robust evidence*) suggests that coral-dominated ecosystems will be nonexistent (IPCC 2013a citing Alvarez-Filip 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 et al. 2007 and Hoegh-Guldberg and Bruno 2010).

Several studies have analyzed the impact of climate change on historical and future coral bleaching. According to an analysis of bleaching records at 100 globally distributed reef locations from 1980 to 2016, the time between recurrent severe coral bleaching events has decreased steadily to 6 years during this period, and coral bleaching is occurring more frequently in all El-Niño-Southern Oscillation phases. These trends prevent the full recovery of mature coral assemblages between bleaching events (Hughes et al. 2018). Based on the high emissions scenario (RCP8.5), by 2055, 90 percent of reef locations are projected to experience annual severe bleaching events, and by 2034, all reef locations are projected to experience 5 percent declines in calcification. In general, the projected year of onset for annual severe bleaching events varies based on latitude, with reefs at lower latitudes expected to experience these events earlier than those at higher latitudes (van Hooidonk et al. 2014; Sully et al. 2019).

NOAA 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 mass loss from mountain glaciers, ice caps, and ice sheets. Sea-level rise was found to be non-uniform around the world, which might result from variations in thermal expansion; exchanges of water, ocean, and atmospheric circulation; and geologic processes (IPCC 2014b; UN 2016). Higher sea levels cause greater coastal erosion; changes in sediment transport and tidal flows; landward migration of barrier shorelines; fragmentation of islands; and saltwater intrusion into aquifers, croplands, and estuaries (GCRP 2014 citing Burkett and Davidson 2012, CCSP 2009, IPCC 2007a, Irish et al. 2010, Rotzoll and Fletcher 2013; Nicholls and Cazenave 2010). Higher sea levels also result in the loss of coastal wetland environments; it was estimated that the United States lost an average of about 80,160 acres of U.S. coastal wetland environments per year between 2004 and 2009 (GCRP 2018a citing Dahl and Stedman 2013). At this rate, the United States would lose an additional 16 percent of coastal wetlands by 2100. 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 2014b).

Oceans have absorbed approximately 28 percent of the human-caused CO_2 over the last 250 years, resulting in a decrease in pH of 0.11 unit[37] 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, and Feely et al. 2009; Longo and Clark 2016 citing Guinotte and Fabry 2008; EPA 2016h). 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 2014b). Increased CO_2 uptake in the oceans makes it more difficult for organisms to form and maintain calcium carbonate shells and skeletal structures; increases erosion and bleaching of coral reefs and their biodiversity; and reduces growth and survival of shellfish stocks globally (GCRP 2014 citing Tribollet et al. 2009, Wisshak et al. 2012, and Doney et al. 2009; Hönisch et al. 2010; Lemasson et al. 2017). For instance, the GCRP notes that under the high emissions scenario (RCP8.5), by 2100, nearly all coral reefs are projected to be surrounded by acidified seawater that will challenge coral growth (GCRP 2018a citing Ricke et al. 2013). IPCC concluded there is *high confidence* that coastal acidification will continue into the 21st century but with large, uncertain regional variation (IPCC 2014b). Further, the GCRP notes that under the RCP8.5 emissions scenario, by 2050, 86 percent of ecosystems will experience combinations of temperature and pH that have never before been experienced by modern species (GCRP 2018a citing Henson et al. 2017).

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 and Gedan 2015). Global ocean oxygen content has

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[37] The pH scale is logarithmic; therefore, each whole unit decrease in pH is equivalent to a 10-fold increase in acidity.

decreased by more than 2 percent since 1960, with large variations in oxygen loss across ocean basins and depths (Schmidtko et al. 2017). Global oxygen content in the upper ocean (0 to 1,000 meters) is also estimated to have changed at the rate of -243 ± 124 10^{12} mol oxygen per decade between 1958 and 2015 (Ito et al. 2017). Accordingly, oxygen-minimum zones have been growing and are projected to continue expanding to temperate and subpolar regions with future warming (IPCC 2014b). Models project 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 and in deep sea areas (Jewett and Romanou 2017 citing Bopp et al. 2013). Decreased oxygen concentrations and hypoxia affect the physiology, behavior, and ecology of marine organisms. For instance, hypoxia has the potential to affect the visual behavior of organisms as visual tissues have high oxygen demands (McCormick and Levin 2017). Hypoxia may also cause deterioration in the reproductive systems of both male and female fish, leading to a significant decrease in hatching success (Lai et al. 2019). 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 2014b citing Durack et al. 2012). Evaporation-dominated subtropical regions are exhibiting definite salinity increases, while regions dominated by precipitation are undergoing increasing freshening in response to intensification of the hydrological cycle. These effects are amplified in regions that are experiencing increasing precipitation or evaporation. Findings through surface water analyses of the Atlantic Ocean show increased salinity, while the Pacific Ocean demonstrates decreased salinity, and the Indian Ocean has observed minimal changes (Durack and Wijffels 2010).

Net primary production refers to the net flux of carbon from the atmosphere into organic matter over a given period.[38] 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 2014b). 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 2016).

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[38] 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 2014b citing Nicholls et al. 2011), which are all widely used around the world (IPCC 2014b 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 2014b). 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 2014b citing Schmitt et al. 2013), oyster reefs (IPCC 2014b citing Beck et al. 2011), and salt marshes (IPCC 2014b citing Barbier et al. 2011) are increasingly attracting attention (IPCC 2014b citing Munroe et al. 2011). In addition, reducing nonclimate stresses (e.g., coastal pollution, overfishing, development) may increase the climate resilience of framework organisms (i.e., tropical corals, mangroves, and seagrass) (World Bank 2013; Ellison 2014; Anthony et al. 2015; Sierra-Correa and Cantera Kintz 2015; Kroon et al. 2016; O'Leary et al. 2017; Donner 2009).

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[39]) 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 2014d; 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 2014b; Walthall et al. 2013); however, most predictions for climate change impacts on crop yields by 2050 are negative (Nelson et al. 2014; IPCC 2014b; 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

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[39] 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.

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 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 Lobell 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 2014b; GCRP 2017, 2018a). 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, 2018a; IPCC 2014b; USDA 2015; EPA 2016h; USFS 2016; Vogel et al. 2019b). 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, 2018a; USDA 2015). Changes in these and other ecosystem services will exacerbate stresses on crops, livestock, and forests (Walthall et al. 2013; GCRP 2014, 2018a). Major staple crops (wheat, rice, maize, and soybean) could suffer reduced yields between 3 and 7.4 percent for each degree-Celsius increase in global mean temperature (Zhao et al. 2017). 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 2014b; IPCC 2014b 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; GCRP 2018a citing Key et al. 2014, Amundson et al. 2006, Dash et al. 2016, Rojas-Downing et al. 2017, Giridhar and Samireddypalle 2015, Lee et al. 2017, Paul et al. 2007, and Zhorov 2013). Overall, climate change is predicted to negatively affect livestock on almost all continents (IPCC 2014b). Climate change impacts on agriculture may also affect socioeconomic conditions, such as the amount of crop insurance paid to cover losses from extreme climate conditions (Walsh et al. 2020).

Studies have concluded that climate change is affecting aquatic ecosystems, including marine and freshwater fisheries (IPCC 2014b; 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 and ocean acidification (IPCC 2014b; GCRP 2018a). 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 2014b; NOAA 2015a). The Food and Agriculture Organization of the United Nations estimates that by 2050, the average total marine maximum catch potential in the world's Exclusive Economic Zones could decline by 7 to 12 percent (relative to 2000) under a higher emissions scenario (RCP8.5); by 2100, this decrease could be as much as 16 to 25 percent (Bell and Bahri 2018 citing FAO 2018). However, these decreases would not be consistent around the globe. Another study found that fisheries productivity could experience a decline in maximum catch potential of 10 to 47 percent as compared to the 1950–1969 level under RCP8.5 in the contiguous United States and increase in potential of 10 percent in the Gulf of Alaska and 46 percent in the Bering Sea (GCRP 2018a citing Cheung et al. 2016).

Climate change threatens forests by increasing tree mortality and forest ecosystem vulnerability due to fire, insect infestations, drought, disease outbreaks, increasing temperatures, and extreme weather events (Joyce et al. 2014; IPCC 2014b; USFS 2016; GCRP 2018a; Aleixo et al. 2019; Williams et al. 2019). Currently, tree mortality is increasing globally due in part to high temperatures and drought (IPCC 2014b). 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 2014b). However, due to the lack of models and limited long-term studies, projections of global tree mortality are currently highly uncertain (IPCC 2014b citing McDowell et al. 2011). GCRP estimates that water-limited forests will be further constrained by a warmer climate, while energy-limited forests may experience an increase in growth due to climate change (GCRP 2018a).

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 2014b; GCRP 2014; IPCC 2014b citing Allen et al. 2010a). A dramatic increase in the area burned by wildfire and risk of wildfire is projected in the contiguous United States through 2100, especially in the West (EPA 2015c; Halofsky et al. 2017; Tett et al. 2018). 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 2014b). GCRP expects carbon storage to generally decrease in the future due to increased temperatures, more frequent droughts, and increased disturbances (GCRP 2018a). In recent years, the rate of sequestration of excess carbon by intact and newly growing forests appears to have stabilized (IPCC 2014b citing Canadell et al. 2007 and Pan et al. 2011). Warming, changes in precipitation, pest outbreaks, and current social trends in land use and forest management are projected to affect the rate of CO_2 uptake in the future (Joyce et al. 2014; IPCC 2014b citing Allen et al. 2010a), making it difficult to predict whether forests will continue to serve as net carbon sinks in the long term (IPCC 2014b). In addition, historic land uses have a legacy effect on patterns of carbon uptake in forests, further complicating the calculation of future CO_2 sequestration patterns (Thom et al. 2018).

Climate change impacts on food security and food systems are predicted to be widespread, complex, geographically and temporally variable, and greatly influenced by socioeconomic conditions (IPCC 2014b citing Vermeulen et al. 2012). For example, smallholder farmers—a group that suffers from chronic food insecurity—are especially vulnerable to the risks of pests, diseases, and extreme weather events that are made worse by climate change (Mbow et al. 2019). An additional challenge for food security will be future population growth, with global population projected to reach 9.8 billion by 2050 (GCRP 2018a citing Hallström et al. 2015, Harwatt et al. 2017, U.N. Department of Economic and Social Affairs 2017). Food security comprises four key components: production; processing, packaging, and storage; transportation; and utilization and waste (GCRP 2014 citing FAO 2011), all of which are closely tied to poverty (IPCC 2014b). Projected rising temperatures, changing weather patterns, and increases in the frequency of extreme weather events will affect food security by potentially altering agricultural yields, post-harvest processing, food and crop storage, transportation, retailing, and food prices (GCRP 2014). 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). The negative consequences of climate change—decreased crop yields, nutrition, and food security—are projected to be more severe under 2°C of warming than under 1.5°C of warming (*high confidence)* (IPCC 2018).

Currently, the vast majority of undernourished people live in developing countries (IPCC 2014b). 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 2014b). Economic literature indicates that in the short term, producers will continue current adaptation practices for weather changes and shocks (e.g., by changing timing of field operations, shifts in crops grown, changing tillage/irrigation practices) (GCRP 2014 citing Antle et al. 2004). In the long term, however, current adaptation technologies are not expected to buffer the impacts of climate change sufficiently (GCRP 2014, 2018a). In fact, significant shifts in crop choice and land-use patterns will be required in order to sustain production growth and match global demand (Mbow et al. 2019).

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; Li et al. 2019). Furthermore, the use of heat- and stress-tolerant and other adaptively advantageous varieties of crops can aid in yield increases in the face of climate change (Zhang and Zhao 2017; GCRP 2018a). 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 and Lin 2011).

For livestock, adaptive capacity is limited by high costs and competition. Possible adaptation measures include breeding livestock to genetically adapt to local conditions, improving the design of livestock housing, and implementing management strategies that cool livestock and reduce stress (GCRP 2018a). However, 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). At the same time, possible projected declines in a skilled forest sector workforce and timber product output (and lower prices for timber) could pose a challenge to climate change adaptation of forests (GCRP 2018a citing U.S. Forest Service 2016). 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 2014b citing UN DESA Population Division 2013 and World Bank 2008). In the United States, approximately 85 percent of the population lives in metropolitan areas[40] (GCRP 2018a). In addition to large numbers of people, urban centers also contain a great concentration of the world’s economic activity, infrastructure, and assets (IPCC 2014b citing UN DESA Population Division 2013 and World Bank 2008; GCRP 2018a). However, definitions of urban centers and their boundaries vary greatly between countries and between various pieces of academic literature (IPCC 2014b).

Wealthy nations are predominantly urbanized, and low- and middle-income nations are rapidly urbanizing. The rate of urbanization is outstripping the rate of investment in basic infrastructure and services, which is creating urban communities with high vulnerability to climate change (IPCC 2014b citing Mitlin and Satterwaite 2013). Across urban communities, there are very large differences in the extent to which economies are dependent on climate-sensitive resources, but in general, a high

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[40] 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).

proportion of people most at risk of extreme weather events are located in urban areas (IPCC 2014b 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 2014b). 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, some communities of color and tribal and Indigenous communities are disproportionately exposed to health risks related to climate hazards, 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 (Ebi et al. 2018; IPCC 2014b; Cutter et al. 2014; GCRP 2014 citing Bates and Swan 2007, NRC 2006, and Phillips et al. 2009). In turn, some populations most vulnerable to climate-related health hazards also experience greater challenges in accessing information, resources, and tools for building resilience to climate change (Ebi et al. 2018).

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) (GCRP 2018a citing Hibbard et al. 2017; IPCC 2014b, 2019b). This could lead to increased health impacts, air pollution, and energy demand, disproportionately affecting low-income, young, historically underserved, and elderly populations (IPCC 2014b citing Hajat et al. 2010, Blake et al. 2011, Basagaña 2019, Campbell-Lendrum and Corvalan 2007, and Lemonsu et al. 2013, Akbari et al. 2016; Hoffman et al. 2020). 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; National Academies of Sciences, Engineering, and Medicine 2019).

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 2014b 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 2014b citing Fane and Turner 2010, Major et al. 2011, and Muller 2007). Additionally, urban populations could be affected by "reductions in groundwater and aquifer quality…, subsidence, and increased salinity intrusion" (IPCC 2014b). 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 2014b citing Howard et al. 2010, Mitlin and Satterthwaite 2013, and Wong and Brown 2009). If storm drains for transportation assets are blocked, then localized flooding can cause delays (GCRP 2014).

Climate change will have direct impacts on both the production and the demand side of the energy system. For example, individual or combinations of hazards may increase risk of direct physical damage to generation as well as transmission and distribution systems, reduce the efficiency of water cooling for large thermoelectric electricity generating facilities, reduce water availability for hydroelectric and wind power potential, and change demands for heating and cooling in developed countries (GCRP 2014; IPCC 2014b citing Mideksa and Kallbekken 2010, DOE 2015a; National Academies of Sciences, Engineering, and Medicine 2017a). 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 and GCRP 2014). They may also be negatively affected by the vulnerability of transportation systems that provide feedstocks such as coal (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 (GCRP 2018a; IPCC 2014b 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, Markolf et al. 2019, Cambridge Systematics Inc. and Texas Transportation Institute 2005, and Schrank et al. 2011; IPCC 2014b citing Love et al. 2010). With climate change, the reliability and capacity of the transportation network could be diminished from an increased frequency of flooding and heat events and an increased intensity of tropical storms (GCRP 2014 citing NRC 2008; DOT 2019a). Telecommunication systems are also sensitive to flooding of electrical support systems, wind damages to cellular phone towers, corrosion due to flooding and sea-level rise, and unstable foundations due to permafrost melt (IPCC 2014b citing Zimmerman and Farris 2010 and Larsen et al. 2008).

Housing in urban areas is one of the pieces of infrastructure most heavily affected by extreme weather events such as cyclones and floods (IPCC 2014b citing Jacobs and Williams 2011). Housing that is constructed out of informal building materials (usually occupied by low-income residents) and without strict building codes is particularly vulnerable to extreme events (IPCC 2014b citing UNISDR 2011). Increased weather variability, including warmer temperatures, changing precipitation patterns, and increased humidity, accelerates the deterioration of common housing building materials (IPCC 2014b citing Bonazza et al. 2009, Grossi et al. 2007, Smith et al. 2008, Stewart et al. 2011, and Thornbush and Viles 2007). Loss of housing due to extreme events and shifts in climate patterns is linked to displacement, loss of home-based businesses, and health and security issues (IPCC 2014b citing Haines et al. 2013). Some of the climate impacts described here (e.g., property damage associated with greater flood risk) are sometimes described as costs of carbon in analyses of the social cost of carbon (National Academies of Sciences, Engineering, and Medicine 2017b).

Climate change will also affect urban public services such as healthcare and social care services, education, police, and emergency services (IPCC 2014b citing Barata et al. 2011). The links between city sectors can mean that climate stressors have cascading impacts across sectors; these impacts increase risk to urban dwellers' health and well-being and make urban areas more vulnerable to disruptions (GCRP 2018a; GCRP 2018a citing Torres and Maletjane 2015). Water shortages can lead to reliance on poorer quality water sources and can increase the likelihood of contracting waterborne illnesses. Changes in temperature extremes will also impact health through heat stress (IPCC 2014b) and changes in air quality (IPCC 2014b citing Athanassiadou et al. 2010); however, impacts of climate change on air quality in particular locations are highly uncertain (IPCC 2014b 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 (GCRP 2018a; GCRP 2018a citing Department of the Interior Strategic Sciences Group 2013, C40 Cities Climate Leadership Group and Arup 2015, and Arup et al. 2013), but early action by urban governments is key to successful adaptation since adaptation measures need to be integrated into local investments, policies, and regulatory frameworks (IPCC 2014b). Existing risk reduction plans, such as public health and natural hazard mitigation plans, provide strong foundations for the development of more comprehensive and forward-thinking documents that address increasing exposure and vulnerability (IPCC 2014b). 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; GCRP 2018a citing Bierbaum et al. 2013, Hughes 2015, and Rosenzweig et al. 2015). Taking a long-term view toward planning is important so that future climate impacts do not undermine plans put in place now (GCRP 2018a).

Financing adaptation strategies could be one of the largest hurdles to overcome; however, urban adaptation can enhance the economic competitiveness of an area by reducing risks to businesses, households, and communities (IPCC 2014b). Additionally, there are emerging synergistic options for urban adaptation measures that also deliver GHG emissions reductions co-benefits (IPCC 2014b).

Rural Areas

This section defines rural areas and describes the existing conditions and potential vulnerability to climate change impacts. There is no clear definition of rural areas—frequently, rural areas are simply defined as areas that are not urban (IPCC 2014b citing Lerner and Eakin 2010). A consistent definition is difficult to reach because human settlements exist along a continuum from urban to rural with many varied land use forms in between and varying development patterns between developed and developing countries. In general, IPCC and this SEIS 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 2014b citing UN DESA Population Division 2013). The U.S. Census Bureau classifies more than 95 percent of the land area in the United States as rural but only 19 percent of the population calls these areas home (GCRP 2014 citing HRSA 2012, U.S. Census Bureau 2012a, 2012b, 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 (GCRP 2018a; IPCC 2014b). 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 and are frequently dependent on natural resources that have unknown future availability such as agriculture, fishing, and forestry (GCRP 2014, 2018a; IPCC 2014b). In addition, communities that rely on mining and extraction will be affected by changes in the water, energy, and transportation sectors (IPCC 2014b; 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 2014b citing Morton 2007 and 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 2014b citing Handmer et al. 2012; Ericksen et al. 2012), inland flooding, sea-level rise, and wildfires (Hales et al. 2014; Gowda et al. 2018).

Rural areas frequently depend on groundwater extraction and irrigation for local agriculture (IPCC 2014b 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 2014b; 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 2014b), 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, 2018a; IPCC 2014b 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 2014b). 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 2014b 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 2014b citing Nyaupane and Poudel 2011, Scott et al. 2007, Hein et al. 2009, Wolfsegger et al. 2008, and Collins 2008). Tourism patterns could be affected by changes to the length and timing of seasons, temperature, precipitation, and severe weather events (GCRP 2014). Changes in the economic values of traditional recreation and tourism locations will affect rural communities because tourism makes up a significant portion of rural land use (IPCC 2014b citing Lal et al. 2011). Coastal tourism is vulnerable to cyclones and sea-level rise (IPCC 2014b citing Klint et al. 2012 and Payet and Agricole 2006) as well as beach erosion and saline intrusion (IPCC 2014b). Nature-based tourism may be affected by declining biodiversity and harsher conditions for trekking and exploring (IPCC 2014b citing Thuiller et al. 2006 and Nyaupane and Chhetri 2009). Winter sport tourism may be affected by declining snow packs and precipitation falling more frequently as rain rather than snow due to warmer temperatures (IPCC 2014b).

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 2014b). Temporary responses to food and water shortages or extreme events could even increase the long-term vulnerability of a community. For example, in Malawi, forest resources are used for coping with food shortages, but this deforestation enhances the community’s vulnerability to flooding (IPCC 2014b citing Fisher et al. 2010). Successful adaptation should allow for the development of long-term strategies that not only respond to climate events but also minimize future vulnerabilities (IPCC 2014b citing Vincent et al. 2013).

Adaptation in rural communities also faces challenges posed by the lack of economic diversity, relatively limited infrastructure and resources, and decreased political influence (GCRP 2018a citing U.S. House of Representatives 2017, Kuttner 2016, and Williamson et al. 2012). Funding for adaptation in rural areas could be linked to other development initiatives that aim to reduce poverty or generally improve rural areas (IPCC 2014b citing Nielsen et al. 2012, Hassan 2010, and Eriksen and O’Brien 2007).

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 of climate change 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 (Watts et al. 2019). Climate change is expected to exacerbate some existing health threats and create new challenges, and a greater number of people could be exposed (GCRP 2018a). At the same time, climate change could decrease the capacity of health systems to manage changes in health outcomes due to climate shifts.

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 2021j).

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 2021j; 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).

Across climate risks, those experiencing discrimination, low-income populations, some communities of color, and older adults and children often experience disproportionate health impacts (Ebi et al. 2018). Populations with greater health and social vulnerability often have less access to resources, information, institutions, or other factors that could help avoid or prepare for the health risks of climate change (Ebi et al. 2018).

One direct way that climate change is projected to affect human health is through increasing exposure to extreme heat, which is the leading source of weather-related deaths in the United States (Nahlik et al. 2017; Sailor et al. 2019). Hospital admissions and emergency room visits tend to increase during hot days with heat-related illnesses, including cardiovascular and respiratory complications, renal failure, electrolyte imbalance, and kidney stones (GCRP 2018a). These hospitalizations come at a monetary cost to patients, who are more likely to be adults over 65 years, African-Americans, Asians/Pacific Islanders, and women (Schmeltz et al. 2016). Higher than usual temperatures can cause heat exhaustion and heat stroke, and exacerbate other cardiovascular and pulmonary conditions (Mora et al. 2017a; Tianqi et al. 2017 citing Borden and Cutter 2008, Bouchama et al. 2007, and Wilker et al. 2012).

Certain populations are more vulnerable to extreme heat events than others. 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 2021j; 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). Higher temperatures and humidity can create negative health outcomes for people engaging in physical activity, or for those who work outside (IPCC 2018). Worker safety and productivity during the hottest days and months will be a greater challenge under a changing climate (IPCC 2018). Certain geographic areas are more likely to experience damaging heat events. For example, the risk of heat waves will be higher in cities as a result of the urban heat island effect (IPCC 2018; GCRP 2018a). Additionally, increased mortality from extreme heat exposure will be more marked in regions that are currently warmer and poorer, particularly around the equator (Gasparrini et al. 2017; Mora et al. 2017a). With 1.5°C of warming, twice as many megacities will be exposed to heat stress, which would expose approximately 350 million additional people to dangerous heatwave conditions by 2050 (IPCC 2018). Globally, roughly 30 percent of the world’s population is exposed to potentially deadly heat conditions. This is projected to increase to about 48 percent under a moderate emissions scenario (RCP4.5) and up to 74 percent under a high emissions scenario (RCP8.5) by 2100 (Mora et al. 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 (GCRP 2018a; EPA 2021j, 2015c; IPCC 2014b citing Ebi and Mills 2013 and Kinney et al. 2010; 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 particulate matter 2.5 microns or less in diameter (PM2.5) and affect their dispersion and transport, affecting ozone and PM2.5 concentrations. Climate change could increase ground-level concentrations of ozone or PM 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). Ozone formation is temperature-dependent and increases in ozone levels could result in more ozone-related mortality (IPCC 2018). 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 2014b 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; Silva et al. 2017).

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, and Trail et al. 2014). Overall, however, eastern, midwestern, and southern states are projected to experience degraded air quality associated with climate change (EPA 2015c; GCRP 2016).

Climate change can also affect air quality through an increasing number of wildfires and changing precipitation patterns. Wildfires produce PM pollutants and ozone precursors that diminish both air quality and human health (EPA 2021j; GCRP 2016; Reid et al. 2016, 2019). The public health burden (in terms of number and economic value of wildfire morbidity and mortality) is “considerable,” with an economic value of up to $20 billion from short-term exposure cases and up to $130 billion for long-term exposure cases (in 2010 dollars) (Fann et al. 2018). 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 2014b 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 2021j; GCRP 2014 citing Sheffield et al. 2011a, Emberlin et al. 2002, Pinkerton et al. 2012, Schmier and Ebi 2009, Shea et al. 2008, Sheffield and Landrigan 2011, and Ziska et al. 2011; 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 2014b). Increases in pollen and other aeroallergens can exacerbate asthma and other health problems such as conjunctivitis and dermatitis (EPA 2021j; IPCC 2014b citing Beggs 2010). Exposure to air pollutants such as increased ozone or PM 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 2021j; IPCC 2014b). Also, changing weather patterns may shift the geographic range, seasonality, and intensity of climate-sensitive infectious disease transmission (IPCC 2018). 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 with increased pathogens and toxic algal blooms (GCRP 2018a; EPA 2021j; GCRP 2016). Diarrheal disease rates are also linked to temperatures (IPCC 2014b). More frequent and intense rainfall and storm surge events could lead to combined sewer overflows that can contaminate water resources, (GCRP 2018a; EPA 2021j; IPCC 2014b citing Patz et al. 2008) and changes in streamflow rates can precede diarrheal disease outbreaks like salmonellosis and campylobacteriosis (GCRP 2014 citing Harper et al. 2011 and Rizak and Hrudey 2008; GCRP 2016). In general, heavy rainfall, flooding, and high temperatures are associated with higher rates of diarrheal disease (GCRP 2018a). 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). Higher temperatures are expected to increase Vibrio, a temperature-sensitive and dangerous marine pathogen (GCRP 2018a; Muhling et al. 2017). 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 (GCRP 2018a; EPA 2021j; IPCC 2014b; Bouchard et al. 2019; 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 (Watts et al. 2017; GCRP 2014 citing Mills et al. 2010, Diuk-Wasser et al. 2010, Ogden et al. 2008, Keesing et al. 2009, The Community Preventive Services Task Force 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 2014b citing van der Leun et al. 2008, Correa et al. 2013, and 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 2021j). Climate change is associated with mental health consequences ranging from stress to clinical disorders, such as anxiety, depression, post-traumatic stress disorder, and thoughts and acts of suicide (GCRP 2018a; Burke et al. 2018; Khafaie et al. 2019). Extreme weather conditions can increase stress population-wide, which can exacerbate preexisting mental health problems and even cause such conditions (EPA 2021j; IPCC 2014b). For example, individuals experiencing loss due to flood or risk of flood report high levels of depression and anxiety, which could persist for years after the event (GCRP 2018a). Children, the elderly, women, people with preexisting mental illness, the economically disadvantaged, Indigenous communities, the homeless, and first responders are at higher risk for distress and adverse mental health consequences from exposure to climate-related disasters (GCRP 2018a; EPA 2021j; GCRP 2016 citing Osofsky et al. 2011 and 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; Rylander et al. 2013). Heat can also affect mental health and has been known to increase aggressive behaviors, in addition to increasing suicide rates, dementia, and problems for patients with schizophrenia and depression (GCRP 2018a; EPA 2021j; 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 (2014b) 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 2014b). 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 2014b).

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.

At the state level, governments can conduct vulnerability and adaptation assessments, develop emergency response plans for climate events, develop climate-proof healthcare infrastructure, and integrate surveillance systems for infectious disease (IPCC 2018).

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). Heatwave early-warning systems can also be used to reduce injuries, morbidity, and mortality due to heatwaves (IPCC 2018). 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 and EPA 2012b; Boumans et al. 2014; McDonald et al. 2016). GHG reduction policies can also create co-benefits for air pollution by reducing pollutants, such as PM, SO_2, nitrogen dioxide, and other harmful pollutants (IPCC 2018). Thus, mitigation strategies can 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 2014b). As there are multiple drivers of human security, it can be difficult to establish direct causation between climate change and impacts on human security. The connections between climate and national security are complex because national security can be affected by a variety of secondary impacts such as resource scarcity and competition (GCRP 2018a). Rather than directly causing conflict, climate stress could drive changes in commodity prices or food and water insecurity, which are drivers of conflict (GCRP 2018a). Overall, the research literature finds that climate change has negative impacts on various dimensions of human security, including livelihoods, food, water, cultures, migration, and conflict. However, some dimensions of human security are driven more by economic and social forces rather than by climate change (IPCC 2014b). As the Department of Defense concluded in a 2015 report to Congress, 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 2014b). Even with an increase of approximately 1.5°C by 2030, climate change will be a “poverty multiplier” that increases levels of poverty and the number of people living in poverty (IPCC 2018 citing Hallegatte et al. 2016 and Hallegatte and Rozenberg 2017). 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 2014b 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 of food insecurity include the urban poor and the rural and indigenous communities whose livelihoods are highly dependent upon natural resources (GCRP 2014, 2018a).

Around the world, it is increasingly challenging for indigenous communities to maintain cultures, livelihoods, and traditional food sources in the face of climate change (IPCC 2014b citing Crate and Nuttall 2009 and Rybråten and Hovelsrud 2010; GCRP 2014 citing Lynn et al. 2013). The impacts of climate change are expected to be more significant in places where indigenous people live and on traditional ecological knowledge (IPCC 2018 citing Olsson et al. 2014). Many studies indicate that further significant changes in the natural resource base would negatively affect indigenous cultures, particularly if people are confined to particular territories created by treaties; if natural resources are lost within that territory, that is a permanent loss to the tribe and their culture (GCRP 2018a; IPCC 2014b 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). Ultimately, this could make life on ancestral lands untenable (IPCC 2018). 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 2014b 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 2014b 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 2014b citing Hitchcock 2009, McNeeley 2012, and Maldonado et al. 2013); “if policy and disaster relief creates dependencies” (IPCC 2014b citing Wenzel 2009 and Fernández-Giménez et al. 2012); “in circumstances of inadequate entitlements, rights, and inequality” (IPCC 2014b citing Shah and Sajitha 2009 and Green et al. 2010; GCRP 2014 citing Lynn et al. 2013); and “when there are constraints to the transmission of language and knowledge between generations” (IPCC 2014b citing Forbes 2007) (IPCC 2014b). Lack of involvement in formal government decision-making over resources also decreases the resilience of indigenous peoples and their cultures to climate change impacts (IPCC 2014b citing Ellemor 2005, Brown 2009, Finucane 2009, Turner and Clifton 2009, Sánchez-Cortés and Chavero 2011, and Maldonado et al. 2013).

Climate change is expected to increase internal migration and displacement, in part due to extreme events or long-term environmental changes (IPCC 2018 citing Albert et al. 2017; Heslin et al. 2019). However, the causation and extent of this risk is hard to determine due to the complexity of migration decisions (IPCC 2018). 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 2014b). Projections indicate that 4.2 million Americans could be at risk with 3 feet of sea-level rise, and 13.1 million people with 6 feet of sea-level rise, which could drive mass migration and societal disruption

(Hauer 2017; Hauer et al. 2016). In the past, major extreme weather events have led to significant population displacement (IPCC 2014b). For example, after Hurricane Katrina, refugees from coastal areas spread to all 50 states, which resulted in economic and social costs around the country (GCRP 2018a). 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 2014b). As a result, only a portion of displacement leads to permanent migration (IPCC 2014b citing Foresight 2011 and Hallegatte 2012).

Climate-driven migration outside of the United States could have implications for national security, either due to immigrants to the United States or instability abroad. For example, there could be significant population displacement in the tropics due to warming. Tropical populations may have to move more than 1,000 kilometers by the end of the century, which could lead to a concentration of displaced persons on the margins, contributing to higher population densities in destination areas (IPCC 2018 citing Hsiang and Sobel 2016). Some of these refugees could come to the United States. For example, the United States granted Temporary Protected Status to 57,000 Honduran and 2,550 Nicaraguan nationals after Hurricane Mitch (GCRP 2018a).

Long-term changes in climate conditions, such as droughts or land degradation, have greater potential to result in permanent migration (Brzoska and Frohlich 2015). For example, higher temperatures have contributed to outmigration in 163 countries, specifically for those dependent on agriculture (IPCC 2018 citing Cai et al. 2016). According to the International Migration Database of the Organisation for Economic Co-operation and Development, a 1°C increase in temperature contributed to a 1.9 percent increase in migration flows from 142 countries moving to 19 receiving countries, and an additional increase in precipitation of 1 millimeter could increase migration by 0.5 percent (IPCC 2018 citing Backhaus et al. 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 2014b 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 2011b). Displacement affects human security by affecting housing, health, and economic outcomes (IPCC 2014b 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 2014b 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 2014b 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 2014b 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 2014b). Most studies find that climate change impacts on armed conflict is negligible in situations where other risk factors are extremely low, such as where per capita incomes are high or governance is effective and stable (IPCC 2014b citing Bernauer et al. 2012, Koubi et al. 2012, Scheffran et al. 2012, and Theisen et al. 2013). 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 2014b citing Bernauer et al. 2012, Gleditsch 2012, Scheffran et al. 2012, and Hsiang et al. 2013). It is, however, not possible to make confident statements regarding the impacts of future climate change on armed conflict due to the lack of "generally supported theories and evidence about causality" (IPCC 2014b).

The 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 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 2015). For example, drought may increase the likelihood of sustained conflict, particularly for groups dependent on agricultural livelihoods, which are more vulnerable to climate change (IPCC 2018). With a 1°C increase in temperature or a greater intensity of extreme rainfall events, intergroup conflicts could increase in frequency by 14 percent (IPCC 2018 citing Hsiang et al. 2013).

Climate change can compromise state integrity by affecting critical infrastructure, threatening territorial integrity, and increasing geopolitical rivalry (IPCC 2014b). Climate change impacts on critical infrastructure will reduce the ability of countries to provide the economic and social services that are important to human security (IPCC 2014b). For example, extreme heat, storms and floods, and sea-level rise could directly affect military assets, such as roads, airport runways, and coastal infrastructure; disrupt supply chains; endanger personnel; inhibit training; and increase operating costs (GCRP 2018a). In addition, 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 2011b, 2013c; CNA Corporation 2014). Power outages and fuel shortages could affect the energy system, which could have cascading impacts on critical sectors that support the economy and national security (GCRP 2018a). 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 2011b; CNA Corporation 2014).

Sea-level rise, storm surge, and coastal erosion can threaten the territorial integrity of small island nations or countries with significant areas of soft low-lying coasts (IPCC 2014b citing Hanson et al. 2011, Nicholls et al. 2011, Barnett and Adger 2003, and Houghton et al. 2010). 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 2014b; 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 and 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 2014b). 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 2014b). There is not enough evidence on the effectiveness of migration and resettlement as adaptation. Migration is costly and disruptive and is thus often perceived as an adaptation of last resort (IPCC 2014b citing McLeman 2009). Poorly designed adaptation strategies can increase the risk of conflict and amplify vulnerabilities in certain populations, if they exacerbate existing inequalities or grievances over resources (IPCC 2014b).

Local and traditional knowledge is a valuable source of information for adapting to climate change (IPCC 2014b; GCRP 2014). There is high agreement in the literature that the integration of local and traditional and scientific knowledge increases adaptive capacity (IPCC 2014b citing Kofinas 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 2014b; GCRP 2014). As a result, current traditional knowledge strategies could be inadequate to manage projected climate changes (IPCC 2014b 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 2014b).

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).[41] 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).

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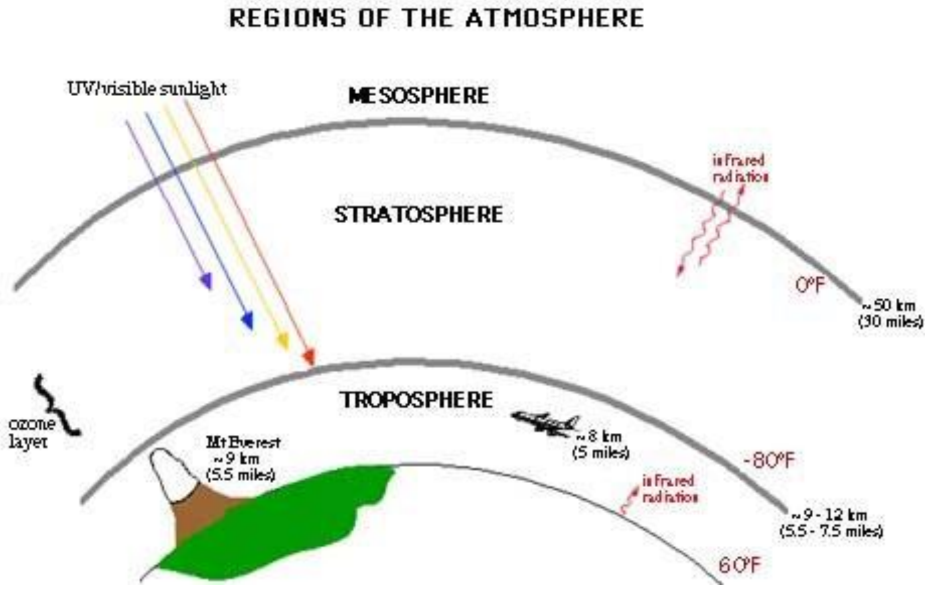
[41] These height measurements defining the bottom and top of the stratosphere vary depending on location and time of year. Different studies might provide similar but not identical heights. The heights indicated for the stratosphere and the layers within the stratosphere are provided in this section 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 CH_4. 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 2014b). 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; Langematz 2019). In response to these efforts, the rate of stratospheric ozone reduction has slowed. Although there are elements of uncertainty, stratospheric ozone concentrations are projected to recover to pre-1980 levels over the next several decades (Fahey and Hegglin 2011; WMO 2011), with further thickening of the ozone layer possible by 2100 in response to climate change (IPCC 2014b citing Correa et al. 2013).

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.[42] 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 reduces radiative forcing and hence reduces the heating of the atmosphere. However, HFCs were not included in the Montreal Protocol. Evidence shows that HFCs could contribute to anthropogenic climate

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[42] 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.

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 nitrous oxide [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).[43] 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 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).

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[43] 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).

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, 2019b). 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” around Greenland that steered the storm toward the mainland and may have been caused by reduced summer sea ice in the region (GCRP 2017).

The interconnectedness of the ocean and cryosphere can also lead to a type of compounding event called a cascade, where changes in one event trigger and increase the likelihood of secondary changes in different but connected elements of the system (IPCC 2019a). For example, enhanced melting and mass loss from ice sheets creates a huge flux of freshwater and iron to the ocean, which can, in turn, have dramatic effects on ocean productivity. Similarly, increasing ocean temperatures and sea level can affect ice shelf, ice sheet, and glacier stability because of the nonlinear response of ice melt, and calving, to ocean temperatures (IPCC 2019a). In this case, small increases in ocean temperature have the potential to destabilize large sections of ice sheets and contribute to large sea-level rise changes (IPCC 2019a).

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 decrease the rate of CO_2 emissions relative to the No Action Alternative, they would contribute to the general decreased risk of extreme compound events. While this rulemaking alone would not necessarily cause decreases in compound event frequency and severity from climate change, it would be one of many global actions that, together, could reduce 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. A recent study suggests that passing some tipping points may increase the likelihood of occurrence of other tipping points (Cai et al. 2016). The following discussion provides examples of tipping points in Earth systems.

Climate feedbacks can also drive tipping points in the climate system. In particular, positive climate feedbacks amplify the impacts of anthropogenic emissions. For example, CO_2 emissions increase atmospheric temperatures, which increase the likelihood of wildfires that, in turn, release more CO_2 into the atmosphere (Liu et al. 2014). Climate feedbacks are complex and not always incorporated into future climate models, and could lead to tipping points being crossed earlier than anticipated.

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 2018 study indicates that these effects are underway, quantifying a 15 percent weakening since the mid-20th century and an overall weakening over the past 150 years (GCRP 2018a citing Caesar et al. 2018, Thornalley et al. 2018)

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, under 2°C (3.6°F), about one-third of the Antarctic ice sheet and three-fifths of the Greenland ice sheet would be lost (GCRP 2018a citing Clark et al. 2016). Similarly, 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. The temperature range of 1.5-2°C (2.7-3.6°F) presents a moderate risk of triggering marine ice sheet instability in Antarctica or irreversible loss of the Greenland ice sheet (IPCC 2018).

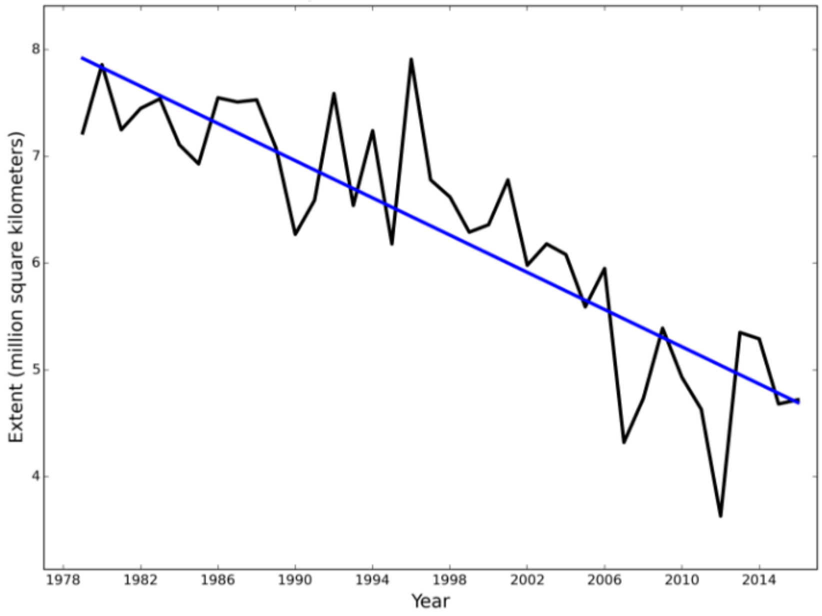
Of particular concern is the potential for abrupt increases in sea-level rise from rapid destabilization and ice loss from glaciers and ice streams grounded on bedrock below sea level. For these glaciers, warming oceans melt and erode the base and cause the ice to float, accelerating losses. In Greenland, most areas of deep water contact between ice sheets and the ocean are limited to narrow troughs and fjord systems that constrict rapid flow into ocean basins, making the likelihood of rapid destabilization during this century 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).

Sea ice loss contributes to positive feedback by changing the albedo of the Arctic's surface, affecting formation of ice the next winter (GCRP 2018a citing Abe et al. 2016, Pedersen et al. 2016, and Post et al. 2013). 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. For instance, sea ice is the primary habitat for polar bears. Polar bear movements are closely tied to the seasonal dynamics of sea-ice extent, and the loss of sea-ice habitat due to climate change is a primary threat to polar bears (USFWS 2016). 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). A recent study indicates that the Earth may be approaching an approximate 2°C threshold after which the system as a whole would be locked into a rapid pathway toward much hotter conditions that would be accelerated by self-reinforcing feedbacks (Steffen et al. 2018).

Delaying Mitigation

Several studies have shown that delaying mitigation of GHG emissions results in a greater accumulation of CO_2 in the atmosphere, thereby increasing the risk of crossing tipping points and triggering abrupt changes (Anderson and Bows 2011; Friedlingstein et al. 2011; UNEP 2020; van Vuuren et al. 2011a, 2011b; Ranger et al. 2012).

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.

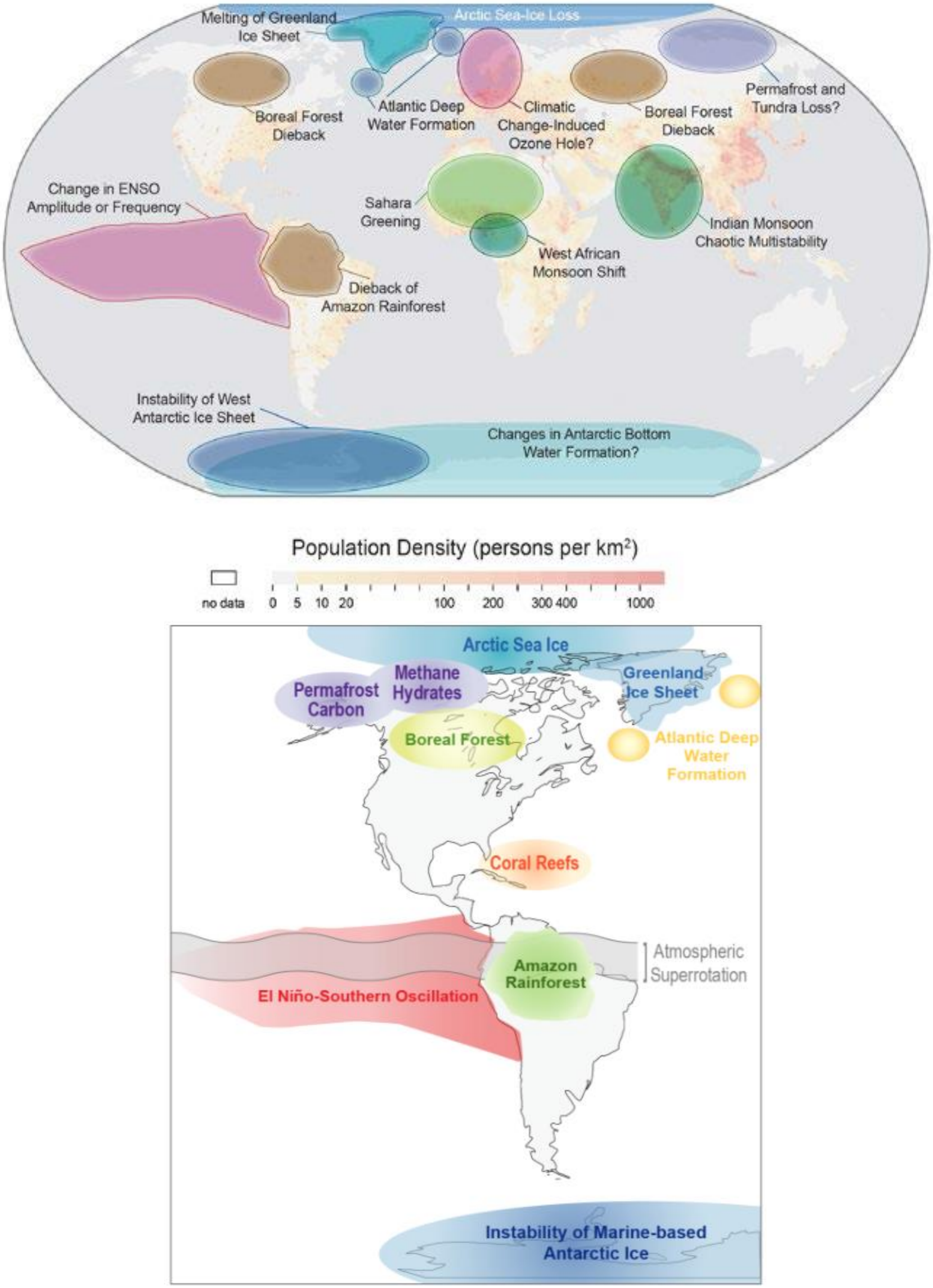
It is expected that some species will become extinct or fall below viable numbers in the next few decades (NRC 2013b). IPCC states that there is *high confidence* that a large fraction of species faces increased extinction risk due to climate change during the 21st century and beyond (IPCC 2014b).

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.

- **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). Research indicates that the frequency of extreme El Niño events increases linearly with global mean temperature; under 1.5°C of temperature warming, the number of extreme El Niño events could double (IPCC 2018 citing Wang et al. 2017).

Figure 8.6.5-3. Potential Tipping Points



Source: GCRP 2017 adapted from Lenton et al. 2008
km^2 = square kilometer

- **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, and 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 emissions 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 CH_4 to the atmosphere from clathrate hydrates[44] 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 CH_4 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). It is very likely that emissions from thawing permafrost are amplifying carbon emissions and will continue to do so (GCRP 2018a citing Schaefer et al. 2014, Koven et al. 2015, and Schuur et al. 2015; Yumashev et al. 2019). 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 decrease the rate of CO_2 emissions relative to the No Action Alternative, they could contribute to the marginal decrease or deceleration of reaching these tipping-point thresholds. Moreover, while this rulemaking alone would not cause sufficient CO_2 emissions reductions to avoid reaching the tipping-point thresholds, it would help make substantial contributions in averting levels of abrupt and severe climate change when paired with many other global actions.

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

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[44] 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).

information contained in state or regional assessments for each region of the United States 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 2016a), 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 Fourth National Climate Assessments (GCRP 2017, 2018a) 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 Fourth National Climate Assessment (GCRP 2018a) include the Northeast, Southeast, U.S. Caribbean, Midwest, Northern Great Plains, Southern Great Plains, Northwest, Southwest, Alaska, and Hawaii and U.S. Affiliated Pacific Islands. Additionally, individual states, such as California, have completed in-depth local climate change assessments (Bedsworth et al. 2018).

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 emissions 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 2016a), and the Third and Fourth National Climate Assessments (GCRP 2014, 2017, 2018a). 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 minor decreases 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 decrease only to a marginal degree.

CHAPTER 9 MITIGATION

The 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. Generally, an agency does not propose mitigation measures for an action resulting in beneficial effects.

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 (Alternative 0), the Proposed Action and alternatives would decrease fuel consumption and greenhouse gas (GHG) emissions. As seen in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, the Proposed Action and alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. As reported in Chapter 4, *Air Quality*, nationwide emissions of criteria air pollutants in 2025 are anticipated to increase slightly under the Proposed Action and alternatives, compared to the No Action Alternative, before declining in 2035 and 2050 under most action alternatives for all criteria pollutants except for sulfur dioxide (SO_2). The same is true for nationwide emissions of hazardous air pollutants (expected increases in 2025 and decreases in 2035 and 2050 under most action alternatives for most pollutants), except for diesel particulate matter (DPM), emissions for which are expected to decrease in all analysis years under all action alternatives, compared to the No Action Alternative. In 2035 and 2050, aggregate emissions of

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[1] 40 CFR § 1502.14(f) (2019).

[2] 40 CFR § 1502.16(h) (2019).

[3] 40 CFR § 1508.20 (2019).

[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).

criteria air pollutants (with the exception of SO_2) and hazardous air pollutants are generally expected to decrease under the Proposed Action and alternatives as compared to the No Action Alternative, with some exceptions (i.e., increases in emissions for carbon monoxide [CO], acetaldehyde, acrolein, and 1,3-butadiene in 2035 under Alternative 1, nitrogen oxides [NO_X] in 2035 under Alternative 3). Aggregate emissions of SO_2 generally are expected to increase in 2035 and 2050, except that Alternative 1 would result in decreases in SO_2 emissions in 2035.

For CO, the majority of nonattainment areas would experience small increases in emissions across all action alternatives in 2025 but decreases in 2035 (except under Alternative 1) and 2050, compared to the No Action Alternative. For NO_X, the majority of nonattainment areas would experience small increases in emissions in 2025 (under all alternatives) and 2035 (Alternatives 2 and 3), and decreases in emissions in 2050, compared to the No Action Alternative. For particulate matter less than 2.5 microns in diameter and volatile organic compounds, across all alternatives, the majority of nonattainment areas would experience small increases in emissions in 2025 but decreases in emissions in 2035 and 2050, compared to the No Action Alternative. For SO_2 in all analysis years, the majority of nonattainment areas would experience decreases in emissions across all alternatives, compared to the No Action Alternative.

In 2025, in the majority of nonattainment areas, all action alternatives would increase emissions of most hazardous air pollutants but would decrease emissions of DPM, compared to the No Action Alternative. In 2035, the results are mixed: for acetaldehyde, emissions would increase under all action alternatives in the majority of nonattainment areas, compared to the No Action Alternative; for acrolein, 1,3-butadiene, and formaldehyde, in the majority of nonattainment areas emissions would increase under Alternative 1 and decrease under Alternatives 2 and 3, compared to the No Action Alternative. For DPM, emissions would decrease under all action alternatives in the majority of nonattainment areas, compared to the No Action Alternative. In 2050, all action alternatives would decrease emissions of all hazardous air pollutants in the majority of nonattainment areas, compared to the No Action Alternative.

Compared to the No Action Alternative, adverse health effects under the Proposed Action and alternatives are estimated to decrease from 2025 to 2050 (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 the Clean Air Act (CAA) emissions standards for criteria pollutants and toxic air pollutants. Conversely, for those pollutant emissions projected to decrease under the Proposed 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 decreases for some pollutants under certain alternatives and analysis years, while other areas could experience increases.

The differences in projected air quality impacts discussed above 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. Other CAFE Model inputs and assumptions, which are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and at length in the proposed rule preamble, Technical Support Document, and Preliminary Regulatory Impact Analysis issued concurrently with this Draft SEIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates.

As discussed in Chapter 4, *Air Quality*, the changes in emissions are small in relation to total criteria pollutant emissions levels during this period and, overall, the health outcomes due to changes in criteria pollutant emissions through 2050 are projected to be beneficial.

9.2 Mitigation Measures

CEQ regulations concerning mitigation refer to mitigation measures that the lead agency can include to mitigate potential adverse impacts. The action in this SEIS primarily reduces the negative environmental consequences of fuel consumption and GHG emissions. However, as discussed above, some nonattainment areas could experience increases in some air pollutant emissions as a result of the Proposed Action and alternatives. Even if emissions in some nonattainment areas increase, the associated harm might not increase concomitantly. As described in Chapter 4, *Air Quality*, ambient levels of most pollutants are trending generally downward, owing to the success of regulations governing fuel consumption and vehicle emissions, as well as stationary sources of emissions (EPA 2021j). Also, vehicle manufacturers can choose which technologies to employ to reach the new CAFE standards. Some of their technology choices could results in higher or lower impacts for these emissions.

Regarding the air pollutants that NHTSA projects would increase under the Proposed Action and alternatives in certain analysis years, 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. Furthermore, NHTSA's statutory authority requires balancing several statutory factors to set maximum feasible fuel economy standards (Chapter 1, *Purpose and Need for the Action*). NHTSA considers environmental impacts (as described in this SEIS) as part of its balancing of those factors, thereby limiting the degree or magnitude of the action as appropriate.

Still, any potential negative impacts of the Proposed Action and alternatives could be mitigated through other means by other federal, state, or local agencies. Examples of mitigation measures include further EPA criteria pollutant 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. Any of these mitigation actions at the federal and state levels would affect environmental and health impacts by reducing fuel use and/or exposure to associated emissions. A reduction of VMT would decrease fuel usage and emissions of criteria and toxic air pollutants, which would reduce the negative health impacts of the Proposed Action and alternatives. A reduction in VMT also would decrease GHG emissions, which would lead to an additional incremental positive impact on global climate change. Programs to encourage reductions in VMT can include pricing strategies (e.g., increases in fuel taxes, higher tolls on bridges and roads, higher tolls during peak hours, and mileage-based fees that some states are considering as a replacement for fuel taxes); infill development (i.e., grants or other efforts to encourage more dense urban housing development in areas that are a short walk from public transit); transportation investments in bicycling and walking paths that can also serve as transportation/commuting routes; transit system investments; and transportation demand management (e.g., programs that encourage ridesharing and teleconferencing and other telework) (Byars et al. 2017).[5]

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[5] As none of these potential mitigation strategies are within the statutory jurisdiction of NHTSA, the agency takes no position on their relative merits or appropriateness. NHTSA provides these mitigation strategies for informational purpose only.

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 a decrease in energy consumption, and mixed increases and decreases in criteria pollutant and hazardous air pollutant emissions, compared to the No Action Alternative. Although increases in VMT under the Proposed Action and alternatives as compared to the No Action Alternative are anticipated, these VMT increases would be offset by the increases in fuel economy associated with the Proposed Action and alternatives, resulting in a net decrease in energy consumption but 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 in analysis year 2025; however, overall U.S. health impacts associated with air quality (e.g., mortality, asthma, bronchitis, emergency room visits, and work-loss days) are anticipated to decrease across the Proposed Action and alternatives as compared to the No Action Alternative in analysis years 2035 and 2050. Any increases in air pollutant emissions and human health impacts are not unavoidable adverse impacts, however, as they could be offset by mobile and stationary source emissions regulations, changes in consumer behavior (e.g., changing driving patterns or increased consumer demand for electric vehicles [EVs]), fluctuations in the energy market, or other future activities.

9.4 Short-Term Uses and Long-Term Productivity

The Proposed Action and alternatives would result in a decrease in crude oil consumption and a decrease in GHG emissions (and associated climate change impacts) compared to the No Action Alternative. To meet CAFE 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.

9.5 Irreversible and Irretrievable Commitments of Resources

As noted in Chapter 7, *Other Impacts*, 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 CAFE 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 10.1-1 identifies the preparers, contributors, and reviewers in the U.S. Department of Transportation.

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10.2 Consultant Team

ICF supported NHTSA in preparing its environmental analyses and this SEIS. Table 10.2-1 identifies the consultant team and their contributions.

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CHAPTER 11 DISTRIBUTION LIST

The CEQ NEPA implementing regulations (40 CFR § 1502.19) specify requirements for circulating an EIS. In accordance with those requirements, NHTSA is mailing notification of the availability of this SEIS, as well as instructions on how to access it to the agencies, officials, and other stakeholders listed in this chapter.

11.1 Federal Agencies

- Advisory Council on Historic Preservation, Office of Federal Agency Programs
- Appalachian Regional Commission, Office of the General Counsel
- Argonne National Laboratory
- Armed Forces Retirement Home, Campus Operations
- Board of Governors of the Federal Reserve System, Engineering and Facilities
- Central Intelligence Agency, Headquarters Environmental Safety Staff
- Committee for Purchase From People Who Are Blind or Severely Disabled, Office of the General Counsel
- Consumer Product Safety Commission, Directorate for Economic Analysis
- Defense Nuclear Facilities Safety Board
- Delaware River Basin Commission
- Denali Commission
- Executive Office of the President, Office of Science and Technology Policy
- Export-Import Bank of the United States, Office of the Senior Counsel
- Export-Import Bank of the United States, Environmental and Social Policy and Review Program
- 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 Energy Regulatory Commission, Office of Energy Projects, Environmental Review and Permitting
- Federal Maritime Commission
- Federal Trade Commission, General Counsel for Litigation
- General Services Administration, Federal Permitting Improvement Streering Council
- General Services Administration, Public Buildings Service, Office of Portfolio Management and Customer Engagement
- International Boundary and Water Commission, U.S. & Mexico, Environmental Management Division
- International Trade Commission, Office of External Relations
- Marine Mammal Commission, Office of the General Counsel
- Millennium Challenge Corporation, Environmental and Social Assessment
- 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 Endowment for the Humanities
- National Indian Gaming Commission, Office of the General Counsel
- National Indian Gaming Commission, Office of the Chief of Staff
- National Institutes of Health, Division of Environmental Protection
- National Institute Standards and Technology, Office of Safety, Health, and Environment
- National Science Foundation, Office of the General Counsel
- Nuclear Regulatory Commission, Division of Fuel Cycle Safety, Safeguards, and Environmental Review
- Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards
- Oak Ridge National Laboratory
- Overseas Private Investment Corporation, Environmental Group
- Presidio Trust, NEPA Compliance
- Small Business Administration, Office of the General Counsel, Department of Litigation
- Social Security Administration, Office of Environmental Health and Occupational Safety
- Tennessee Valley Authority, Environmental Policy and Planning
- U.S. Access Board (Architectural and Transportation Barriers Compliance Board), Office of the General Counsel
- 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 Risk and Analysis Services
- U.S. Department of Agriculture, Farm Service Agency
- U.S. Department of Agriculture, National Institute of Food and Agriculture, Institute of Bioenergy, Climate, and Environment
- U.S. Department of Agriculture, Natural Resources Conservation Service, Ecological Services Division
- U.S. Department of Agriculture, Rural Development, 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, Energy and Environmental Law Division, Office of the General Counsel for Administration and Transactions
- U.S. Department of Commerce, First Responder Network Authority (FirstNet)
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Review and Coordination Section, Office of the General Counsel
- U.S. Department of Defense, Army Corps of Engineers (Civil Works), Office of the Assistant Secretary of the Army

- U.S. Department of Defense, Army Corps of Engineers, Planning and Policy Division, Office of Water Project Review
- U.S. Department of Defense, Defense Logistics Agency; DLA Installation Support, Environmental Management
- U.S. Department of Defense, Department of Air Force, Air Force Civil Engineer, Strategic Plans and Programs Division, DCS/Logistics, Installations, and Mission Support
- 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, Department of the Navy, Office of the Chief of Naval Operations, Energy and Environmental Readiness Division, Environmental Planning and Conservation Branch
- U.S. Department of Defense, Missile Defense Agency, Environmental Management
- U.S. Department of Defense, National Guard Bureau
- U.S. Department of Defense, National Guard Bureau, Military Construction Branch Installations and Environment Division
- U.S. Department of Defense, National Guard Bureau, Real Estate Branch Installations and Environment Division
- U.S. Department of Defense, National Guard Bureau, Environmental Installations and Environment Division
- U.S. Department of Defense, National Security Agency
- U.S. Department of Defense, National Security Agency, National Nuclear Security Administration NEPA Program, Office of General Counsel
- U.S. Department of Defense, Office of the Deputy Assistant Secretary of Defense, Environment, Safety, and Occupational Health
- U.S. Department of Defense, U.S. Marine Corps, Headquarters
- U.S. Department of Education, Office of the General Counsel
- U.S. Department of Energy, Bonneville Power Administration, Environmental Planning and Analysis
- U.S. Department of Energy, Office of the General Counsel, Office of NEPA Policy and Compliance
- U.S. Department of Energy, Office of Environmental Management
- U.S. Department of Energy, National Nuclear Security Administration NEPA Program, Office of General Counsel
- U.S. Department of Energy, Western Area Power Administration
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Division of Emergency and Environmental Health Services, National Center for Environmental Health
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Office of Safety, Security, and Asset Management
- U.S. Department of Health and Human Services, Food and Drug Administration, Center for Food Safety and Applied Nutrition
- U.S. Department of Health and Human Services, Indian Health Service, Division of Sanitation Facilities Construction
- U.S. Department of Health and Human Services, National Institutes of Health, Division of Environmental Protection

- U.S. Department of Homeland Security
- U.S. Department of Homeland Security, Customs and Border Protection
- U.S. Department of Homeland Security, Environmental Planning and Historic Preservation Program
- 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, Environmental and Safety Division
- U.S. Department of Homeland Security, Immigration and Customs Enforcement, Environmental Program
- U.S. Department of Homeland Security, Transportation Security Administration, Office of Occupational Safety, Health and Environment
- 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, Office of Environmental Management
- U.S. Department of Interior, Bureau of Indian Affairs, Division of Environmental and Cultural Resources Management, Office of Trust Services
- 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
- U.S. Department of Interior, Bureau of Ocean Energy Management, Branch of Environmental Coordination, 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 the Associate Deputy Secretary
- U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement, Division of Regulatory Support
- U.S. Department of Interior, U.S. Fish and Wildlife Service
- 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 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, Environmental Compliance Program
- U.S. Department of Justice, Federal Bureau of Prisons, Real Estate and Environmental Law

- U.S. Department of Justice, Federal Bureau of Prisons, Construction and Environmental Review Branch
- U.S. Department of Justice, Justice Management Division, Environmental and Sustainability Services
- 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, Infrastructure Permitting Improvement Center
- U.S. Department of Transportation, Federal Aviation Administration, Environmental Policy and Operations, Office of Environment and Energy
- 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, Regulatory and Legislative Affairs Division, Office of the Chief Counsel
- U.S. Department of Transportation, Federal Railroad Administration, Environmental and Corridor Planning, Office of Program Delivery
- U.S. Department of Transportation, Federal Transit Administration, Office of Environmental Programs
- U.S. Department of Transportation, Maritime Administration, Office of Environment
- U.S. Department of Transportation, National Highway Traffic Safety Administration
- U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Hazardous Materials Safety
- U.S. Department of Transportation, Saint Lawrence Seaway Development Corporation, Office of the Chief Counsel
- U.S. Department of Transportation, Volpe Center, Environmental Science and Engineering Division
- U.S. Department of Transportation, Volpe Center, Policy Analysis and Strategic Planning Division
- 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, NEPA Compliance Division, Office of Federal Activities
- U.S. Environmental Protection Agency, NEPA Office Region 1
- U.S. Environmental Protection Agency, NEPA Office Region 2
- U.S. Environmental Protection Agency, NEPA Office Region 3
- U.S. Environmental Protection Agency, NEPA Office Region 4
- U.S. Environmental Protection Agency, NEPA Office Region 5
- U.S. Environmental Protection Agency, NEPA Office Region 6

- U.S. Environmental Protection Agency, NEPA Office Region 7
- U.S. Environmental Protection Agency, NEPA Office Region 8
- U.S. Environmental Protection Agency, NEPA Office Region 9
- U.S. Environmental Protection Agency, NEPA Office Region 10
- U.S. Postal Service, Environmental Compliance/Risk Management
- U.S. Securities and Exchange Commission, Office of Support Operations

11.2 State and Local Government Organizations

- American Samoa Office of Grants Policy/Office of the Governor, Department of Commerce, American Samoa Government
- Arizona Department of Environmental Quality
- Arkansas Department of Environmental Quality
- Arkansas Office of Intergovernmental Services, Department of Finance and Administration
- Boulder County Public Health
- California Air Resources Board
- California Department of Justice
- California Office of the Attorney General
- Connecticut Department of Environmental Protection
- Connecticut Department of Transportation
- Connecticut Office of the Attorney General
- Delaware Department of Justice
- District of Columbia Office of the City Administrator
- Florida State Clearinghouse, Florida Department of Environmental Protection
- 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
- Hawaii Office of the Attorney General
- Hawaii Office of Environmental Quality
- Illinois Department of the Attorney General
- Iowa Department of Management
- Iowa Office of the Attorney General
- Los Angeles City Attorney’s Office
- Los Angeles County, Public Health
- 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
- Minnesota Office of the Attorney General
- 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
- New Jersey Environmental Practice Group, Division of Law
- New Mexico Office of the Attorney General
- New York City Law Department
- New York State Department of Environmental Conservation
- North Carolina Department of Environmental Quality
- North Carolina Department of Justice
- North Dakota Department of Commerce
- Oakland City Attorney
- Oregon Department of Environmental Quality
- Pennsylvania Department of Environmental Protection
- Puerto Rico Highway and Transportation Authority
- Puerto Rico Planning Board, Federal Proposals Review Office
- Regional Air Pollution Control Agency
- Rhode Island Department of the Attorney General
- Rhode Island Division of Planning
- Sacramento Municipal Utility District
- Saint Thomas, VI Office of Management and Budget
- San Fransisco Office of the City Attorney
- San Jose Office of the City Attorney
- South Carolina Office of State Budget
- Southeast Michigan Council of Governments
- State of Vermont Agency of Natural Resources
- The Governor of Kentucky’s Office for Local Development
- Town of Brookhaven, Planning, Environment, and Land Management
- Town of Brookline
- Utah State Clearinghouse, Governor's Office of Planning and Budget Utah State
- Virginia Office of the Attorney General
- Virgin Islands, Office of Management and Budget
- Washington State Department of Ecology
- West Virginia Development Office

11.3 Elected Officials

- The Honorable Karl Racine, Attorney General of the District of Columbia
- The Honorable Tom Miller, Attorney General of Iowa
- The Honorable Aaron Frey, Attorney General of Maine
- The Honorable Brian Frosh, Attorney General of Maryland
- The Honorable Maura Healey, Attorney General of Massachusetts
- The Honorable Letitia James, Attorney General of New York
- The Honorable Ellen Rosenblum, Attorney General of Oregon
- The Honorable Josh Shapiro, Attorney General of Pennsylvania
- The Honorable Thomas J. Donovan, Attorney General of Vermont
- The Honorable Bob Ferguson, Attorney General of Washington
- The Honorable Kay Ivey, Governor of Alabama
- The Honorable Michael Dunleavy, Governor of Alaska
- The Honorable Lemanu Peleti Mauga, Governor of American Samoa
- The Honorable Doug Ducey, Governor of Arizona
- The Honorable Asa Hutchinson, Governor of Arkansas
- The Honorable Gavin Newsom, Governor of California
- The Honorable Jared Polis, Governor of Colorado
- The Honorable Ned Lamont, Governor of Connecticut
- The Honorable John Carney, Governor of Delaware
- The HonorableRon DeSantis, Governor of Florida
- The Honorable Brian Kemp, Governor of Georgia
- The Honorable Lourdes Leon Guerrero, Governor of Guam
- The Honorable David Ige, Governor of Hawaii
- The Honorable Brad Little, Governor of Idaho
- The Honorable Jay Pritzker, Governor of Illinois
- The Honorable Eric Holcomb, Governor of Indiana
- The Honorable Kim Reynolds, Governor of Iowa
- The Honorable Laura Kelly, Governor of Kansas
- The Honorable Andy Beshear, Governor of Kentucky
- The Honorable John Bel Edwards, Governor of Louisiana
- The Honorable Janet Mills, Governor of Maine
- The Honorable Larry Hogan, Governor of Maryland
- The Honorable Charles Baker, Governor of Massachusetts
- The Honorable Gretchen Whitmer, Governor of Michigan
- The Honorable Tim Walz, Governor of Minnesota
- The Honorable Tate Reeves, Governor of Mississippi

- The Honorable Michael L. Parson, Governor of Missouri
- The Honorable Greg Gianforte, Governor of Montana
- The Honorable Pete Ricketts, Governor of Nebraska
- The Honorable Steve Sisolak, Governor of Nevada
- The Honorable Christopher Sununu, Governor of New Hampshire
- The Honorable Philip Murphy, Governor of New Jersey
- The Honorable Michelle Grisham, 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 Richard Michael DeWine, Governor of Ohio
- The Honorable Kevin Stitt, Governor of Oklahoma
- The Honorable Kate Brown, Governor of Oregon
- The Honorable Tom Wolf, Governor of Pennsylvania
- The Honorable Pedro Pierluisi, Governor of Puerto Rico
- The Honorable Daniel McKee, Governor of Rhode Island
- The Honorable Henry McMaster, Governor of South Carolina
- The Honorable Kristi Noem, Governor of South Dakota
- The Honorable Bill Lee, Governor of Tennessee
- The Honorable Greg Abbott, Governor of Texas
- The Honorable Albert Bryan, Governor of the United States Virgin Islands
- The Honorable Spencer Cox, 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 Anthony Evers, Governor of Wisconsin
- The Honorable Mark Gordon, 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
- 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
- Arapaho Tribe of the Wind River Reservation, Wyoming
- Arctic Village
- Aroostook Band of Micmacs
- Asa'carsarmiut Tribe
- Assiniboine & Sioux Tribes of the Fort Peck Indian Reservation, Montana
- Augustine Band of Cahuilla Indians, California
- Bad River Band of Lake Superior Tribe of Chippewa Indians of the Bad River Reservation, Wisconsin
- 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 Indians
- 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
- Chickahominy Indian Tribe—Eastern Division
- 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 and 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
- 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 and 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 and Chippewa Indians, Michigan
- Greenville Rancheria
- Grindstone Indian Rancheria of Wintun-Wailaki Indians of California
- Guidiville Rancheria of California
- Gulkana Village Council
- 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 Tribe
- 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 and Nebraska
- Iowa Tribe of Oklahoma
- Iqugmiut 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 Community
- Kewa Pueblo, New Mexico
- Keweenaw Bay Indian Community, Michigan
- Kialegee Tribal Town
- Kickapoo Traditional Tribe of Texas
- Kickapoo Tribe of Indians of the Kickapoo Reservation in Kansas
- Kickapoo Tribe of Oklahoma
- King Island Native Community
- King Salmon Tribe
- Kiowa Indian Tribe of Oklahoma
- Klamath Tribes
- Klawock Cooperative Association
- Kletsel Dehe Band of Wintun Indians
- Knik Tribe
- Koi Nation of Northern California
- Kokhanok Village
- Kootenai Tribe of Idaho
- Koyukuk Native Village
- La Jolla Band of Luiseno Indians, California

- La Posta Band of Diegueno Mission Indians of the La Posta Indian Reservation, California
- Lac Courte Oreilles Band of Lake Superior Chippewa Indians of Wisconsin
- Lac du Flambeau Band of Lake Superior Chippewa Indians of Wisconsin
- Lac Vieux Desert Band of Lake Superior Chippewa Indians of 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 Shell Tribe of Chippewa Indians of Montana
- Little Traverse Bay Bands of Odawa Indians, Michigan
- Lone Pine Paiute-Shoshone Tribe
- Los Coyotes Band of Cahuilla and 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 of the Mescalero Reservation, New Mexico
- 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
- Modoc Nation
- Monacan Indian Nation
- Mooretown Rancheria of Maidu Indians of California
- Morongo Band of Mission Indians, California
- Muckleshoot Indian Tribe
- Naknek Native Village
- Nansemond Indian Nation
- 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 Atqasuk
- 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 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 and 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 Cheyenne Tribe of the Northern Cheyenne Indian Reservation, Montana
- 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, New Mexico
- Omaha Tribe of Nebraska
- Oneida Indian Nation
- 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
- Pitka's Point Traditional Council
- 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
- Pribilof Islands Aleut Communities of St. Paul and St. George Islands
- Pueblo of Acoma, New Mexico
- Pueblo of Cochiti, New Mexico
- Pueblo of Isleta, New Mexico
- Pueblo of Jemez, New Mexico
- Pueblo of Laguna, New Mexico
- Pueblo of Nambe, New Mexico
- Pueblo of Picuris, New Mexico
- Pueblo of Pojoaque, New Mexico
- Pueblo of San Felipe, New Mexico
- Pueblo of San Ildefonso, New Mexico
- Pueblo of Sandia, New Mexico
- Pueblo of Santa Ana, New Mexico

- Pueblo of Santa Clara, New Mexico
- Pueblo of Taos, New Mexico
- Pueblo of Tesuque, New Mexico
- Pueblo of Zia, New Mexico
- Puyallup Tribe of the Puyallup Reservation
- Pyramid Lake Paiute Tribe of the Pyramid Lake Reservation, Nevada
- Quapaw Nation
- Qagan Tayagungin Tribe of Sand Point
- Qawalangin Tribe of Unalaska
- Quartz Valley Indian Community of the Quartz Valley Reservation of California
- Quechan Tribe of the Fort Yuma Indian Reservation, California and Arizona
- Quileute Tribe of the Quileute Reservation
- Quinault Indian Nation
- Ramona Band of Cahuilla, California
- Rampart Village
- Rappahannock Tribe, Inc.
- 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, 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 (Pribilof Islands Aleut Communities of St. Paul and St. George Islands)
- Saint Paul Island (Pribilof Islands Aleut Communities of St. Paul and St. George Islands)
- Saint Regis Mohawk Tribe
- Salamatof 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 of the Shoalwater Bay Indian Reservation
- 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 of the Southern Ute Reservation, Colorado
- 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 and 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 Muscogee (Creek) Nation
- The Osage Nation
- The Seminole Nation of Oklahoma
- Thlopthlocco Tribal Town
- Three Affiliated Tribes of the Fort Berthold Reservation, North Dakota
- Timbisha Shoshone Tribe
- 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 Mattaponi Tribe
- 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 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 and California (Carson Colony, Dresslerville Colony, Woodfords Community, Stewart Community, and Washoe Ranches)
- White Mountain Apache Tribe of the Fort Apache Reservation, Arizona
- Wichita and Affiliated Tribes

- Wilton Rancheria, Californa
- 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 and 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

- American Honda Motor Company, Inc.
- Aston Martin Logonda
- BMW of North America, LLC
- BYD Motors, Inc.
- CODA Automotive, Inc.
- Ferrari North America, Inc.
- Fiat Chrysler Automobiles US LLC
- Ford Motor Company
- General Motors, LLC
- Hyundai Kia America Technical Center, Inc.
- Jaguar Land Rover North America, LLC
- Karma Automotive, LLC
- Koenigsegg Automotive AB
- Lotus Cars USA, Inc.
- Mazda North American Operations
- McLaren Automotive Limited
- Mercedes-Benz USA, LLC
- Mitsubishi Motors North America, Inc.
- Mobility Ventures, LLC

- Nissan North America, Inc.
- RUF Automobile GmbH
- Subaru of America, Inc.
- Suzuki Motor of America, Inc.
- Tesla Motors, Inc.
- Toyota Motor Engineering & Manufacturing North America, Inc.
- Volkswagen Group of America, Inc.
- Volvo Car USA, LLC

11.6 Stakeholders

- 1854 Treaty Authority
- 350 Bay Area Transportation Campaign
- AAA Mid-Atlantic
- Advanced Engine Systems Institute
- Alaska Public Interest Research Group
- Alliance for Automotive Innovation
- Alliance to Save Energy
- 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
- American Thoracic Society
- Appalachian Mountain Club
- Arizona Public Interest Research Group
- Association of International Automobile Manufacturers, Inc.
- Association of Metropolitan Planning Organizations

- Auto Research Center
- BlueGreen Alliance
- 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
- Central States Air Resources Agencies
- Ceres and the Investor Network on Climate Risk (INCR)
- Ceres BICEP Network
- ChargePoint, Inc.
- Citizens' Utility Board of Oregon
- Clean Air Task Force
- Clean Energy
- Clean Fuel Development Coalition
- Climate Institute
- Columbian Justice Peace and Integrity of Creation Office
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Conservation Law Foundation
- Consumer Action
- Consumer Assistance Council of Cape Cod
- Consumer Federation of America
- Consumer Federation of the Southeast
- Consumers for Auto Reliability and Safety
- Consumers Union
- Convoy Solutions dba IdleAir
- Con-way Inc.
- CoPIRG Foundation
- Coulomb Technologies, Inc.
- Criterion Economics, LLC
- Crowell Moring
- CSRA
- Dale Kardos & Associates, Inc.

- Dallas Clean Energy, LLC
- Dana Holding Corporation
- Defenders of Wildlife
- Delaware Interfaith Power and Light
- Democratic Processes Center
- Ecology Center
- Edison Electric Institute
- Electric Applications Inc.
- Electric Drive Transportation Association
- Electric Power Research Institute
- Emmett Institute on Cimate Change and the Environment
- Empire State Consumer 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.
- Florida Public Interset Research Group
- FreedomWorks Foundation
- Friends Committee on National Legislation
- Gibson, Dunn & Crutcher LLP
- Greater Washington Interfaith Power and Light
- Growth Energy
- HayDay Farms, Inc.
- Honeywell Transportation Systems
- ICM
- IdleAir
- Illinois Corn Growers Association
- Illinois Trucking Association
- Illnois Public Interest Research Group
- Indiana Corn Growers Association
- Indiana University
- Ingevity
- Insurance Institute for Highway Safety

- International Council on Clean Transportation
- International Mosaic
- Jewish Community Relations Council
- Justice and Witness Ministries
- Kansas Corn Growers Associaiton
- 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
- Meszler Engineering Services
- 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 Conference of State Legislatures
- National Corn Growers Assocation
- National Council of Churches USA
- National Governors Association
- National Groundwater Association
- National League of Cities
- National Propane Gas Association
- National Tribal Air Association
- National Wildlife Federation
- Natural Gas Vehicles (NGV) America

- Natural Resources Canada
- Natural Resources Defense Council
- Nebraska Corn Board
- Nebraska Corn Growers Association
- New Jersey Citizen Action
- New Mexico Public Interest Research Group
- New York Corn & Soybean Growers Association
- Northeast Ohio Areawide Coordination Agency
- Northeast States for Coordinated Air Use Management
- Novation Analytics
- NTEA - The Association for the Work Truck Industry
- NY Public Interest Research Group
- Ohio Corn Wheat Growers Associaiton
- Original United Citizens of Southwest Detroit
- Ozone Transport Commission
- Pew Environment Group
- Pierobon & Partners
- Plastics Industry Association
- Podesta Group
- Pollution Probe
- Presbyterian Church (USA)
- Public Citizen
- Recreation Vehicle Industry Association
- Renewable Fuels Association
- Republicans for Environmental Protection
- Respiratory Health Association
- Resources for the Future
- Road Safe America
- Rocky Mountain Institute
- Rubber Manufacturers Association
- Safe Climate Campaign
- Santa Clara Pueblo
- SAVE EPA
- SaviCorp, Inc.
- Securing America's Future Energy
- Sentech, Inc.
- Sierra Club
- Single Springs Rancheria

- Socially Responsible Investing
- South Coast Air Quality Management District
- Sport Utility Vehicle Owners of America
- Stellantis
- SUN DAY Campaign
- Susquehanna River Basin Commission
- Teamsters Joint Council 25
- Tetlin Village Council
- Texas Corn Producers Association (TCPA)
- The Accord Group
- The Aluminium Association, Inc.
- The Consumer Alliance
- The Council of State Governments
- The Environmental Council of the States
- The Episcopal Church
- The Hertz Corporation
- The Lee Auto Malls
- The Pew Charitable Trusts
- The Truman National Security Project
- The United Methodist Church General
- TIAX LLC
- ToChi Technologies Inc
- Trillium Asset Management Corporation
- Truck Manufacturer's Association
- Truman Center for National Policy
- Tufts University
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- U.S. Public Interest Research Group
- 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

- University of Southern California
- Utility Consumers Action Network
- Vermont Public Interest Research Group
- Victims Committee for Recall of Defective Vehicles
- Virginia Citizens Consumer Council
- VNG.co LLC
- Washtenaw Climate Reality
- 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

11.7 Individuals

Individual commenters are not named in this distribution list for their privacy. NHTSA is mailing notification of the availability of this SEIS to individual commenters who provided a mailing address as part of their comment submission in response to the Notice of Intent or the Draft EIS.

CHAPTER 12 REFERENCES

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CHAPTER 13 INDEX