Corporate Average Fuel Economy Standards Model Years 2024–2026

Final Supplemental Environmental Impact Statement

March 2022

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U.S. Department of Transportation
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NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Final 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 Final Supplemental Environmental Impact Statement (Final 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 Final SEIS include those related to fuel and energy use, air quality, and climate change. In developing the final 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).

Timing of Agency Action

NHTSA is issuing this Final SEIS concurrently with the final rule (Record of Decision), which states and explains NHTSA's decision and describes NHTSA's consideration of applicable environmental laws and policies. *See* 49 U.S.C. § 304a(b) and U.S. Department of Transportation's *Guidance on the Use of Combined Final Environmental Impact Statements/Records of Decision and Errata Sheets in National Environmental Policy Act Reviews* (Apr. 25, 2019) (https://www.transportation.gov/sites/dot.gov/files/docs/mission/transportation-policy/permittingcenter/337371/feis-rod-guidance-final-04302019.pdf).

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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
ACS	American Cancer Society
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
COVID-19	coronavirus disease 2019
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
ERF	effective radiative forcing
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	grams 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

OSPW	oil sands process-affected water
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 2.5
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
SSP	Shared Socioeconomic Pathway
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 Final SEIS compares the potential environmental impacts of five alternatives for setting fuel economy standards for MY 2024–2026 passenger cars and light trucks (four 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. Though EO 13990 prompted NHTSA's review, NHTSA is exercising its own authority, consistent with its statutory factors, to amend the CAFE standards for MY 2024–2026 passenger cars and light trucks in a final rule being issued concurrent with this Final SEIS. As NHTSA discusses in the preamble to the final rule, this action reflects a conclusion significantly different from the conclusion that NHTSA reached in the 2020 SAFE Vehicles Final Rule, but this is because important facts have changed, and because NHTSA has reconsidered how to balance the relevant statutory considerations in light of those facts. NHTSA concludes that significantly more stringent standards are maximum feasible. For a further discussion on NHTSA's explanation on this action, see Section VI.D in the final rule. As described in the final rule, NHTSA is retaining 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.[5]

To inform its development of the CAFE standards for MYs 2024–2026, NHTSA prepared this SEIS, pursuant to NEPA,[6] 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).[7] In revising the CAFE standards established in the SAFE Vehicles Final Rule, NHTSA is making 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.[8] 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,[9] NHTSA will continue to apply the NEPA implementing regulations that were in effect prior to that date.[10] This SEIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of alternatives, including a No

[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] 49 U.S.C. § 32902(g)(2).

[6] 42 U.S.C. §§ 4321–4347.

[7] 42 U.S.C. § 4332.

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

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

[10] 40 CFR § 1506.13 (2020) (specifying that the new NEPA implementing regulations apply to any NEPA process begun after September 14, 2020).

Action Alternative and a Preferred Alternative, and discusses impacts in proportion to their significance. NHTSA is issuing this Final SEIS concurrently with the final rule.

Purpose and Need for the Action

In accordance with EPCA, as amended by EISA, 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 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. The conclusion reached in this rulemaking 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 Section 1 of the preamble to the final rule, NHTSA's review of its standards responds to the President's direction in EO 13990, and the final rule 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 SEIS. Throughout this SEIS, estimated impacts are shown for four action alternatives that illustrate the following range of estimated average annual percentage increases in fuel economy for both passenger cars and light trucks:

Alt. 1 Alternative 1 would require a 10.5 percent annual increase for MY 2024 over MY 2023 and a 3.26 percent annual average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2025–2026.

Alt. 2 Alternative 2 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 2 was identified as NHTSA's Preferred Alternative in the NPRM and Draft SEIS; however, Alternative 2.5 is now NHTSA's Preferred Alternative.

Alt. 2.5 Alternative 2.5 (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 and 2025, and a 10.0 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MY 2026.

Alt. 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. 2.5	Alt. 3
MY 2024	38.1	41.8	40.6	40.6	41.5
MY 2025	38.7	43.2	44.2	44.2	46.1
MY 2026	39.4	44.7	48.1	49.1	51.3

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.

As noted in the preamble to the final rule, NHTSA has determined that Alternative 2.5 is technologically feasible, economically practicable, supports the need of the United States to conserve energy, and is complementary to other motor vehicle standards of the government that are simultaneously applicable. NHTSA concludes that Alternative 2.5 is maximum feasible for MYs 2024–2026.

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, and environmental justice.

The impacts on energy use, air quality, and climate include *direct*, *indirect*, and *cumulative impacts.*[11] Direct impacts occur at the same time and place as the action. Indirect impacts occur later in time and/or are farther removed in distance. Cumulative impacts are the incremental direct and indirect impacts resulting from the action added to those of other past, present, and reasonably foreseeable future actions. The cumulative impacts associated with the Proposed Action and alternatives are discussed in Chapter 8, *Cumulative Impacts.*

To derive the direct and indirect impacts of the action alternatives, NHTSA compares each action alternative to a No Action Alternative, which reflects baseline trends that would be expected in the absence of any regulatory action as discussed above. The No Action Alternative for this 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.

[11] 40 CFR § 1508.8 (2019).

petroleum consumption. In 2050, transportation is expected to account for 76.9 percent of total U.S. petroleum consumption.[12]

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. 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. 2.5	Alt. 3
Fuel Consumption					
Cars	1,408	1,367	1,309	1,301	1,270
Light trucks	2,151	2,104	2,082	2,070	2,051
All light-duty vehicles	3,559	3,471	3,391	3,371	3,321
Decrease in Fuel Consumption Compared to the No Action Alternative					
Cars	-	-41	-99	-107	-138
Light trucks	-	-47	-69	-81	-100
All light-duty vehicles	-	-88	-168	-188	-238

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 3,559 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the Proposed Action and alternatives is projected to range from 3,471 billion GGE under Alternative 1 to 3,321 billion GGE under Alternative 3. All of the action alternatives would decrease fuel consumption

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

compared to the No Action Alternative, with fuel consumption decreases that range from 88 billion GGE under Alternative 1 to 238 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[13] 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

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

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 emissions are not consistent across all pollutants. This 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 Section III.C of the final rule preamble, Chapter 2 of the Technical Support Document, and Chapter 3 of the Final Regulatory Impact Analysis (FRIA) issued concurrently with this Final 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 CO, NO_X, and SO_2 in 2025, emissions increase slightly under the action alternatives compared to the No Action Alternative; however, for PM2.5, emissions decrease slightly 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.
- In 2025, across all criteria pollutants and action alternatives, the smallest increase in emissions is 0.03 percent and occurs for NO_X under Alternative 1; 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 decrease under the action alternatives compared to the No Action Alternative, with the more stringent alternatives having the largest decreases. 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 0.1 percent and occurs for CO and SO_2 under Alternative 1; the largest decrease is 12.0 percent and occurs for VOCs under Alternative 3. The smallest increase in emissions is 0.03 percent and occurs for NO_X under Alternative 1; the largest increase is 7.4 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 acetaldehyde, acrolein, benzene, and 1,3-butadiene by up to about 0.2 percent, and for formaldehyde by 0.1 percent. DPM emissions would decrease by as much as 0.7 percent. For 2025, the largest relative increase in emissions would occur for 1,3-butadiene, for which emissions would increase by up to 0.23 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 with the more stringent alternatives having the largest decreases. 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

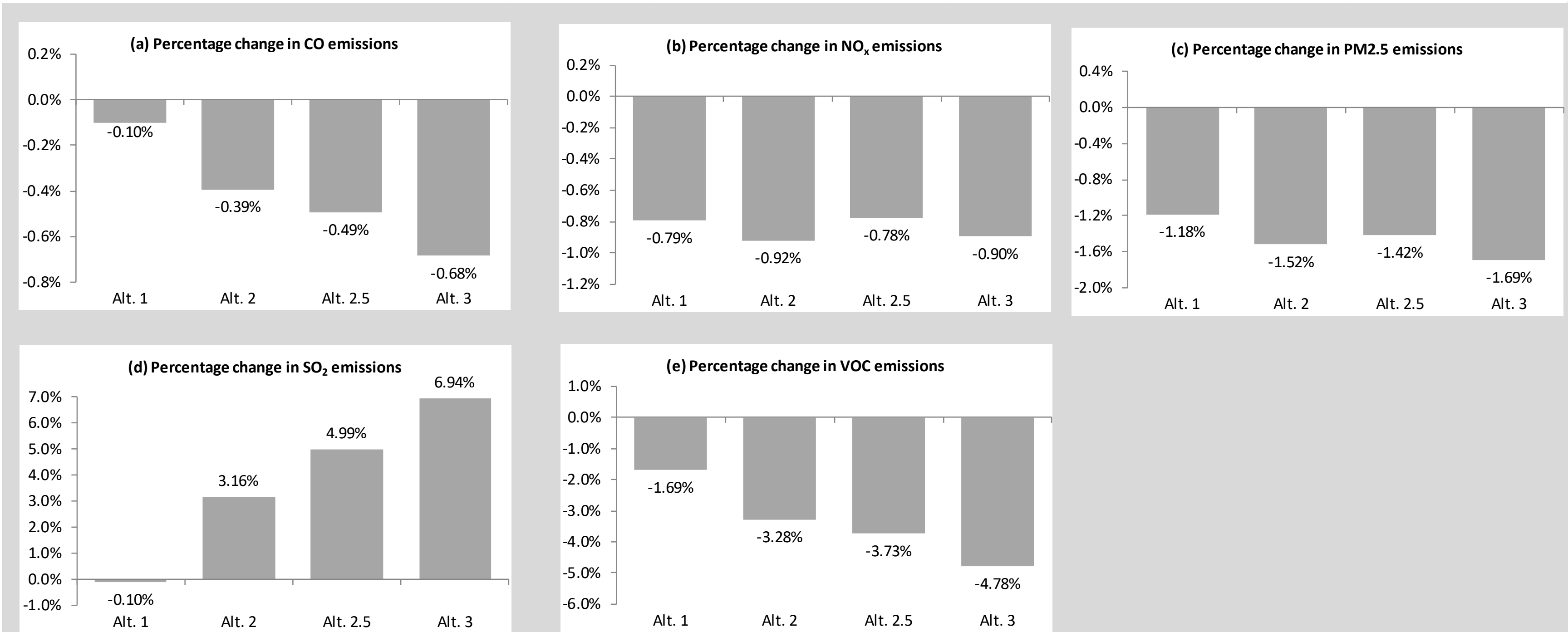
The air quality analysis identified the following health impacts.

- In 2025, all action alternatives would result in decreases in adverse health impacts (mortality, acute bronchitis, respiratory emergency room visits, and other health effects) nationwide compared to the

No Action Alternative, primarily as a result of decreases in emissions of PM2.5. Decreases in adverse health impacts would be largest for Alternative 1, smaller for Alternative 3, still smaller for Alternative 2, and smallest for Alternative 2.5 relative to the No Action Alternative. However, the differences among the action alternatives are small. These decreases result from projected decreases in emissions of PM2.5 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 be offset by upstream emissions reductions due to decreases in fuel usage. As mentioned above, it is important to stress that changes in these assumptions would alter these health impact results; however, NHTSA believes that these assumptions are reasonable.

- 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 and PM2.5. The decreases in adverse health impacts get larger from Alternative 1 to Alternative 3 in 2035 and 2050, except that for some health impacts in 2035 and 2050 the decreases are smaller for Alternative 2.5 than for Alternative 2. These decreases reflect the generally increasing stringency of the action alternatives as they become implemented.

Figure S-1. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Alternative Compared to the No Action Alternative, Direct and Indirect Impacts

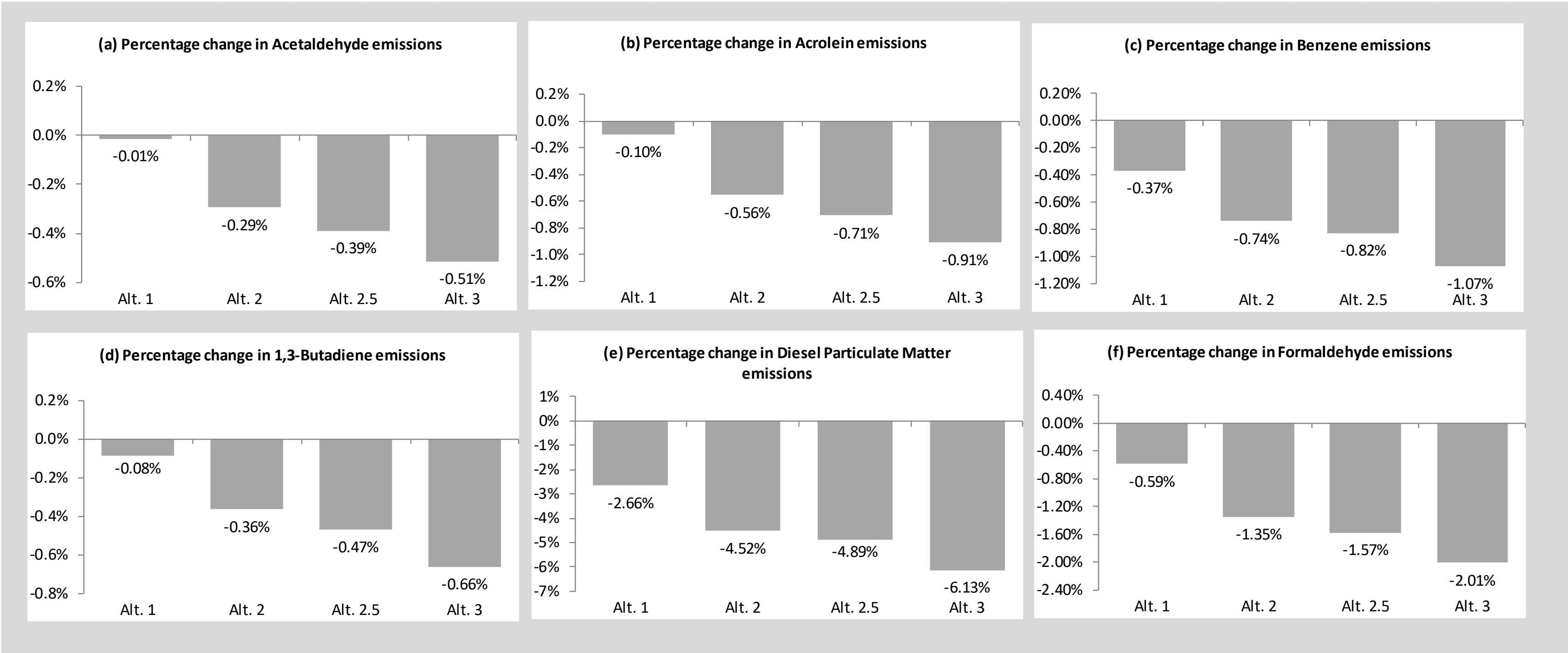


Notes:

Negative values indicate emissions decreases; positive values are emissions increases.

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

Figure S-2. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Alternative Compared to the No Action Alternative, Direct and Indirect Impacts



Notes:

Negative values indicate emissions decreases; positive values are emissions increases.

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 decreases 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 2021a). Annual average global temperature has increased by 1.0 degree Celsius (°C) (1.8 degrees Fahrenheit [°F]) from 1901 to 2016, and global temperatures are rising at an increasing rate (U.S. Global Change Research Program [GCRP] 2017). 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). Global mean sea level rose faster in the 20th century than in any prior century over the last three millennia (IPCC 2021a).

Global atmospheric CO_2 concentration has increased 48.4 percent from approximately 278 parts per million (ppm) in 1750 (before the Industrial Revolution) (IPCC 2021a) to approximately 412 ppm in 2020 (NOAA 2021). Atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O) increased approximately 158 and 19 percent, respectively, over roughly the same period (IPCC 2021a). IPCC concluded, "it is unequivocal that human influence has warmed the atmosphere, ocean and land. … Overall, the evidence for human influence has grown substantially over time and from each IPCC report to the subsequent one." (IPCC 2021a).

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 2021a; 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 (IPCC 2021a; GCRP 2017).

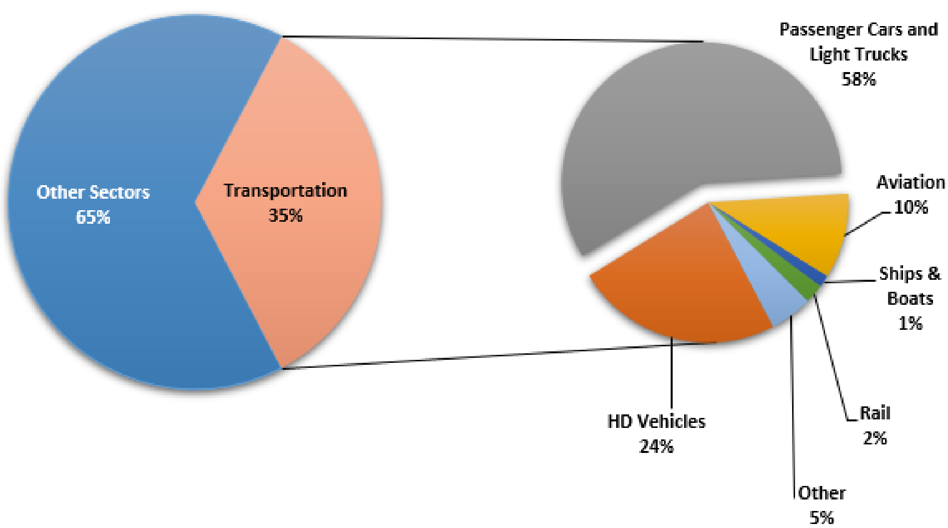
This SEIS draws primarily on panel-reviewed synthesis and assessment reports from IPCC and GCRP, supplemented with past reports from the U.S. Climate Change Science Program (CCSP), the National Research Council, and the Arctic Council.

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 global 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.[14] 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 (EPA 2021a). 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).[15] 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

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

[15] 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 associated with 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

For the analysis of direct and indirect impacts, NHTSA used the Global Change Assessment Model (GCAM) Reference scenario and the Shared Socioeconomic Pathway (SSP) 3-7.0 scenario to represent the reference case emissions scenarios (i.e., future global emissions assuming no comprehensive global actions to mitigate GHG emissions). NHTSA selected the GCAMReference and SSP3-7.0 scenarios for their 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. Both of these scenarios yield a radiative forcing of approximately 7.0 watts per square meter in the year 2100.

Greenhouse Gas Emissions

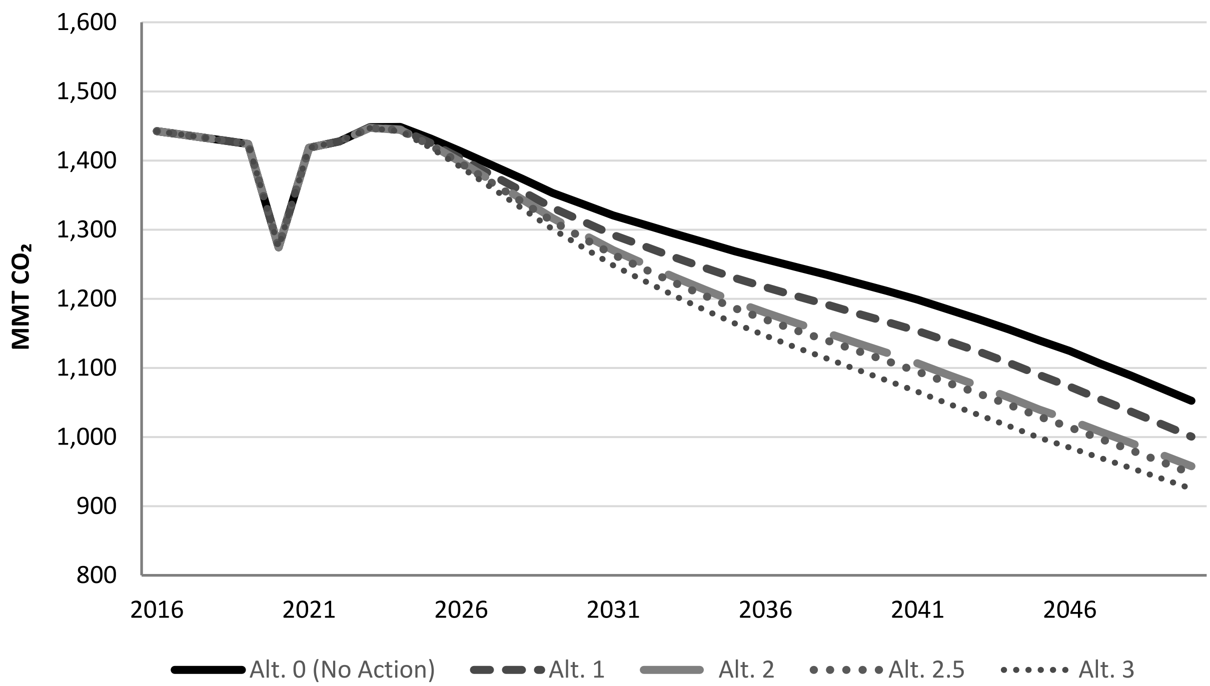
The alternatives would have the following impacts related to GHG emissions.

- 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 89,200 million metric tons of carbon dioxide ($MMTCO_2$) from 2021 through 2100 under the No Action Alternative. Alternative 1 and Alternative 2 would decrease these emissions by 4 and 7 percent respectively through 2100. The Preferred Alternative (Alternative 2.5) would decrease these emissions by 8 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 967 $MMTCO_2$ 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 5 percent under Alternative 1, 9 percent under Alternative 2, and 12 percent under Alternative 3. Under the

Preferred Alternative, the 2100 total projected CO_2 emissions for all passenger cars and light trucks are 870 $MMTCO_2$, reflecting a 10 percent decrease.

- Compared to GCAMReference total global CO_2 emissions projection 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 0.07 percent under Alternative 1, 0.13 percent under Alternative 2, 0.15 percent under the Preferred Alternative, and 0.18 percent under Alternative 3 by 2100. Using the SSP3-7.0 total global emissions projection of 5,277,281 $MMTCO_2$ over this same period, the Proposed Action and alternatives are expected to reduce global CO_2 by 0.07 percent under Alternative 1, 0.12 percent under Alternative 2, 0.14 percent under the Preferred Alternative, and 0.17 percent under Alternative 3 by 2100.
- The emissions reductions in 2025 compared with emissions under the No Action Alternative are approximately equivalent to the annual emissions from 1,143,017 vehicles under Alternative 1, 1,613,007 vehicles under Alternative 2, 1,763,066 vehicles under the Preferred Alternative, and 2,379,681 vehicles under Alternative 3. (A total of 253,949,461 passenger cars and light truck 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.

- Estimated CO_2 concentrations in the atmosphere for 2100 under the GCAMReference scenario 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 0.78 ppm compared to the No Action Alternative. Atmospheric CO_2 concentration under Alternative 1 would decrease by 0.31 ppm compared with the No Action Alternative. The CO_2 concentrations under the SSP3-7.0 emissions scenario in 2100 would range from 799.57 ppm under Alternative 3 to approximately 800.39 ppm under the No Action Alternative, indicating a maximum atmospheric CO_2 decrease of approximately 0.82 ppm compared to the No Action Alternative. Alternative 1 would decrease by 0.30 ppm compared with the No Action Alternative.

- Under the GCAMReference scenario, 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 0.001°C (0.002°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 under GCAMReference.
- Under the SSP3-7.0 emissions scenario, global mean surface temperature is projected to increase by approximately 3.56°C (6.41°F) under the No Action Alternative by 2100. Implementing the most stringent alternative (Alternative 3) would decrease this projected temperature rise by 0.004°C (0.007°F), while implementing Alternative 1 would decrease projected temperature rise by 0.001°C (0.002°F). Figure S-6 shows the increase in projected global mean surface temperature under each action alternative compared with temperatures under the No Action Alternative under SSP3-7.0.
- Projected sea-level rise in 2100 under the GCAMReference scenario 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 0.07 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. Projected sea-level rise in 2100 under the SSP3-7.0 scenario ranges from a high of 78.53 centimeters (30.92 inches) under the No Action Alternative to a low of 78.43 centimeters (30.88 inches) under Alternative 3. Alternative 3 would result in a decrease in sea-level rise equal to 0.10 centimeter (0.04 inch) by 2100 compared with the level projected under the No Action Alternative. Alternative 1 would result in a decrease of 0.02 centimeter (0.008 inch) compared with the No Action Alternative.
- Under the GCAMReference scenario, 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. Under the SSP3-7.0 scenario, global mean precipitation is anticipated to increase by 6.09 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 under the GCAMReference scenario 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. Ocean pH in 2100 under the SSP3-7.0 scenario is anticipated to be 8.2123 under Alternative 3, about 0.0004 more than the No Action Alternative. Under Alternative 1, ocean pH in 2100 would be 8.2120, or 0.0002 more than the No Action Alternative.

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

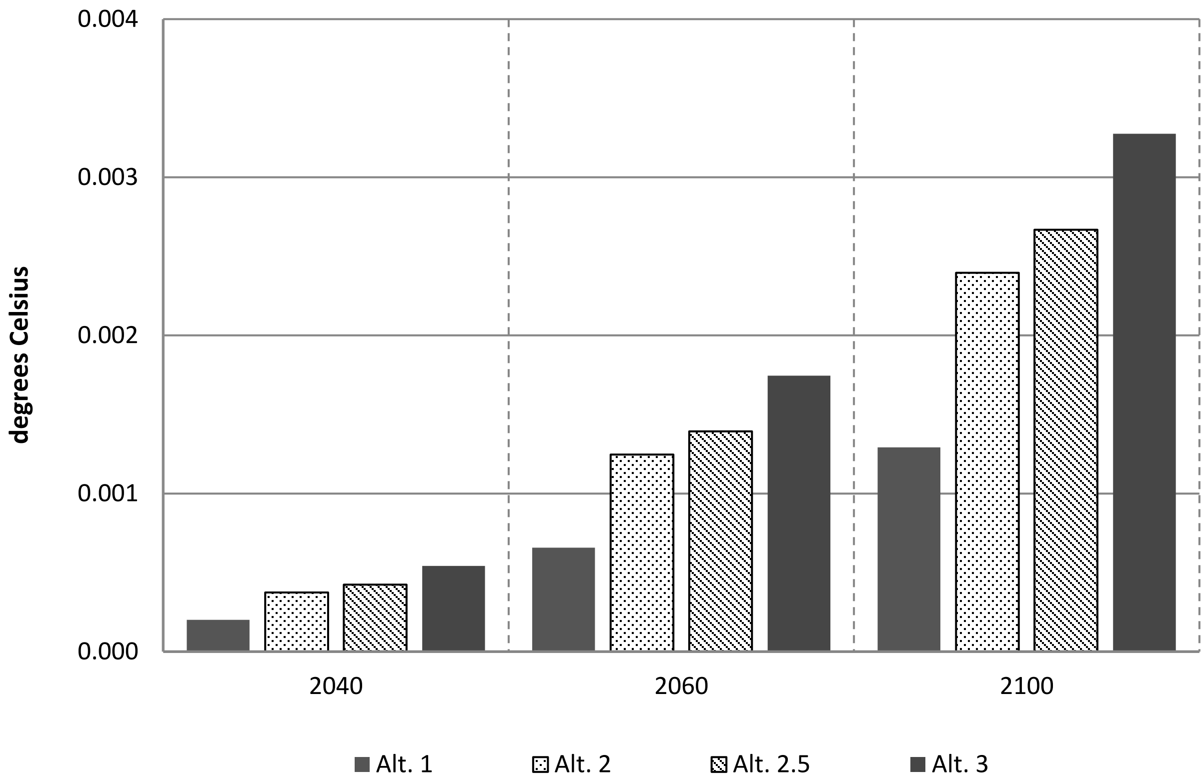
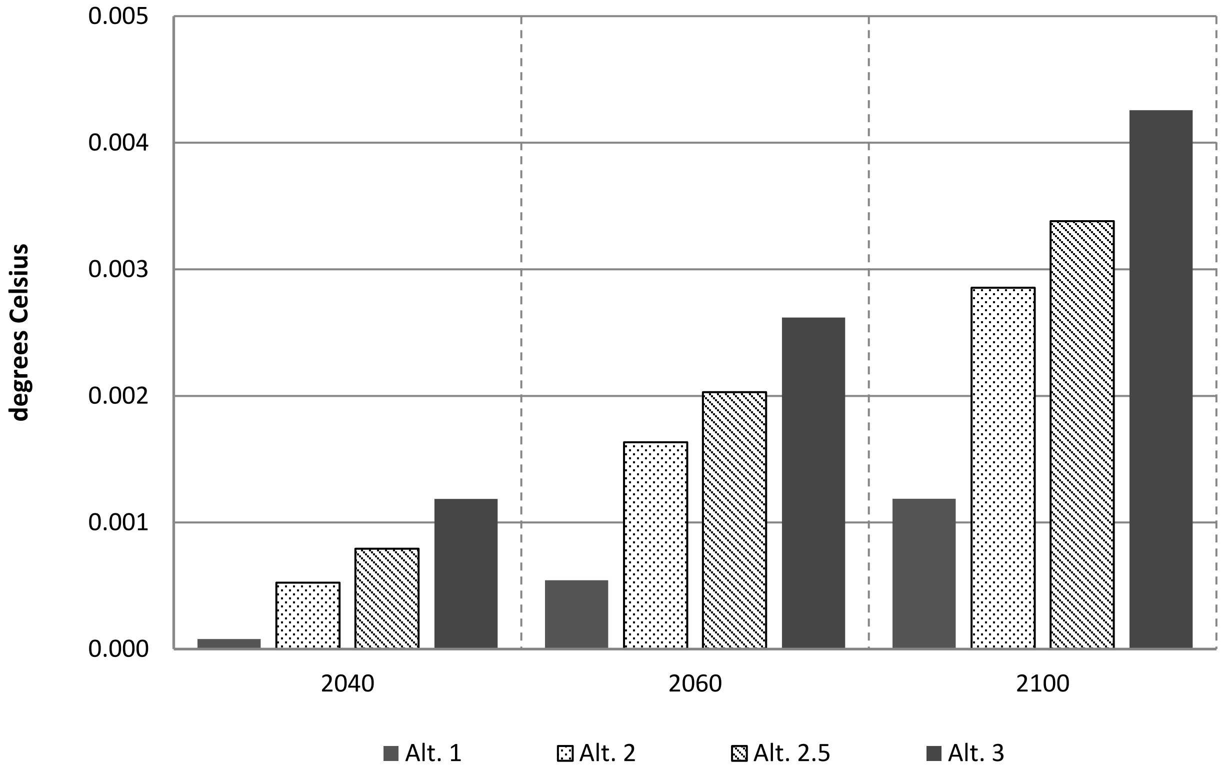


Figure S-6. Reductions in Global Mean Surface Temperature Compared with the No Action Alternative—SSP3-7.0



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, global electric vehicle market projections, and electric vehicle charging infrastructure, as well as changes in 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. All of these potential cumulative actions would reduce U.S. petroleum consumption and slightly increase U.S. electricity consumption.

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 3,500 $MMTCO_2$ (under Alternative 1) to 8,800 $MMTCO_2$ (under Alternative 3). The Proposed Action and alternatives would decrease total vehicle emissions by between 4 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 under GCAM6.0, the incremental impact of this rulemaking is expected to decrease global CO_2 emissions between 0.10 (Alternative 1) and 0.22 (Alternative 3) percent by 2100. Using the SSP2-4.5 emissions scenario, global CO_2 emissions from 2021 to 2100 are projected to be 1,873,002 $MMTCO_2$. Global emissions through 2021 are considerably less than in the GCAM6.0 scenario due to the projections that emissions will begin to decline around mid-century. The incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.20 (Alternative 1) and 0.50 (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 from the GCAM6.0 scenario in 2100 range from a high of 687.29 ppm under the No Action Alternative to a low of 686.49 ppm under Alternative 3, the lowest CO_2 emissions alternative. This is a decrease of 0.80 ppm compared with the No Action Alternative. Estimated atmospheric CO_2 concentrations from the SSP2-4.5 scenario in 2100 range from 568.07 ppm (No Action Alternative) to 567.34 ppm (Alternative 3). This is a decrease of 0.73 ppm compared with the No Action Alternative.
- Under the GCAM6.0 scenario, global mean surface temperature increases for the Proposed Action and alternatives compared with the No Action Alternative in 2100 range from a low of 0.001°C (0.002°F) under Alternative 1 to a high of 0.005°C (0.009°F) under Alternative 3. Figure S-7 illustrates the increases in global mean temperature under each action alternative compared with the No Action Alternative. Similarly, under the SSP2-4.5 scenario global mean surface temperature increases range from 0.001°C (0.002°F) under Alternative 1 to 0.005°C (0.009°F) under Alternative 3 (Figure S-8).
- Using the GCAM6.0 scenario, 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. Using the SSP2-4.5 scenario, global mean precipitation is anticipated to increase 4.78 percent under the No Action Alternative, with the action alternatives reducing this effect 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 70.11 centimeters (27.60 inches) under Alternative 3, indicating a maximum increase of sea-level rise of 0.11 centimeter (0.04 inch) by 2100. Under the SSP2-4.5 scenario, sea-level rise in 2100 ranges from 60.73 centimeters (23.91 inches) under the No Action Alternative to 60.63 centimeters (23.87 inches) under Alternative 3, for a maximum decrease of 0.10 centimeter (0.04 inch) by 2100.
- Ocean pH in 2100 is anticipated to be 8.2727 under Alternative 3, about 0.005 more than the No Action Alternative. Alternatively, the SSP2-4.5 scenario identifies ocean pH values ranging from 8.3458 (No Action Alternative) to 8.3463 (Alternative 3) for a maximum increase in pH of 0.0005 by 2100.

Figure S-7. Reductions in Global Mean Surface Temperature Compared with the No Action Alternative, Cumulative Impacts—GCAM6.0

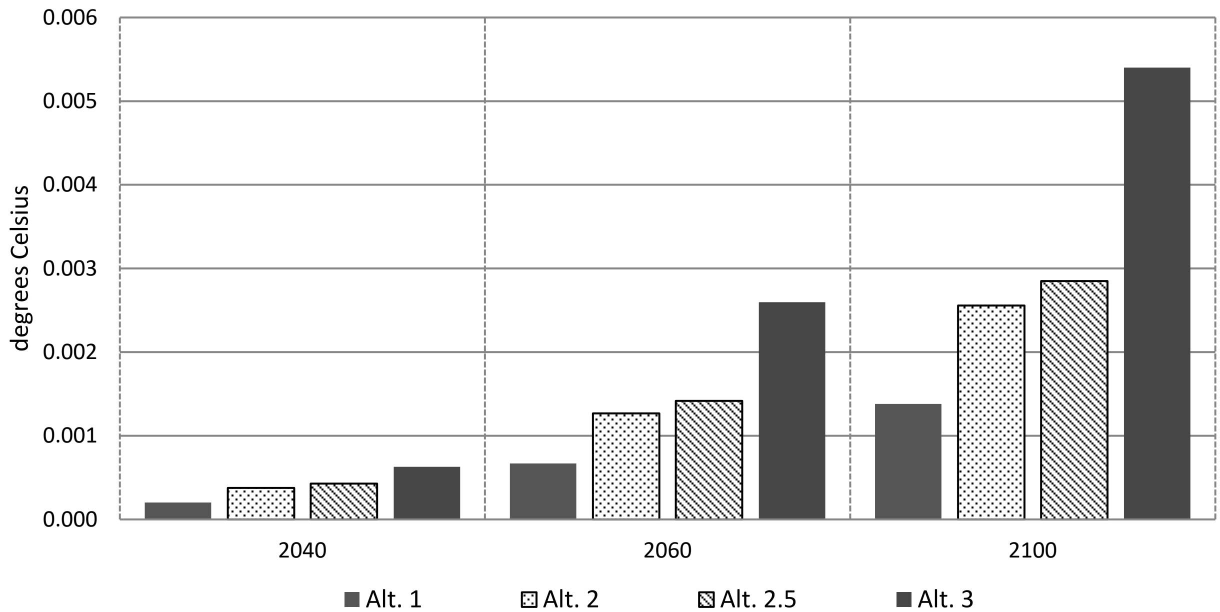
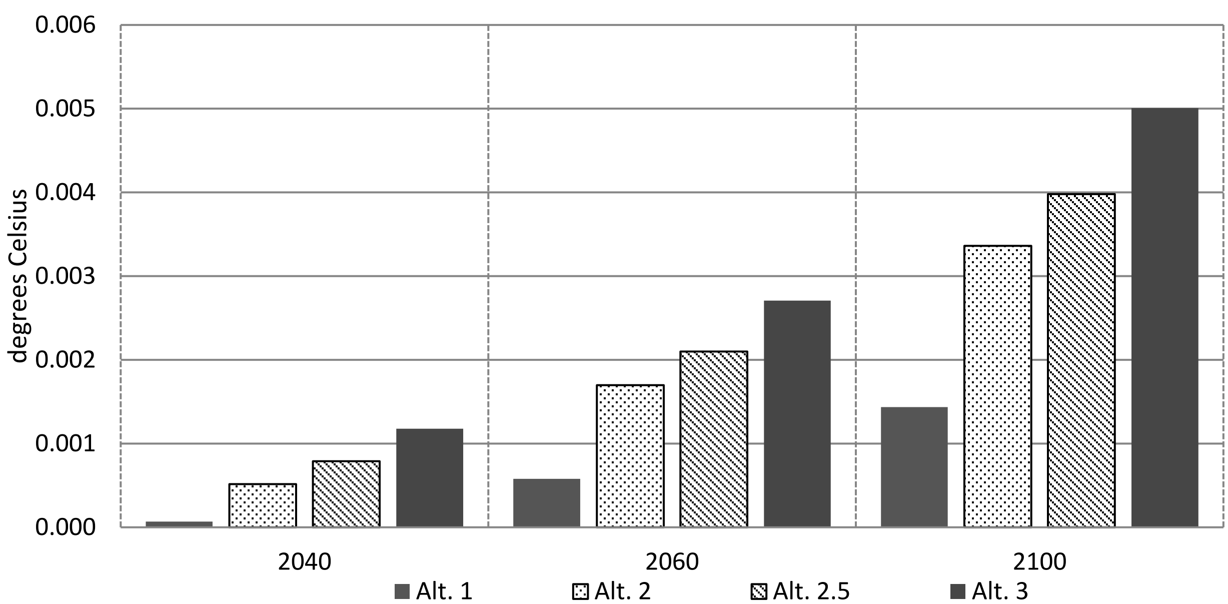


Figure S-8. Reductions in Global Mean Surface Temperature Compared with the No Action Alternative, Cumulative Impacts—SSP2-4.5



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) using the three degree sensitivity analysis by the year 2100 is between 0.73 ppm and 0.80 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, between 0.10 and 0.11 centimeter (0.04 inch) decrease in sea-level rise, and an increase of between 0.0004 and 0.0005 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.

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 entirely 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 rulemaking, overall impacts are very likely to be beneficially affected 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 an increasing intensity of precipitation events, drought, changes in sediment transport, and reductions 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 and other gases.
- 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 ambient air can also stimulate plant growth to some degree, a phenomenon known as the CO_2 fertilization effect, although the impact varies by species and location. Many marine fish species could migrate to deeper and/or colder waters in response to rising ocean temperatures, and global potential fish

catches could decrease. Impacts on food and agriculture including changing 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 induced by climate change.

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

[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 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 Safer Affordable Fuel-Efficient (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. Though EO 13990 prompted NHTSA's review, NHTSA is exercising its own authority, consistent with its statutory factors, to amend the CAFE standards for MY 2024–2026 passenger cars and light trucks in a final rule being issued concurrent with this Final Supplemental Environmental Impact Statement (SEIS). As NHTSA discusses in the preamble to the final rule, this action reflects a conclusion significantly different from the conclusion that NHTSA reached in the 2020 SAFE Vehicles Final Rule, but this is because important facts have changed, and because NHTSA has reconsidered how to balance the relevant statutory considerations in light of those facts. NHTSA concludes that significantly more stringent standards are maximum feasible. For a further discussion on NHTSA's explanation on this action, see Section VI.D in the final rule. As described in the final rule, NHTSA is retaining the existing CAFE standards for MYs 2021–2023 in light of EPCA's requirement that

[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).

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]

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 making 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, Final EIS, and Draft SEIS, NHTSA is also informed by the public comments it received and which are available for review in the docket.[22]

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[15] 49 U.S.C. § 32902(g)(2).

[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 opened a new docket for this SEIS to reduce confusion, Docket Number

1.2 Purpose and Need

NEPA requires that agencies develop alternatives to a proposed action based on the action's purpose and need. The purpose and need statement explains why the action is needed, describes the action's intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis.[23] In accordance with EPCA/EISA, 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 emissions, 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.

NHTSA-2021-0054. However, the agency has considered the comments received in the prior docket as part of the preparation of this SEIS.

[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* final rule preamble, Section VI.A.5.d).

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]

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 final rule to amend CAFE standards for light-duty vehicles for MYs 2024–2026. In addition, in conjunction with NHTSA's Proposed Action, EPA has finalized amendments to its carbon dioxide (CO_2) emissions standards under Section 202(a) of the Clean Air Act (CAA) for MYs 2023–2026.[30] 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 considered 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*.[31]

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 44.8 to 51.3 mpg in MY 2026. This compares to estimated average required fuel economy levels of 38.1 mpg and

[28] 49 U.S.C. § 32902(a), (b)(2)(B).

[29] 49 U.S.C. § 32902(b)(3)(A).

[30] Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emission Standards; Final Rule, 86 FR 74434 (Dec. 30, 2021).

[31] 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 final rule issued concurrently with this Final 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*.

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, 44.2 mpg in MY 2025, and 49.2 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 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,[32] 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.[33] 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.[34] In this rulemaking for MYs 2024–2026, NHTSA again adopts 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 employs 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 final rule preamble.

Under the final 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[35] average (for CAFE, harmonic average[36]) 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

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

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

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

[35] Production for sale in the United States.

[36] 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.

passenger car, or light truck) on average must meet or exceed the average required level for the entire fleet in order to comply. In other words, a manufacturer's individual CAFE standards for cars and trucks would be based on the target levels associated with the footprints of its particular mix of cars and trucks manufactured in that model year. Because of the curves that represent the CAFE standard for each model year, a manufacturer with a relatively high percentage of smaller vehicles would have a higher standard than a manufacturer with a relatively low percentage of smaller vehicles.

Therefore, although a manufacturer's fleet average standard could be estimated throughout the model year based on the projected production volume of its vehicle fleet, the standard with which the manufacturer must comply would be based on its final model year vehicle production. Compliance would be determined by comparing a manufacturer's harmonically averaged fleet fuel economy level in a model year with a required fuel economy level calculated using the manufacturer's actual production levels and the targets for each vehicle it produces.[37] 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 final rule 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 final rule 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 final rule. 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

[37] 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).

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 final rule preamble.

NHTSA makes its ultimate determination of a manufacturer's CAFE compliance obligation based on official reported and verified CAFE data received from EPA.[38] 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*,[39] a case involving a 2003 EPA order denying a petition for rulemaking to regulate GHG emissions from motor vehicles under CAA Section 202(a).[40] 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."[41] 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.[42]

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 most recent light-duty GHG standards rulemaking (2021), are part of EPA's response to the U.S.

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

[39] 549 U.S. 497 (2007).

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

[41] 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.

[42] 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).

Supreme Court decision.[43] EPA has amended its CO_2 emissions standards under Section 202(a) of the CAA for MYs 2023–2026. EPA's standards are projected to require that manufacturers, on average, meet a combined average emissions level of approximately 161 grams per mile of CO_2 in MY 2026.

The NHTSA and EPA rulemakings to revise the standards set forth in the 2020 SAFE Vehicles Final Rule remain closely coordinated despite being issued as separate regulatory actions. 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 has revised 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.[44] 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.[45] EPA and DOE personnel were asked to review and comment on the Draft and Final SEISs prior to publication.

1.5 Public Review and Comment

NHTSA submitted the Draft SEIS to EPA to disclose and analyze the potential environmental impacts of the agency's Proposed Action and reasonable alternative standards pursuant to CEQ NEPA implementing regulations, DOT Order 5210.1C, and NHTSA's regulations. On August 11, 2021, NHTSA posted the Draft SEIS to the NHTSA SEIS docket (Docket No. NHTSA-2021-0054-0002), and EPA published a Notice of Availability in the *Federal Register* on August 20, 2021.[46] The Draft SEIS requested public input on the agency's environmental analysis by October 4, 2021; publication of the Notice of Availability in the *Federal Register* initiated the Draft SEIS public comment period. On September 3, 2021, NHTSA published the proposed rule in the *Federal Register* and opened a 60-day comment

[43] 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).

[44] 40 CFR § 1501.6 (2019).

[45] 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.

[46] Environmental Impact Statements; Notice of Availability, 86 FR 46847 (Aug. 20, 2021); *see also* NHTSA. 2022. Corporate Average Fuel Economy. Available at: https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy (Accessed: Jan. 12, 2022) (announcing Draft SEIS comment period extension on September 24, 2021).

period.[47] NHTSA subsequently extended the comment period for the Draft SEIS to conclude with the proposed rule's October 26, 2021, public comment deadline.[48]

Consistent with NEPA and its implementing regulations, NHTSA mailed a notification of availability of the 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.

NHTSA also held a virtual public hearing on the Draft SEIS and the proposed rule on October 13, 2021.[49] NHTSA received oral statements from 78 individuals at the hearing. The agency also received more than 68,800 comments in the docket for the proposed rule (Docket No. NTHSA-2021-0053) and 14 comments in the docket for the Draft SEIS (Docket No. NHTSA-2021-0054). NHTSA reviewed the oral and written submissions in both dockets for comments relevant to the SEIS.

As described in Chapter 10 of this Final SEIS, *Responses to Public Comments*, comments that raised issues central to the rule or the rulemaking process are addressed in the preamble to the final rule, the Final Regulatory Impact Analysis (FRIA), or associated documents in the public docket.

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

NHTSA is issuing this Final SEIS concurrent with the final rule, which serves as the Record of Decision. The Record of Decision states and explains NHTSA's decision and describes NHTSA's consideration of applicable environmental laws and policies.[50] NHTSA has determined that concurrent issuance of the Final SEIS and Record of Decision is not precluded by statutory criteria[51] or practicability considerations. NHTSA will announce the availability of this Final SEIS in the *Federal Register*.[52]

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[47] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Notice of Proposed Rulemaking, 86 FR 49602 (Sept. 3, 2021).

[48] Environmental Impact Statements; Notice of Availability, 86 FR 53054 (Sept. 24, 2021).

[49] Public Hearing for Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Notification of Public Hearing, 86 FR 51092 (Sept. 14, 2021).

[50] *See* 49 U.S.C. § 304a (Pub. L. No. 114-94, 129 Stat. 1312, Section 1311(a)) and U.S. Department of Transportation, Office of Transportation Policy, *Guidance on the Use of Combined Final Environmental Impact Statements/Records of Decision and Errata Sheets in National Environmental Policy Act Reviews* (Apr. 25, 2019), available at https://www.transportation.gov/sites/dot.gov/files/docs/mission/transportation-policy/permittingcenter/337371/feis-rod-guidance-final-04302019.pdf.

[51] 49 U.S.C. § 304a(b)(1)-(2).

[52] 40 CFR § 1506.10(a).

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

[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] The conclusion reached in this rulemaking 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 Section II of the preamble to the final rule, NHTSA's review of its standards responds to the President's direction in EO 13990, and the final rule 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 2.5, 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 rule 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 final 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	38.7	39.4

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,

[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 four action alternatives that illustrate the following range of estimated average annual percentage increases in fuel economy for both passenger cars and light trucks:

Alt. 1 10.5 percent increase for MY 2024 over MY 2023[15] and a 3.26 percent annual average increase for both passenger cars and light trucks for MYs 2025–2026

Alt. 2 8.0 percent average annual increase for both passenger cars and light trucks for MYs 2024–2026 (Alternative 2 was NHTSA's Preferred Alternative in the Draft SEIS)

Alt. 2.5 8.0 percent average annual increase for MYs 2024 and 2025 and a 10.0 percent annual average increase for both passenger cars and light trucks for MY 2026 (Alternative 2.5 is NHTSA's Preferred Alternative)

Alt. 3 10.0 percent annual average increase for both passenger cars and light trucks for MYs 2024–2026

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

[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 final rule. NHTSA balances the statutory factors in Section VI.A of the preamble.

[15] Estimated average reflects 9.14 percent increase for passenger cars and 11.02 percent increase for light trucks.

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.)

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.

As noted in the preamble to the final rule, NHTSA has determined that Alternative 2.5 is technologically feasible, economically practicable, supports the need of the United States to conserve energy, and is complementary to other motor vehicle standards of the government that are simultaneously applicable. NHTSA concludes that Alternative 2.5 is maximum feasible for MYs 2024–2026.

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.[16]

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	43.2	44.7

mpg = miles per gallon

2.2.2.2 Alternative 2: 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 was NHTSA's Preferred Alternative in the Draft SEIS. Table 2.2.2-2 lists the estimated average required fleet-wide fuel economy under Alternative 2.

[16] 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.

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	40.6	44.2	48.1

mpg = miles per gallon

2.2.2.3 Alternative 2.5 (Preferred Alternative): 8.0 Percent Increase for MYs 2024 and 2025 and a 10.0 Percent Increase in Fuel Economy for MY 2026

Alternative 2.5 would require an 8.0 percent average annual increase for MYs 2024 and 2025 and a 10.0 percent annual average increase for both passenger cars and light trucks for MY 2026. Table 2.2.2-3 lists the estimated average required fleet-wide fuel economy under Alternative 2.5.

Table 2.2.2-3. Alternative 2.5: 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	59.4
Light trucks	35.1	38.2	42.4
Combined cars and trucks	40.6	44.2	49.1

mpg = miles per gallon

2.2.2.4 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 2.2.2-4 lists the estimated average required fleet-wide fuel economy under Alternative 3.

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

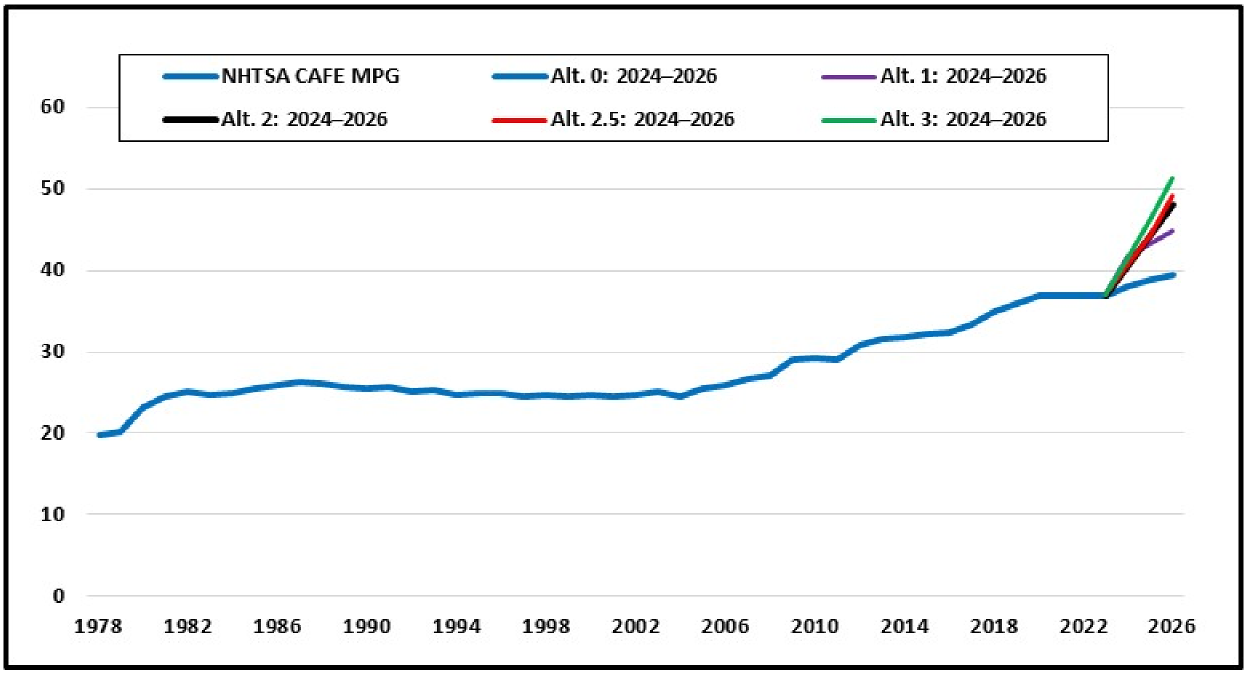
	MY 2024	MY 2025	MY 2026
Passenger cars	50.2	55.8	62.0
Light trucks	35.9	39.9	44.3
Combined cars and trucks	41.5	46.1	51.3

mpg = miles per gallon

2.2.3 No Action and Action Alternatives in Historical Perspective

NHTSA has set CAFE standards since 1978. Figure 2.2.3-1 illustrates unadjusted[17] 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, Alternative 2.5 (Preferred Alternative), Alternative 3, and the No Action Alternative (Alternative 0) to demonstrate the range of alternatives currently under consideration.

Figure 2.2.3-1. Historical CAFE Fuel Economy Requirements for Passenger Cars and Light Trucks through MY 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.

[17] 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 the No Action and action alternatives) because projected achieved fuel economy data would also be derived from laboratory testing and would not include an adjustment factor. See Section 2.2.5, *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.

2.2.4 EPA's Carbon Dioxide Standards

EPA has amended 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 revised standards.

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

	MY 2022 [a]	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	180	166	158	149	132
Light trucks	260	234	222	207	187
Combined cars and trucks [b]	220	202	192	179	161

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.[18]

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 its statutory factors 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

[18] 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.

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 Chapters 3, 4, and 6 of 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)[19] 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 rule, the model begins with a representation of the MY 2020 offerings for each manufacturer that includes the specific engines and transmissions on each model variant, observed sales volumes, and all fuel economy improvement technology already present on those vehicles. From there it adds technology, in response to 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.

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

- Economic factors, including mileage accumulation patterns, future fuel prices, the rebound effect (the increase in vehicle use that results from improved fuel economy), and emissions factors and the costs of emissions (or benefits of emissions reductions).
- 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 Final Regulatory Impact Analysis (FRIA). 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 promulgates what it 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.C and Section III.D of the final rule preamble. 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 may partly offset the gallons of fuel saved and the air pollutant emissions reductions, and may contribute to some 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 driving tends to increase as it becomes less expensive— a widely observed response referred to in this context as the *rebound effect*. Specifically, when a vehicle's fuel economy increases, the cost of fuel consumed per mile driven declines, thereby creating an incentive for additional vehicle use. Any resulting increase in vehicle use offsets part of the fuel savings that would otherwise result from higher fuel economy, although at the same time that additional mobility creates benefits for drivers and their passengers. When CAFE standards are raised, total passenger car and light-truck VMT will increase slightly because of the rebound effect, and tailpipe emissions of pollutants strictly related to vehicle use will 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 10 percent. The rebound effect is a change in driving demand that is separate from other potential sources of changing demand, such as growth in population or household income levels. These other sources of changing demand for vehicle travel are accounted for in the projection of VMT that is developed before applying the rebound effect, and NHTSA's analysis holds this underlying VMT constant across regulatory alternatives. Thus, only the effects of differences in the levels of fuel economy they require 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 Notice of Proposed Rulemaking, 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[20] of those targets. NHTSA has retained that approach in the final rule accompanying this Final 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 Chapter 6 of the FRIA and in Section V of the preamble to the final 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."[21] The SEIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of

[20] 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.

[21] 40 CFR § 1500.1(c) (2019).

alternative fuel technologies in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

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 (2021 Version) Fuel-Cycle Model		
Greenhouse Gases and Regulated Emissions in Transportation	• Estimates for nationwide average electricity generating mix from NEMS forecasts in AEO 2021 • Emission factors for petroleum extraction, transportation, and refining as well as finished gasoline and diesel transportation, storage, and distribution • Other inputs are default GREET 2018 data	• Upstream emissions for EV electricity generation used in transportation applications • 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 and evaporative) for CAFE Model for cars and light-duty trucks, for two fuel types: gasoline and diesel
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, emissions valuations, 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	• Regional population estimates • Labor productivity growth • Energy demand	• GCAMReference, GCAM6.0, and RCP4.5 global GHG emission scenarios (baselines)

Model Title	Model Inputs	Model Outputs Used in this Analysis
concentration pathway radiative forcing targets	• Agriculture, land cover, and land-use models • Atmospheric gas concentrations	
International Institute for Applied Systems Analysis and Integrated Assessment Modeling Consortium (IAMC): Shared Socioeconomic Pathways		
Quantitative projections of the Shared Socioeconomic Pathways and Integrated Assessment scenarios	• Regional population estimates • Urbanization projections • GDP estimates • Economic, technological, and agricultural indicators • Energy use and supply • Climate change and policy costs	• SSP1-2.6, SSP2-4.5, and SSP3-7.0 global GHG emissions scenarios (baselines)
Brookhaven National Laboratory and Oak Ridge National Laboratory: CO2SYS (v.2.3)		
CO_2 System Calculations Model	• Atmospheric gas concentrations from MAGICC model output • Natural sea water observations prepared at the Scripps Institution of Oceanography • Constants from the CO2SYS model	• Projected ocean pH in 2040, 2060, and 2100 under GHG emission scenarios
National Center for Atmospheric Research: MAGICC6		
Model for the Assessment of Greenhouse-gas Induced Climate Change	• Adjusted 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 2020 through 2100

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 2.5 microns or less in diameter; GCAM = global change assessment model; RCP = representative concentration pathway; SSP = Shared Socioeconomic 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 for the SAFE Vehicles Final Rule, 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:[22]

- 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 final rule, is uncertain and incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (2021a, 2021b), 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."[23] Some discussions, such as in Section 8.6.4, *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.

[22] 40 CFR § 1502.22(b) (2019).

[23] 40 CFR § 1502.22(b)(3) (2019).

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 Assessment 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 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.[24] 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 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

[24] Although EPA's MOVES3 is able to generate emissions for particulate matter (PM2.5) brake and tire wear, the CAFE Model's PM2.5 estimates include exhaust only.

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. 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.[25] 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, 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.[26] 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.[27] 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.[28]

[25] 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.

[26] A calendar-year 2050 run in MOVES 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.

[27] The emissions rates 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. However, they *exclude* emissions associated with activities such as vehicle storage, because those do not vary directly with vehicle use. In addition, they *exclude* particulate emissions associated with brake and tire wear. 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.

[28] 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.

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,[29] 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.

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 an increase 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, as well as the makeup of the electricity grid mix, 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 final 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 2021 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 (2021 version) (ANL 2021) 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

[29] 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.

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,[30] and by causing changes in emissions related to electricity generation due to the different EV deployment levels projected under each action alternative. NHTSA calculated the impacts of decreased fuel production on total emissions of each pollutant using the volumes of petroleum-based fuels estimated to be produced and consumed under each action alternative, together with emission factors for individual phases of the fuel production and distribution process derived from GREET. The emission factors derived from GREET (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."[31] 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 Assessment Implications of Vehicle Energy, Materials, and Technologies s*, 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 and upstream emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 and upstream emissions from passenger cars and light trucks. NHTSA estimates that the final CAFE standards and each of the action alternatives

[30] 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.

[31] 40 CFR § 1502.14 (2019).

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."[32] Indirect impacts "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable."[33] For detailed 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 3.3, *Environmental Consequences* (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*.

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[32] 40 CFR § 1508.8 (2019).

[33] Ibid.

Table 2.5.2-1. Direct and Indirect Impacts

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Energy: Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2020–2050 (billion gasoline gallon equivalent)				
3,559	3,471	3,391	3,371	3,321
Energy: Combined U.S. Passenger Car and Light Truck Decrease in Fuel Consumption for 2020–2050 (billion gallons)				
--	-88	-168	-188	-238
Air Quality: Criteria Air Pollutant Emissions Changes in 2035				
--	Decrease: CO, NO_X, PM2.5, SO_2, and VOCs. Increase: None.	Decrease: CO, NO_X, PM2.5, and VOCs, emissions smaller than Alt. 1. Increase: SO_2, emissions larger than Alt. 1.	Decrease: CO and VOCs, emissions smaller than Alts. 1 and 2. NO_X and PM2.5, emissions larger than Alt. 2 but smaller than Alt. 1. Increase: SO_2, emissions larger than Alts. 1 and 2.	Decrease: CO, PM2.5, and VOCs, emissions smaller than Alts. 1, 2, and 2.5. NO_X, emissions larger than Alts. 2 but smaller than Alts. 1 and 2.5. Increase: SO_2, emissions larger than Alts. 1, 2, and 2.5.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035				
--	Decrease: Acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. Increase: None.	Decrease: Acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde, emissions smaller than Alt. 1. Increase: None.	Decrease: Acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde, emissions smaller than Alts. 1 and 2 but larger than Alt. 3. Increase: None.	Decrease: Acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde, emissions smaller than Alts. 1, 2, and 2.5. Increase: None.
Air Quality: Decreases in Premature Mortality Cases and Work-Loss Days in 2035				
--	Premature mortality: 23 cases Work-loss: 3,295 days	Premature mortality: 31 cases Work-loss: 4,888 days	Premature mortality: 28 cases Work-loss: 4,923 days	Premature mortality: 34 cases Work-loss:6,046 days
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 ($MMTCO_2$)				
89,200	85,700	82,700	82,000	80,400
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)				
GCAMReference				
789.11	788.80	788.53	788.47	788.33
SSP3-7.0				

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
800.39	800.09	799.80	799.73	799.57
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)				
GCAMReference				
3.484°C (6.271°F)	3.483°C (6.269°F)	3.482°C (6.267°F)	3.481°C (6.265°F)	3.481°C (6.265°F)
SSP3-7.0				
3.564°C (6.414°F)	3.562°C (6.412°F)	3.561°C (6.409°F)	3.560°C (6.408°F)	3.559°C (6.407°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)				
GCAMReference				
76.28 (30.03)	76.26 (30.02)	76.23 (30.01)	76.23 (30.01)	76.22 (30.01)
SSP3-7.0				
78.53 (30.92)	78.51 (30.91)	78.47 (30.89)	78.45 (30.89)	78.43 (30.88)
Climate: Global Mean Precipitation Increase by 2100				
GCAMReference				
5.85%	5.85%	5.85%	5.85%	5.85%
SSP3-7.0				
6.09%	6.09%	6.09%	6.09%	6.09%
Climate: Ocean Acidification in 2100 (pH)				
GCAMReference				
8.2176	8.2177	8.2179	8.2179	8.2180
SSP3-7.0				
8.2119	8.2120	8.2122	8.2122	8.2123

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 or less in diameter; 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. 2.5	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.				
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 ($MMTCO_2$)[a]				
89,200	85,700	82,700	82,000	80,400
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)				
GCAM6.0				
687.29	686.99	686.74	686.68	686.49
SSP2-4.5				
568.07	567.79	567.54	567.47	567.34
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)				
GCAM6.0				
2.838°C (5.108°F)	2.837°C (5.106°F)	2.835°C (5.103°F)	2.835°C (5.103°F)	2.832°C (5.098°F)
SSP2-4.5				
2.212°C	2.210°C	2.208°C	2.208°C	2.207°C

Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
(3.98°F)	(3.98°F)	(3.98°F)	(3.97°F)	(3.97°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)				
GCAM6.0				
70.22 (27.65)	70.19 (27.63)	70.17 (27.63)	70.16 (27.62)	70.11 (27.60)
SSP2-4.5				
60.73 (23.91)	60.71 (23.90)	60.67 (23.88)	60.65 (23.88)	60.63 (23.87)
Climate: Global Mean Precipitation Increase by 2100				
GCAM6.0				
4.77%	4.77%	4.76%	4.76%	4.76%
SSP2-4.5				
4.78%	4.77%	4.77%	4.77%	4.77%
Climate: Ocean pH in 2100				
GCAM6.0				
8.2723	8.2724	8.2726	8.2726	8.2727
SSP2-4.5				
8.3458	8.3460	8.3462	8.3462	8.3463

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 scenarios (GCAM6.0 and SSP2-4.5) as opposed to the high emissions scenarios (GCAMReference and SSP3-7.0) used in the direct and indirect impacts analysis. NHTSA chose the GCAM6.0 and SSP2-4.5 scenarios as plausible global emissions baseline for the cumulative analysis, as these scenarios are 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 or less in diameter; 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 projects 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;[2] however, the data presented in this chapter reflect adjustments to provide supply and demand values that are comparable within fuel categories in the CAFE Compliance and Effects Model (referred to as the CAFE Model).[3] This chapter also discusses how the Proposed Action and alternatives would affect passenger car and light truck energy consumption, as projected by the CAFE Model. Note that the AEO and CAFE Model use different underlying assumptions but show similar resulting trends in projected 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 projects 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 projection reflects enacted legislation and final regulations, including the MY 2021–2026 CAFE standards established by the 2020 SAFE Vehicles Final Rule.[4]

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",[5] which have also adopted the California ZEV standard and collectively represent about 35 percent of the new passenger car and light truck vehicle market.

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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] AEO 2022 is scheduled for release in March 2022 and was not available for this analysis.

[3] The Docket for the SEIS includes an Excel workbook that shows how values reported in this chapter reflect separate AEO 2021 tables for Energy Supply and Disposition, Energy Consumption by Sector and Source, and Renewable Consumption by sector and source (NHTSA-2021-0054-007, file name "Draft SEIS Energy Figures based on 2021 AEO"). The data presented in this chapter do include electricity losses, again in order to provide supply and demand values that are comparable. The British thermal unit (Btu) amounts used in electricity generation include electricity losses because those losses are part of the supply Btus (coal, natural gas, etc.) used to deliver electricity for consumption.

[4] 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").

[5] 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.

Past and projected 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.[6]

In light of the important role of the transportation sector in overall U.S. energy supply and demand, this chapter discusses past, present, and projected 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

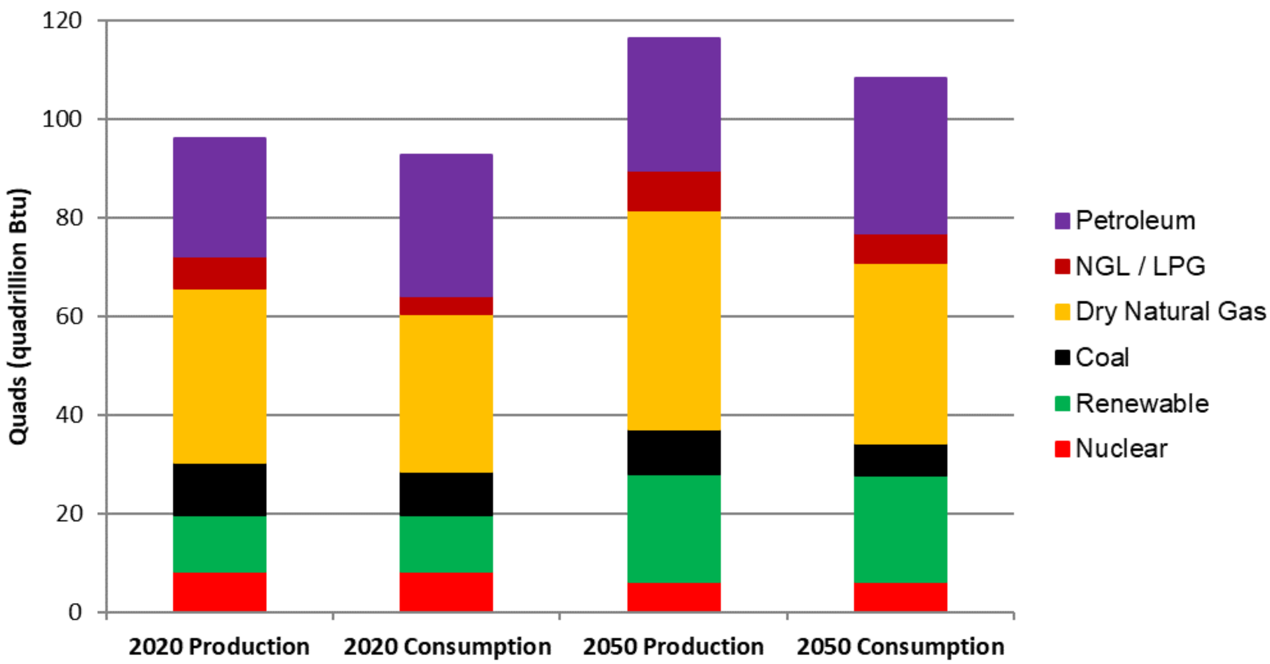
Primary fuels are energy sources consumed in the initial production of energy. Energy sources used in the United States include nuclear power, coal, natural gas, crude oil (converted to petroleum products for consumption), and natural gas liquids (converted to liquefied petroleum gases [LPG] for consumption). These five energy sources accounted for 87.8 percent of U.S. energy consumption in

[6] The March 2020 Final EIS 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.

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 projected 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 projected to rise to 19.8 percent (EIA 2021a). Projected 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 projected to decrease from 8.2 to 6.2 quadrillion Btu (quads), and consumption of renewable fuel is projected to increase from 11.3 quads in 2020 to 21.5 quads in 2050.[7] The projected 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 projected 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

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

essentially no net imports associated with these energy sources.[8] These fuels supplied 21 percent of U.S. energy consumption in 2020, and their combined share of consumption is projected to increase to 26 percent by 2050. In addition to the Reference case projection, 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).

U.S. coal production is projected 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 projected 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 projected 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 projected 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 projected 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 projected 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 projected to increase from 28.5 quads in 2020 to 31.5 quads in 2050. However, U.S. net imports of petroleum are projected 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.[9]

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 (crude oil and refined petroleum products) are only expected to increase slightly, resulting in a projection of net energy exports from 2020 through 2050 (EIA 2021a).

[8] 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).

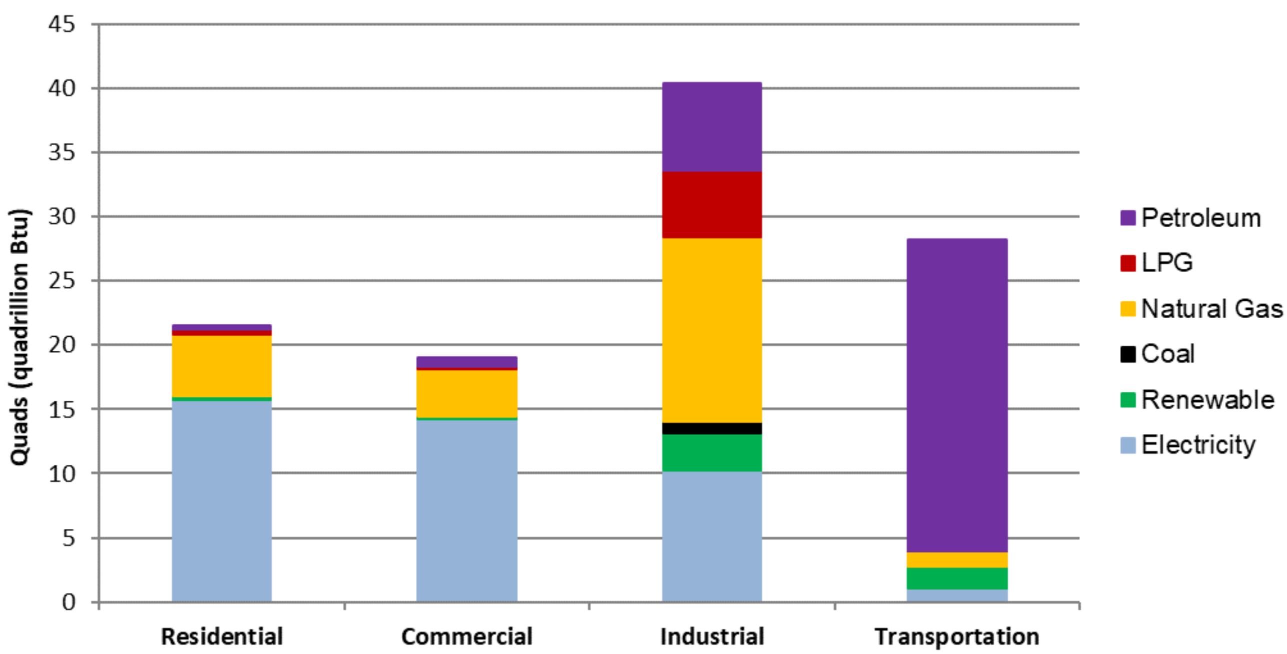
[9] NHTSA also reports on many of these results with the CAFE Model; however, AEO reporting information shown here is consistent with other information reported within this chapter.

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 projected 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.

Figure 3.1.2-1 illustrates sharply contrasting profiles for 2050 fuel consumption projections 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. Projected 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 projected 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 projected 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 projected 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 projected U.S. energy consumption in 2050. Commercial sector energy consumption is projected 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 projected 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 projected 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 projects 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 projected 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 (including the MY 2021–2026 CAFE standards established in the 2020 SAFE Vehicles Final Rule) in the AEO 2021 projection contributes to a 34.7 percent projected 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 projection for the No Action Alternative.[10]

The AEO 2021 also projects 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 projected increase in HD vehicle VMT results in a relatively small increase in HD vehicle fuel use because there is a large projected 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 projected increase in energy used by HD vehicles is associated with a 1.0 percent forecast increase from 2020 to 2050 in transportation sector

[10]AEO is an energy projection, 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 final rule 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.

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 (crude oil and refined petroleum products) are also only expected to increase slightly. The February 2022 EIA Short-Term Energy Outlook reports that the United States returned to being a net importer of petroleum (crude oil and refined petroleum products) in 2021 following its historic shift to being a net exporter of petroleum in 2020. The February 2022 Short-Term Energy Outlook also expects net crude oil imports to increase, making the United States a net importer of petroleum in 2022 (EIA 2022). As noted above, the 2021 AEO projects that the United States would continue to be a net petroleum importer through 2050.

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 projected 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 52 percent from 2020 through 2050. Under Alternatives 1, 2, 2.5 (NHTSA's Preferred Alternative), and 3, the average fuel economy of all light-duty vehicles in use would increase by 60, 68, 69, and 74 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 92 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.
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. 2.5	Alt. 3
Fuel Consumption					
Cars	1,408	1,367	1,309	1,301	1,270
Light trucks	2,151	2,104	2,082	2,070	2,051
All light-duty vehicles	3,559	3,471	3,391	3,371	3,321
Decrease in Fuel Use Compared to the No Action Alternative					
Cars	--	-41	-99	-107	-138
Light trucks	--	-47	-69	-81	-100
All light-duty vehicles	--	-88	-168	-188	-238

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 3,559 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the action alternatives is projected to range from 3,471 billion GGE under Alternative 1 to 3,321 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 88 billion GGE under Alternative 1 to 238 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, other property, and the natural environment. 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

[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 2021a). 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.

[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

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

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 10 microns or less in diameter; PM2.5 = particulate matter 2.5 microns or less in diameter

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,[5] 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

[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).

[5] EPA no longer considers acrolein to be a key driver of health risk from mobile sources (EPA 2018b). However, this analysis retains acrolein for consistency with the Draft SEIS.

component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class. On-road mobile sources are responsible (as of 2017) for 20,593 tons per year (3 percent of total U.S. 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).[6]

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.[7] 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.[8] 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

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

[7] 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).

[8] 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.

supported a conclusion of a causal association with traffic-associated air pollution as either "sufficient," "suggestive but not sufficient," or "inadequate and insufficient." The panel categorized evidence of a causal association for exacerbation of childhood asthma as "sufficient," and categorized evidence of a causal association for new onset asthma as between "sufficient" and "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 EPA Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (EPA 2020n), 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[9] 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).[10] Gasoline-fueled and diesel-fueled vehicles emit PM. In general, the

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

[10] 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

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). PM2.5 has been associated with risk for several respiratory conditions, including coronavirus disease 2019 (COVID-19) (Pozzer et al. 2020; Wu et al. 2020; Zhou et al. 2021). 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,[11] 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.[12] 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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characteristics. The term *black carbon* describes particles of mostly pure carbon that absorb solar radiation at all wavelengths (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).

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

[12] 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. NO_2 from vehicle traffic has been associated with risk for several respiratory conditions, including COVID-19 (Lipsitt et al. 2021). 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 EPA Regulatory Impact Analysis for the Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards (EPA 2021b).

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 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 from 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 (NRC) and public comment in June 2010 (EPA 2010a). The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011 (NRC 2011a). EPA's draft assessment, which addresses NRC recommendations, was suspended in 2018. The draft assessment was resumed in March 2021 (EPA 2021b).

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 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

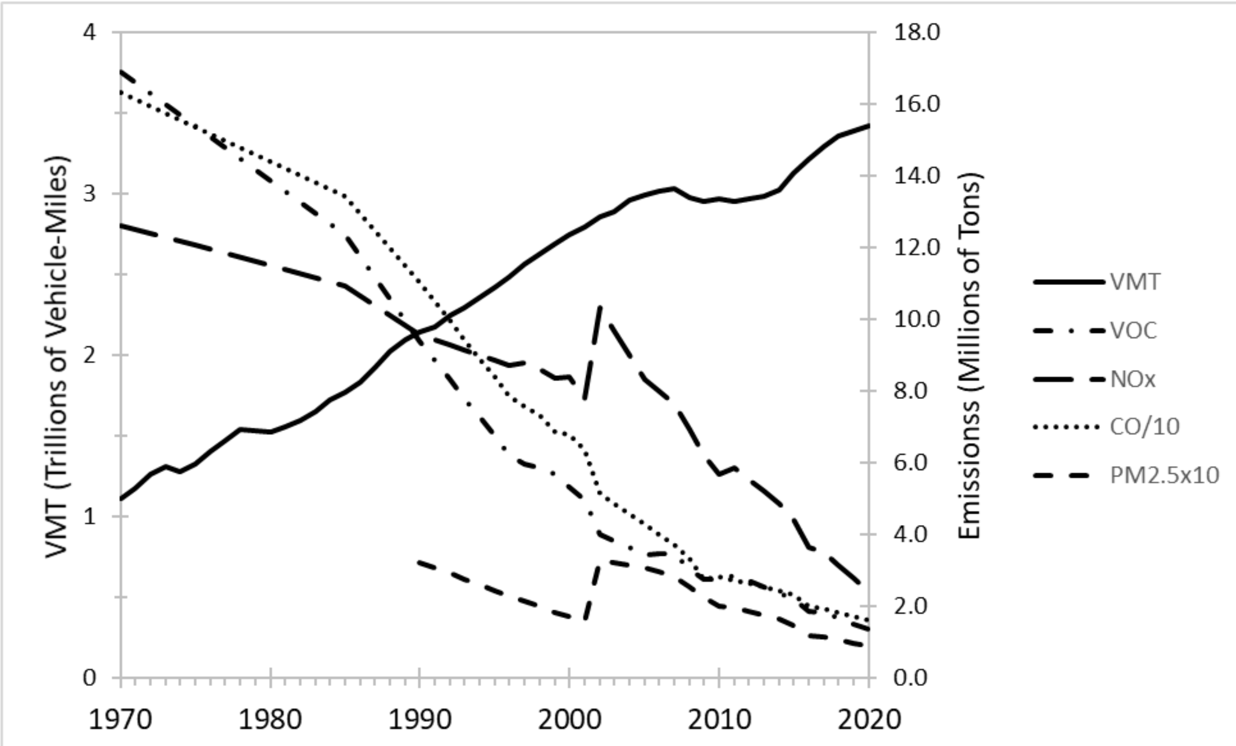
[13] The CAA, Section 177 (42 U.S.C. § 7507), gives states the option to adopt California's emissions standards provided they are more stringent than the corresponding federal standards; states that have done so sometimes are referred to as "Section 177" states. In addition to California and Section 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.

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

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.

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 2021c

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

[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

[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 VIII.D of the preamble to the final 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

[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 in vehicle sales 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 sales and use of PHEVs and BEVs.

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 estimates from the Motor Vehicle Emission Simulator (MOVES3), 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 2021 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. NHTSA developed upstream emission factors for air toxics that are consistent with EPA's National Emission Inventory and emission factors from the MOVES3 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.

[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.

average electricity-generating fuel mix, this rulemaking uses the Annual Energy Outlook 2021 forecast 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's assessment emphasized 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. 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 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.

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

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.[27] 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.[28] As noted throughout this methods section, the estimates of emissions rely on models and forecasts that contain numerous assumptions and data that are uncertain. Examples of areas in which information is uncertain (and therefore may be incomplete or unavailable) include future emissions rates, vehicle manufacturers' decisions about vehicle technology and design, the mix of vehicle types and model years in the passenger car and light truck fleet, VMT projections, emissions from fuel refining and distribution, the future composition of the grid mix, and economic factors.

[27] 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.

[28] 40 CFR § 1502.22(b) (2019).

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[29]

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).[30] 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 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

[29] 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.

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

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 from 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- Rock Hill, NC-SC	Ozone	Maintenance	100
Chicago-Naperville, IL-IN-WI	Ozone	Serious	50
Chico (Butte County), CA	Ozone	Marginal	100
Chico, CA	PM2.5	Maintenance	100
Cincinnati, OH-KY	Ozone	Marginal	100

Nonattainment/Maintenance Area	Pollutant	Status [a]	General Conformity Threshold [b]
Cleveland, OH	Ozone	Marginal	100
Cleveland, 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-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 – Revised, WI	Ozone	Nonattainment	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
Jamestown, NY	Ozone	Marginal	50
Johnstown, PA	PM2.5	Maintenance	100
Kern County (Eastern Kern), CA	Ozone	Severe-15	25
Klamath Falls, OR	PM2.5	Moderate	100
Knoxville, TN	Ozone	Maintenance	100
Knoxville-Sevierville-La Follette, 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
Los Angeles-San Bernardino Counties (West 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	70
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

Nonattainment/Maintenance Area	Pollutant	Status [a]	General Conformity Threshold [b]
Muskegon County, MI	Ozone	Marginal	100
Nevada County (western part), CA	Ozone	Serious	50
New York, NY-NJ-CT	PM2.5	Maintenance	100
New York-N. New Jersey-Long Island, NY-NJ-CT	Ozone	Serious	50
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 Luiseño Mission Indians of the Pechanga Reservation	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, CA	PM2.5	Moderate	100
Salt Lake City, UT	PM2.5	Serious	70
San Antonio, TX	Ozone	Marginal	100
San Diego County, CA	Ozone	Severe-15	25
San Francisco Bay Area, CA	Ozone	Marginal	100
San Francisco Bay Area, CA	PM2.5	Moderate	100
San Joaquin Valley, CA	Ozone	Extreme	10
San Joaquin Valley, CA	PM2.5	Serious	70
San Luis Obispo (Eastern San Luis Obispo), CA	Ozone	Marginal	100
Seaford, DE	Ozone	Marginal	50
Seattle-Tacoma, WA	PM2.5	Maintenance	100
Shoreline Sheboygan County, WI	Ozone	Maintenance	100
Inland Sheboygan County, WI	Ozone	Maintenance	100
Sheboygan County, WI	Ozone	Marginal	100
Southern Wasatch Front, UT	Ozone	Marginal	100
St. Louis, MO-IL	Ozone	Marginal	100
Steubenville-Weirton, OH-WV	PM2.5	Maintenance	100
Sutter Buttes, CA	Ozone	Marginal	100

Nonattainment/Maintenance Area	Pollutant	Status [a]	General Conformity Threshold [b]
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 December 2021. 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 2.5 microns or less in diameter; 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 15 percent and 62 percent of all upstream emissions per unit of fuel produced and distributed (based on GREET version 2021). 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.[31] 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 assumptions for this analysis because of uncertainty over the accuracy of the allocation of upstream emissions. A similar analysis was performed for

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

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.[32] 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 calculations for all pollutants. This calculation provides the total health impacts that would result under each alternative.

[32] 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.

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 2018c. See this source for more information related to the affected ages included in the analysis.
PM2.5 = particulate matter 2.5 microns or less in diameter; 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 2018c).[33] 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 a major cohort study 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[34] as reported in the epidemiology literature.[35]

EPA developed national per-ton estimates for selected pollutants emitted through stationary and mobile activity (EPA 2018c; 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. The following description of EPA's approach is adapted from the *Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards* (EPA 2021b). EPA bases its benefits analyses on peer-reviewed studies of air quality and health effects. EPA calculated the premature mortality-related effect coefficients that underlie the benefits-per-ton estimates from an epidemiology study that examined a large population cohort—the American Cancer Society (ACS) cohort (Krewski et al. 2009). Very recently, EPA updated its approach to estimating the benefits of changes in PM2.5 and ozone. These updates were based on information drawn from EPA's 2019 PM2.5 and 2020 Ozone ISAs, which were reviewed by the Clean Air Science Advisory Committee and the public (EPA 2019a, 2020n). EPA has not updated its mobile source benefit-per-ton estimates to reflect these updates in time for this analysis. Instead, based on the recommendation of EPA staff, NHTSA used the same PM2.5 benefit-per-ton estimates that were used in the Notice of Proposed Rulemaking and the Draft SEIS, to ensure consistency between the values corresponding to different source sectors. These benefit-per-ton estimates are based on the review of the EPA 2009 PM ISA and 2012 PM ISA Provisional Assessment and include a mortality risk estimate derived from the Krewski et al. (2009) analysis of the ACS cohort and nonfatal illnesses consistent with benefits analyses performed for the analysis of the final EPA Tier 3 Vehicle Rule, the final EPA 2012 PM NAAQS Revision, and the final EPA 2017–2025 Light-duty Vehicle GHG Rule. NHTSA expects this interval in updating the benefit-per-ton estimates to have a minimal impact on total PM benefits, since the underlying mortality risk estimate based on the Krewski study is identical to an updated PM2.5 morality risk estimate derived from an expanded analysis of the same ACS cohort. EPA

[33] 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.

[34] 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).

[35] 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.

intends to update its mobile source benefit-per-ton estimates to reflect these recent updates for use in future rulemaking analyses, and NHTSA would work with EPA in future rulemakings to update and synchronize approaches to benefit-per-ton estimates.

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.
- 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 conducted 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). For this SEIS analysis, NHTSA conducted the photochemical modeling analysis using a 12-kilometer (7.5-mile) by 12-kilometer grid cell size in accordance with EPA guidance (EPA 2018d), making use of the most recent EPA emissions information that is based on a 12-kilometer by 12-kilometer grid cell size. Appendix D discusses the photochemical modeling analysis and results.
- 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 (Krewski)	0.00082	0.0082	0.039	0.00029	0.0025	0.015
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 (Krewski)	0.00087	0.0088	0.041	0.00029	0.0025	0.015
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 other studies)	0.000095	0.00099	0.0045	0.000030	0.00027	0.0016
2030						
Premature Deaths (Krewski)	0.00094	0.0095	0.044	0.00029	0.0025	0.015
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 other studies)	0.00010	0.0011	0.0049	0.000030	0.00027	0.0016

NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less in diameter; SO_X = sulfur oxides

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 (Krewski)	0.00043	0.0061	0.022	0.00039	0.0088	0.026
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 other studies)	0.000046	0.00068	0.0025	0.000043	0.00098	0.0029
2025						
Premature Deaths (Krewski)	0.00040	0.0062	0.022	0.00039	0.0091	0.026
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 other studies)	0.000044	0.00069	0.0025	0.000042	0.0010	0.0029
2030						
Premature Deaths (Krewski)	0.00039	0.0062	0.022	0.00039	0.0091	0.026
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 other studies)	0.000042	0.00069	0.0025	0.000042	0.0010	0.0029

NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less in diameter; SO_X = sulfur oxides; TS&D = transportation, storage, and distribution

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

Calendar Year	Upstream Emissions (Electricity Generation Sector)			Vehicle Emissions (On-Road Light-Duty Gas Cars & Motorcycles Sector)		
	NO_X	SO_X	PM2.5	NO_X	SO_X	PM2.5
2020						
Premature Deaths (Krewski)	0.00066	0.0045	0.016	0.00075	0.013	0.073
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 other studies)	0.000068	0.00049	0.0017	0.000080	0.0015	0.0082
2025						
Premature Deaths (Krewski)	0.00070	0.0048	0.017	0.00075	0.013	0.073
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 other studies)	0.000074	0.00054	0.0019	0.000080	0.0015	0.0082
2030						
Premature Deaths (Krewski)	0.00074	0.0051	0.018	0.00075	0.013	0.073
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 other studies)	0.000079	0.00058	0.0021	0.000080	0.0015	0.0082

NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less in diameter; SO_X = sulfur oxides

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)			Vehicle Emissions (On-Road Light-Duty Diesel Sector)		
	NO_X	SO_X	PM2.5	NO_X	SO_X	PM2.5
2020						
Premature Deaths (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
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 other studies)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057
2025						
Premature Deaths (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
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 other studies)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057
2030						
Premature Deaths (Krewski)	0.00068	0.011	0.061	0.00060	0.031	0.050
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 other studies)	0.000073	0.0012	0.0069	0.000065	0.0035	0.0057

Sources: EPA 2018c; Fann 2020

NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less in diameter; SO_X = sulfur oxides

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 2.5 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[36] 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*

[36] 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 all action alternatives, but increase from 2035 to 2050 under all action alternatives. 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 Section III of the final rule preamble, Technical Support Document, and Final Regulatory Impact Analysis issued concurrently with this Final 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. 2.5	Alt. 3
Carbon monoxide (CO)					
2025	11,379,800	11,389,575	11,391,899	11,396,946	11,403,440
2035	4,561,397	4,556,698	4,543,500	4,538,868	4,530,176
2050	1,653,330	1,632,395	1,582,175	1,568,781	1,543,383
Nitrogen oxides (NO_X)					
2025	965,231	965,489	965,800	966,126	966,472
2035	406,733	403,512	402,995	403,575	403,092
2050	207,612	204,070	202,447	202,722	201,716
Particulate matter (PM2.5)					
2025	35,079	35,051	35,058	35,061	35,055
2035	25,236	24,937	24,852	24,878	24,809
2050	19,007	18,682	18,486	18,490	18,372
Sulfur oxides (SO_2)					
2025	74,532	74,578	74,853	74,877	75,009
2035	67,472	67,406	69,604	70,841	72,155
2050	73,806	74,696	77,066	78,245	79,296
Volatile organic compounds (VOCs)					
2025	1,327,614	1,326,844	1,326,371	1,326,645	1,326,288
2035	671,468	660,130	649,462	646,391	639,368
2050	363,182	346,695	331,396	327,371	319,517

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

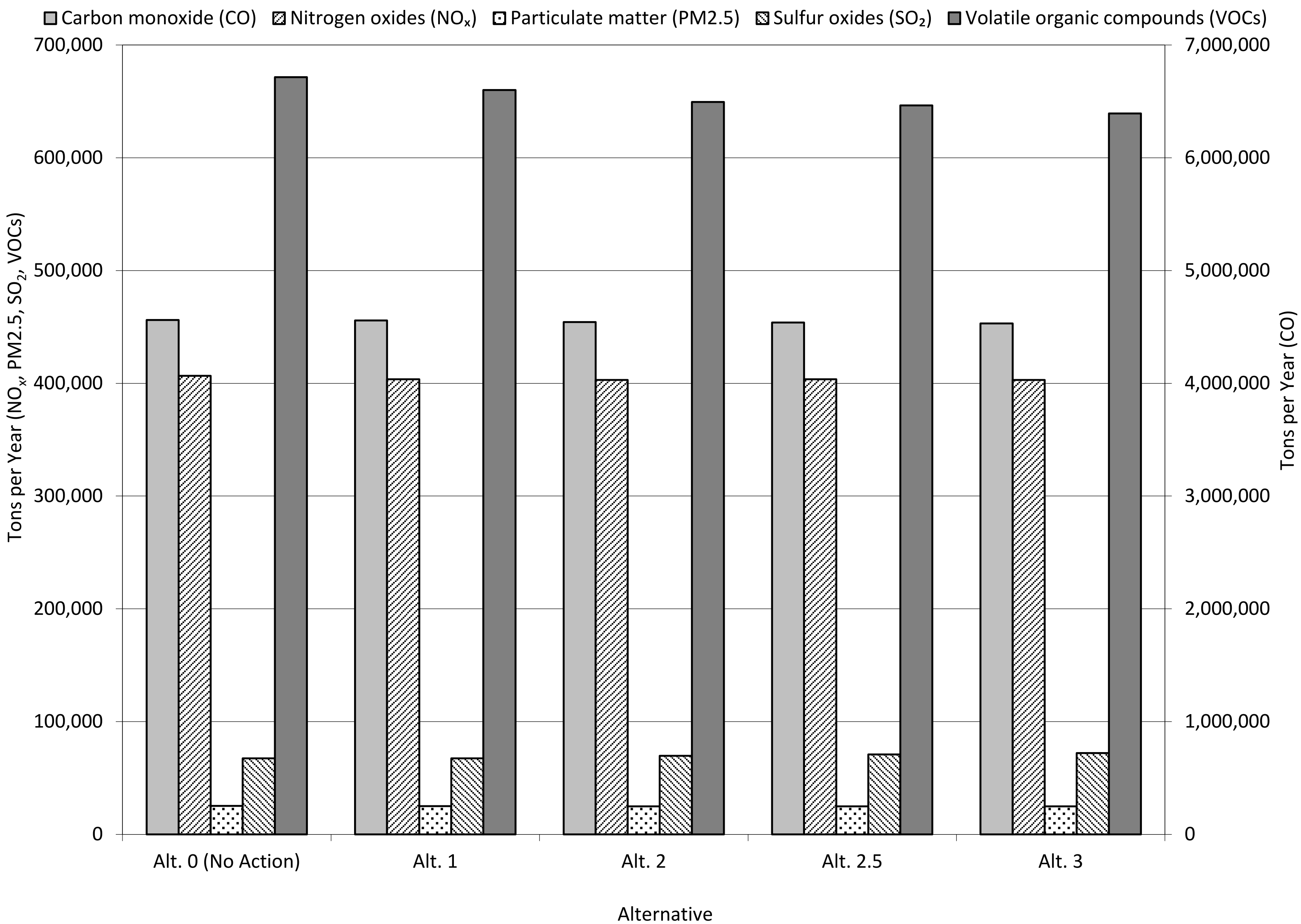


Figure 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives 1 and 3, Providing the Lowest and Highest Range in Direct and Indirect Impacts

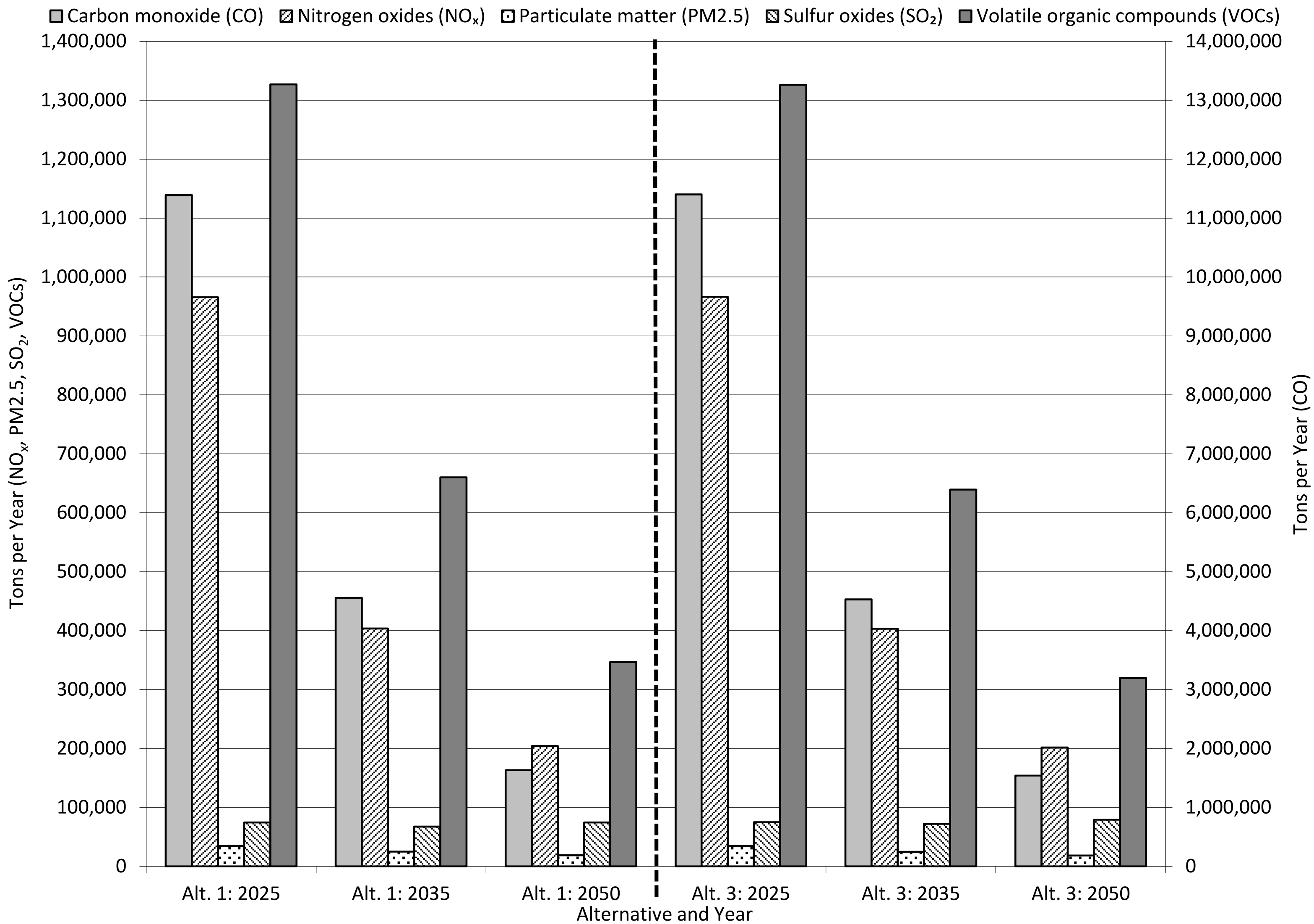


Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks by Vehicle Type and Alternative, Direct and Indirect Impacts

Vehicle Class	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Carbon monoxide (CO)					
Cars tailpipe	1,705,564	1,696,261	1,679,435	1,678,001	1,671,244
Cars upstream	40,741	40,000	39,420	39,273	38,748
Trucks tailpipe	2,755,591	2,762,050	2,765,881	2,762,342	2,760,622
Trucks upstream	59,500	58,388	58,765	59,252	59,562
Total	4,561,397	4,556,698	4,543,500	4,538,868	4,530,176
Nitrogen oxides (NO_X)					
Cars tailpipe	70,743	70,613	70,324	70,342	70,257
Cars upstream	72,955	71,575	70,446	70,169	69,200
Trucks tailpipe	156,041	156,353	156,649	156,674	156,766
Trucks upstream	106,994	104,971	105,576	106,390	106,869
Total	406,733	403,512	402,995	403,575	403,092
Particulate matter (PM2.5)					
Cars tailpipe	3,960	3,932	3,884	3,879	3,861
Cars upstream	6,168	6,051	5,956	5,933	5,851
Trucks tailpipe	6,072	6,088	6,094	6,079	6,070
Trucks upstream	9,037	8,866	8,917	8,987	9,028
Total	25,236	24,937	24,852	24,878	24,809
Sulfur oxides (SO_2)					
Cars tailpipe	2,752	2,627	2,466	2,436	2,358
Cars upstream	26,415	26,821	27,892	28,037	28,198
Trucks tailpipe	4,449	4,337	4,267	4,228	4,159
Trucks upstream	33,856	33,620	34,979	36,140	37,439
Total	67,472	67,406	69,604	70,841	72,155
Volatile organic compounds (VOCs)					
Cars tailpipe	115,718	115,491	114,982	115,019	114,880
Cars upstream	137,199	131,298	123,779	122,363	118,672
Trucks tailpipe	199,604	200,081	200,443	200,383	200,445
Trucks upstream	218,947	213,261	210,259	208,626	205,371
Total	671,468	660,130	649,462	646,391	639,368

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 CO, NO_X, and SO_2 increase under the action alternatives compared to the No Action Alternative, while emissions of PM2.5 and VOCs decrease. Relative to the No Action Alternative, the modeling results suggest CO, NO_X, and SO_2 emissions increases in 2025 that 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 in percentage terms and, given the difficulties and assumptions involved in estimating, could easily trend in the opposite direction with slight changes in assumptions. While emissions of PM2.5 and VOCs decrease in 2025 relative to the No Action Alternative, the decreases are not consistent across the action alternatives. For PM2.5, the decreases are largest for Alternative 1, smaller for Alternative 3, still smaller for Alternative 2, and smallest for Alternative 2.5. For VOCs, the decreases are largest for Alternative 3, smaller for Alternative 2, still smaller for Alternative 2.5, and smallest for Alternative 1. As with the emissions increases, these decreases are quite small in percentage terms and, given the difficulties and assumptions involved in estimating, could easily trend in the opposite direction with slight changes in assumptions.
- In 2035, emissions of all criteria pollutants (except SO_2) decrease under the action alternatives compared to the No Action Alternative. For CO and VOCs, the decreases get larger from Alternative 1 through Alternative 3. For NO_X, the decreases are largest for Alternative 2, smaller for Alternative 3, still smaller for Alternative 1, and smallest for Alternative 2.5. For PM2.5, the decreases are largest for Alternative 3, smaller for Alternative 2, still smaller for Alternative 2.5, and smallest for Alternative 1. Emissions of SO_2 decrease slightly under Alternative 1 but increase under Alternatives 2, 2.5, and 3.
- In 2050, emissions for all criteria pollutants (except SO_2) decrease under the action alternatives compared to the No Action Alternative. For CO and VOCs, the emissions decreases get larger from Alternative 1 through Alternative 3. For NO_X and PM2.5, the decreases are largest for Alternative 3, smaller for Alternative 2, still smaller for Alternative 2.5, and smallest for Alternative 1. 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. The increases in SO_2 emissions 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.

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. 2.5	Alt. 3
Carbon monoxide (CO)					
2025	0	9,775	12,099	17,146	23,640
2035	0	-4,698	-17,897	-22,529	-31,221
2050	0	-20,935	-71,155	-84,549	-109,947
Nitrogen oxides (NO_X)					
2025	0	258	570	895	1,242
2035	0	-3,222	-3,739	-3,158	-3,641
2050	0	-3,542	-5,165	-4,890	-5,896

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Particulate matter (PM2.5)					
2025	0	-28	-21	-17	-23
2035	0	-299	-384	-358	-427
2050	0	-325	-521	-517	-635
Sulfur oxides (SO_2)					
2025	0	45	321	345	476
2035	0	-66	2,132	3,370	4,683
2050	0	891	3,260	4,439	5,490
Volatile organic compounds (VOCs)					
2025	0	-770	-1,243	-969	-1,326
2035	0	-11,338	-22,006	-25,077	-32,100
2050	0	-16,487	-31,787	-35,811	-43,666

Notes:

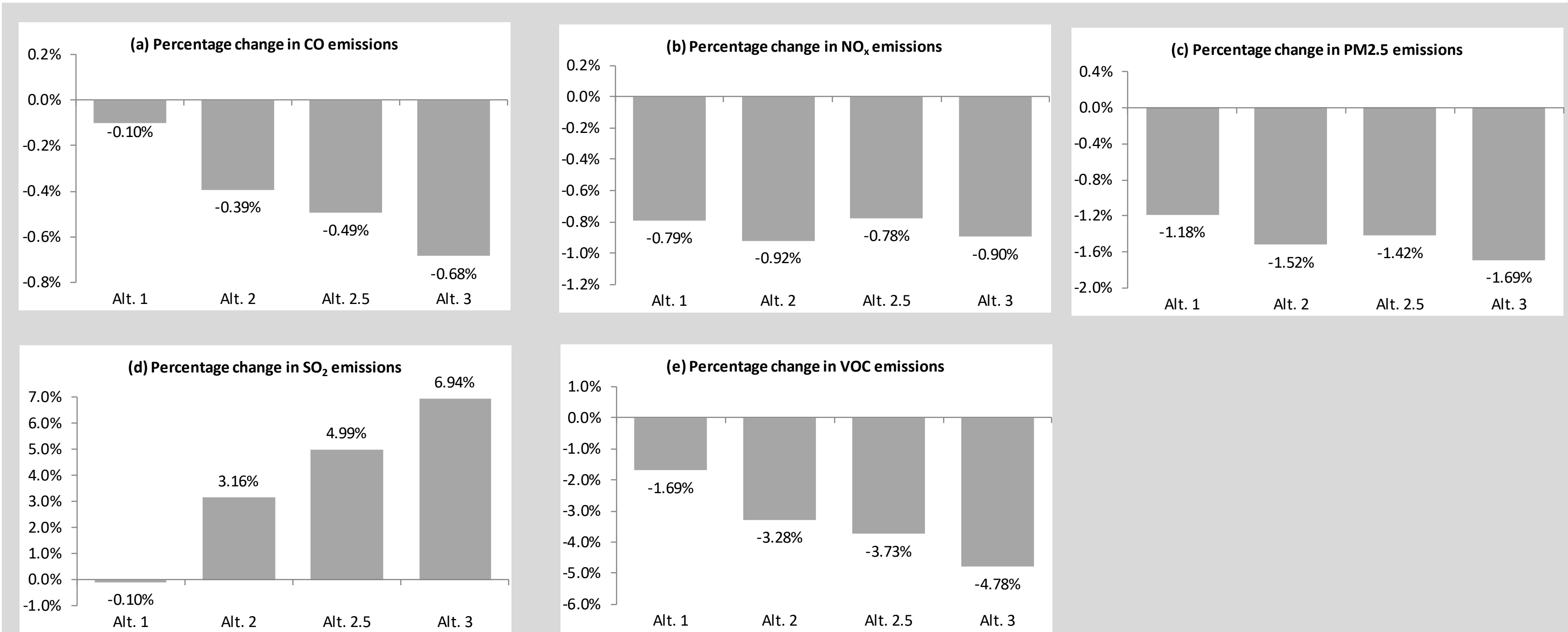
[a] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the action alternatives are compared.

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 7.4 percent under Alternative 3 in 2050 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 12.0 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



Notes:

Negative values indicate emissions decreases; positive values are emissions increases.

CO = carbon monoxide; NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less 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.[37] 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 and NO_X, the majority of nonattainment areas would experience increases in emissions across all action alternatives in 2025, but decreases in 2035 and 2050, compared to the No Action Alternative. For PM2.5, SO_2, and VOCs, across all alternatives, the majority of nonattainment areas would experience decreases in emissions in 2025, 2035, and 2050, 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	1,145	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-5,233	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 8-hour)]
Nitrogen oxides (NO_X)	Maximum increase	81	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-515	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Particulate matter (PM2.5)	Maximum increase	1	2025	Alt. 3	New York, NY-NJ-CT [CO (2008 and 2015 8-hour); PM2.5 (2006 24-hour)]
	Maximum decrease	-72	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]

[37] In Section 4.2.1.2, *Nonattainment Areas* (criteria pollutants), and Section 4.2.2.2, *Nonattainment Areas* (air toxics), the term *nonattainment* refers to both nonattainment areas and maintenance areas.

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	1,126	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-23	2050	Alt. 3	New York, NY-NJ-CT [PM2.5 (2006 24-hour)]
Volatile organic compounds (VOCs)	Maximum increase	88	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-1,344	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.

[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. 2.5	Alt. 3
Acetaldehyde					
2025	7,584	7,589	7,591	7,594	7,598
2035	3,312	3,311	3,302	3,299	3,295
2050	891	878	851	843	831
Acrolein					
2025	408	408	408	408	409
2035	183	183	182	182	182
2050	58	57	55	55	54
Benzene					
2025	29,757	29,782	29,788	29,803	29,820
2035	9,958	9,921	9,884	9,876	9,851
2050	2,232	2,155	2,071	2,048	2,006
1,3-Butadiene					
2025	3,410	3,413	3,414	3,415	3,417
2035	1,264	1,263	1,260	1,258	1,256
2050	342	337	326	323	318
Diesel particulate matter (DPM)					
2025	35,953	35,823	35,790	35,774	35,710
2035	32,072	31,218	30,624	30,503	30,107
2050	28,110	27,084	26,371	26,246	25,861
Formaldehyde					
2025	6,504	6,507	6,507	6,510	6,512
2035	2,569	2,554	2,535	2,529	2,518
2050	865	837	802	793	776

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

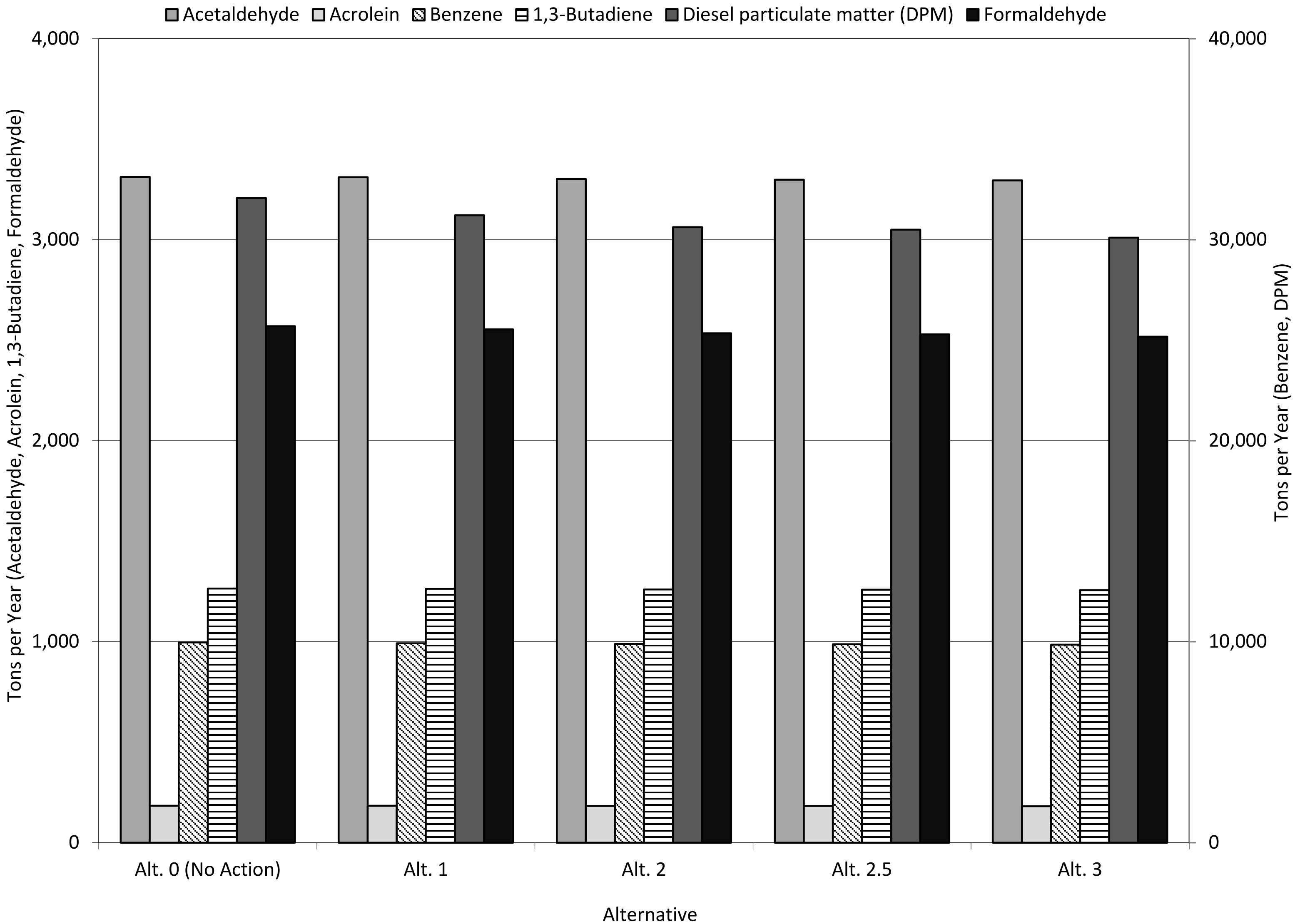


Figure 4.2.2-2 summarizes the changes over time in total national emissions of toxic air pollutants under Alternative 1 (the least stringent and highest fuel-use action alternative) and Alternative 3 (the most stringent and lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts. This figure indicates a consistent trend among the toxic air pollutants. Table 4.2.2-2 and Figure 4.2.2-3 show that emissions decline from 2025 to 2050. This is likely because of 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. (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 stay the same or increase in 2025 (except for DPM, which decreases in 2025 across all action alternatives) and show decreases in 2035 and 2050 (except for acrolein emissions, which stay the same in 2035 under Alternative 1) 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 stay the same or 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. However, emissions of DPM would decrease in 2025 under all action alternatives, with the decreases getting larger from Alternative 1 to 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 0.2 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 0.7 percent.

In 2035 and 2050, emissions of all air toxic pollutants would decrease under the action alternatives, compared to the No Action Alternative (except they would stay the same for acrolein in 2035 under Alternative 1). The decreases get larger from Alternative 1 through Alternative 3, except that for acrolein in 2035 the emissions decrease from the No Action Alternative is unchanged for Alternatives 2, 2.5, and 3, and in 2050 is unchanged between Alternatives 2 and 2.5.

The largest relative decreases in emissions generally would occur for formaldehyde for which emissions would decrease by as much as 10.3 percent under Alternative 3 in 2050 compared to the No Action Alternative (Table 4.2.2-3). Percentage decreases in emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and DPM 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, Providing the Lowest and Highest Range in Direct and Indirect Impacts

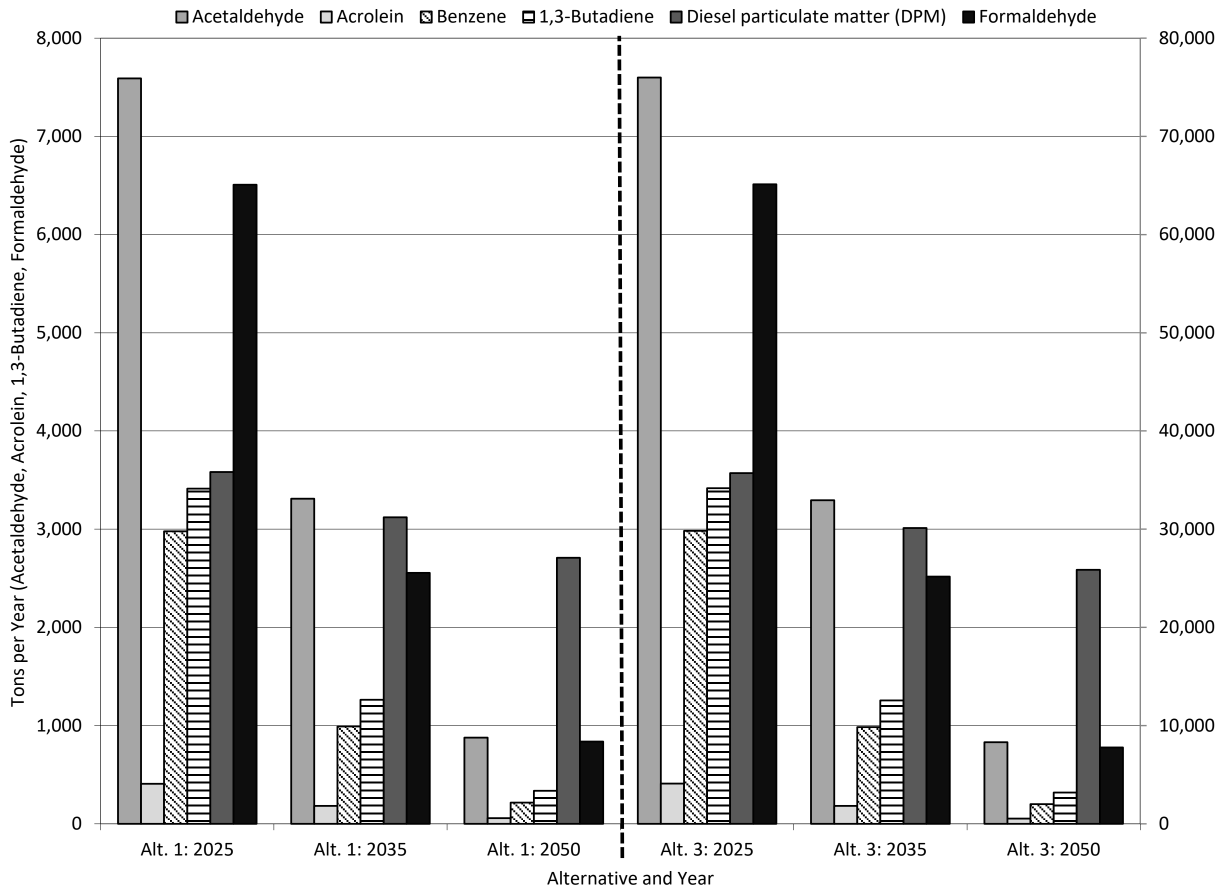


Table 4.2.2-2. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks, by Vehicle Type and Alternative, Direct and Indirect Impacts

Vehicle Class	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Acetaldehyde					
Cars tailpipe	1,202	1,197	1,187	1,186	1,183
Cars upstream	26	25	24	23	22
Trucks tailpipe	2,041	2,048	2,051	2,049	2,050
Trucks upstream	42	41	41	40	40
Total	3,312	3,311	3,302	3,299	3,295
Acrolein					
Cars tailpipe	68	68	67	67	67
Cars upstream	4	3	3	3	3
Trucks tailpipe	106	106	106	106	106
Trucks upstream	6	6	6	6	5
Total	183	183	182	182	182
Benzene					
Cars tailpipe	3,007	3,006	3,003	3,005	3,006
Cars upstream	533	509	478	472	457
Trucks tailpipe	5,560	5,571	5,582	5,584	5,588
Trucks upstream	858	835	822	814	800
Total	9,958	9,921	9,884	9,876	9,851
1,3-Butadiene					
Cars tailpipe	474	472	467	467	465
Cars upstream	6	5	5	5	5
Trucks tailpipe	775	777	778	778	777
Trucks upstream	9	9	9	9	9
Total	1,264	1,263	1,260	1,258	1,256
Diesel particulate matter (DPM)					
Cars tailpipe	4	4	4	4	4
Cars upstream	12,613	12,200	11,721	11,626	11,360
Trucks tailpipe	10	12	11	11	13
Trucks upstream	19,445	19,002	18,887	18,862	18,730
Total	32,072	31,218	30,624	30,503	30,107
Formaldehyde					
Cars tailpipe	736	733	729	729	727
Cars upstream	197	188	177	175	169
Trucks tailpipe	1,317	1,322	1,323	1,323	1,324
Trucks upstream	319	311	306	303	298
Total	2,569	2,554	2,535	2,529	2,518

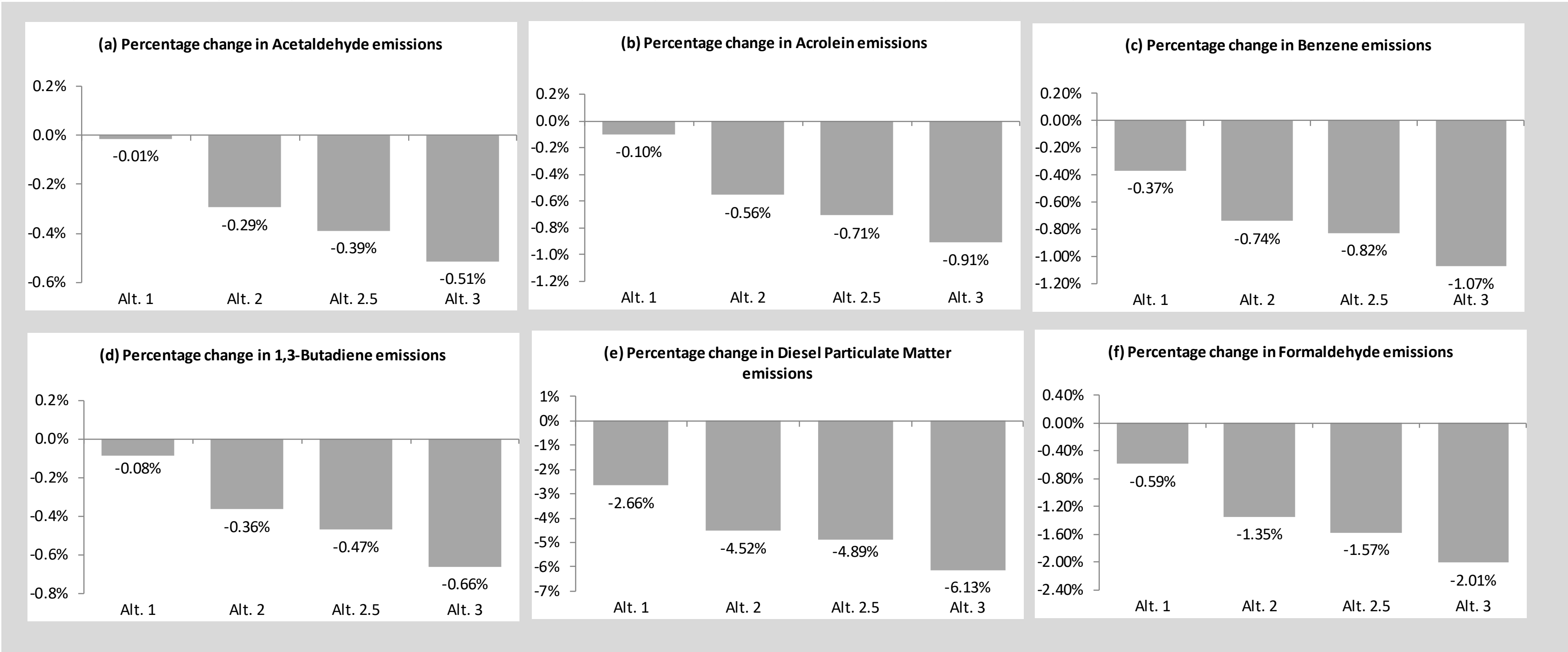
Table 4.2.2-3. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts[a,b]

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Acetaldehyde					
2025	0	6	7	10	15
2035	0	0	-10	-13	-17
2050	0	-13	-40	-47	-60
Acrolein					
2025	0	0	0	0	1
2035	0	0	-1	-1	-2
2050	0	-1	-3	-3	-4
Benzene					
2025	0	24	31	45	62
2035	0	-37	-74	-82	-107
2050	0	-76	-161	-184	-226
1,3-Butadiene					
2025	0	3	4	6	8
2035	0	-1	-5	-6	-8
2050	0	-5	-16	-20	-25
Diesel particulate matter (DPM)					
2025	0	-130	-163	-179	-243
2035	0	-853	-1,448	-1,569	-1,965
2050	0	-1,026	-1,739	-1,865	-2,249
Formaldehyde					
2025	0	3	3	6	8
2035	0	-15	-35	-40	-52
2050	0	-29	-63	-72	-89

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



Notes:
Negative values indicate emissions decreases; positive values are emissions increases.

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 and acrolein, emissions would increase in the majority of nonattainment areas under Alternative 1 and decrease under Alternatives 2, 2.5, and 3, while for benzene, 1,3-butadiene, DPM, and formaldehyde, emissions in 2035 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); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-2	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]

[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	0.04	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-0.2	2050	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
Benzene	Maximum increase	4	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-9	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
1,3-Butadiene	Maximum increase	0.4	2025	Alt. 3	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-2	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Diesel particulate matter (DPM)	Maximum increase	0.007	2035	Alt. 3	Tucson Area, AZ [CO (1971 8-hour)]
	Maximum decrease	-401	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 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); Ozone (2008 and 2015 8-hour); PM2.5 (2006 24-hour and 2012 Annual)]
	Maximum decrease	-2	2050	Alt. 3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]

CO = carbon monoxide; NAAQS = National Ambient Air Quality Standards; NO_2 = nitrogen dioxide; PM2.5 = particulate matter 2.5 microns or less in diameter

4.2.3 Health Impacts

Adverse health impacts from criteria pollution emissions would decrease nationwide in 2025, 2035, and 2050 under all action alternatives, except that some adverse health impacts would not decrease in 2025. In 2025, the improvements to health impacts (or decreases in health incidences) would be largest for Alternative 1, smaller for Alternative 3, still smaller for Alternative 2, and smallest for Alternative 2.5. The improvements to health impacts (or decreases in health incidences) would get larger from Alternative 1 to Alternative 3 in 2035 and 2050, except that for some health impacts in 2035 and 2050 the decreases are smaller for Alternative 2.5 than for Alternative 2. These decreases reflect the generally increasing stringency of the action alternatives as they become implemented. Under each action alternative the decreases in health impacts would get larger from 2025 to 2050 (except that decreases in "non-fatal heart attacks [all other studies]" would remain unchanged in 2035 under Alternatives 1, 2, and 2.5, and would remain unchanged in 2050 under Alternatives 2 and 2.5). 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 CO, NO_X, and SO_2 from combined upstream and tailpipe sources would increase under all of the action alternatives (Table 4.2.1-1) though emissions of PM2.5 and 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).

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. 2.5	Alt. 3
Premature mortality (Krewski et al. 2009)					
2025	0	-2	-1	-1	-1
2035	0	-23	-31	-28	-34
2050	0	-27	-44	-44	-55
Emergency room visits: respiratory					
2025	0	-1	-1	-1	-1
2035	0	-14	-20	-20	-24
2050	0	-16	-29	-30	-36
Acute bronchitis					
2025	0	-3	-3	-2	-3
2035	0	-36	-53	-52	-64
2050	0	-44	-76	-79	-98

Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Lower respiratory symptoms					
2025	0	-39	-35	-28	-36
2035	0	-463	-670	-665	-813
2050	0	-556	-970	-1,011	-1,243
Upper respiratory symptoms					
2025	0	-56	-52	-42	-54
2035	0	-657	-955	-951	-1,163
2050	0	-791	-1,383	-1,444	-1,776
Minor restricted activity days					
2025	0	-1,685	-1,587	-1,287	-1,678
2035	0	-19,354	-28,815	-29,077	-35,732
2050	0	-23,617	-41,931	-44,116	-54,298
Work-loss days					
2025	0	-288	-271	-220	-287
2035	0	-3,295	-4,888	-4,923	-6,046
2050	0	-4,012	-7,109	-7,471	-9,195
Asthma exacerbation					
2025	0	-66	-62	-50	-65
2035	0	-767	-1,112	-1,106	-1,352
2050	0	-922	-1,613	-1,683	-2,070
Hospital admissions: cardiovascular					
2025	0	0	0	0	0
2035	0	-6	-8	-8	-9
2050	0	-7	-12	-12	-15
Hospital admissions: respiratory					
2025	0	0	0	0	0
2035	0	-6	-8	-7	-9
2050	0	-7	-11	-11	-14
Non-fatal heart attacks (Peters et al. 2001)					
2025	0	-2	-1	-1	-1
2035	0	-24	-31	-29	-35
2050	0	-27	-45	-46	-56
Non-fatal heart attacks (All other studies)					
2025	0	0	0	0	0
2035	0	-3	-3	-3	-4
2050	0	-3	-5	-5	-6

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.

[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.[3]

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.[4] 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.

[2] Working Group I of the IPCC's Sixth Assessment Report was released in August 2021. Where possible, this SEIS has been updated to reflect the findings of the latest IPCC panel-reviewed reports.

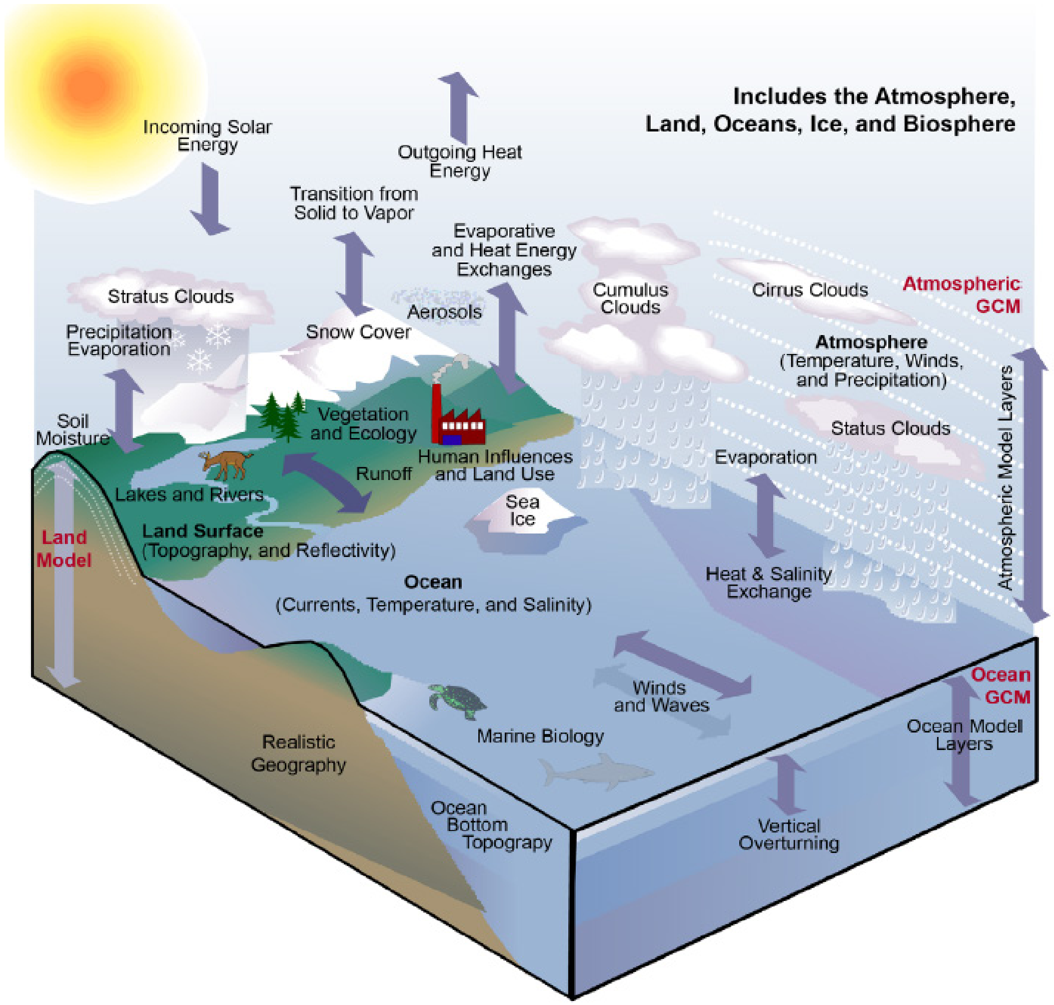
[3] NHTSA notes, for example, that these previous NHTSA EISs also relied on reports by the IPCC, GCRP, CCSP, NRC, and Arctic Council, and EPA's 2009 TSD. These previous NHTSA EISs also used the MAGICC model, compared emissions reductions to a global carbon budget, and considered effects on global CO_2 concentration, global mean surface temperature, global mean precipitation, global sea-level rise, and global ocean pH.

[4] 40 CFR § 1502.22 (2019).

The IPCC reports communicate uncertainty and confidence bounds using commonly understood but carefully defined words in italics, such as *likely* and *very likely*, to represent likelihood of occurrence. The *IPCC Working Group I Sixth Assessment Report Summary for Policymakers* (IPCC WGI AR6) (IPCC 2021b) 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 AR6 (IPCC 2021a) 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 AR6, 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 demonstrates how the combination of evidence and agreement statements results in confidence level and shows that the degree of confidence increases as evidence becomes more robust and agreement is greater. Level of confidence is expressed with five qualifiers: *very low, low, medium, high,* or *very high.*[5]

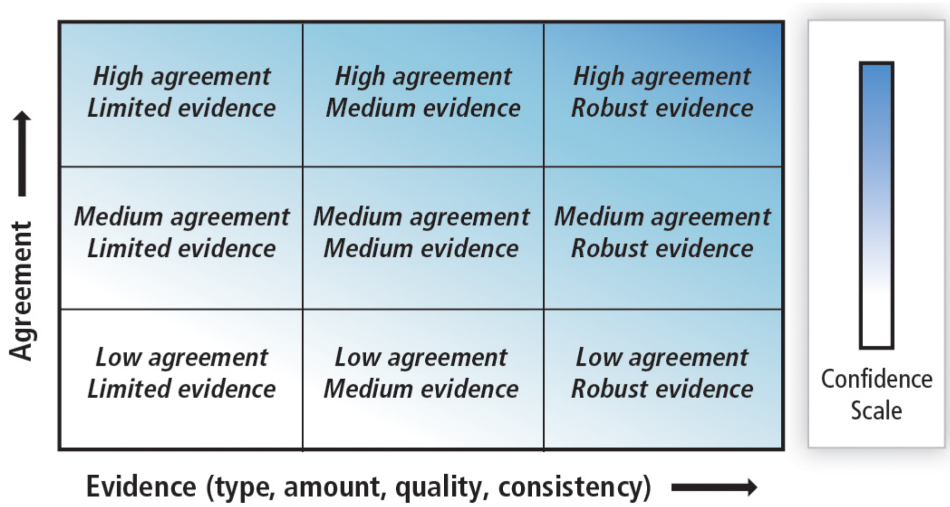
[5] Figure 5.1.1-2 shows the relationship between confidence level and summary statements for evidence and agreement. This relationship is flexible and different confidence levels can be assigned for a given evidence and agreement statement (IPCC 2010).

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 Fifth Assessment Report (AR5) (*extremely likely* = 95−100% probability, *more likely than not* ≥ 50−100% probability, and *extremely unlikely* = 0−5% probability) were also used in IPCC WGI AR6 when appropriate, and in the *Fourth National Climate Assessment* (GCRP 2017).
Source: IPCC 2021a

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

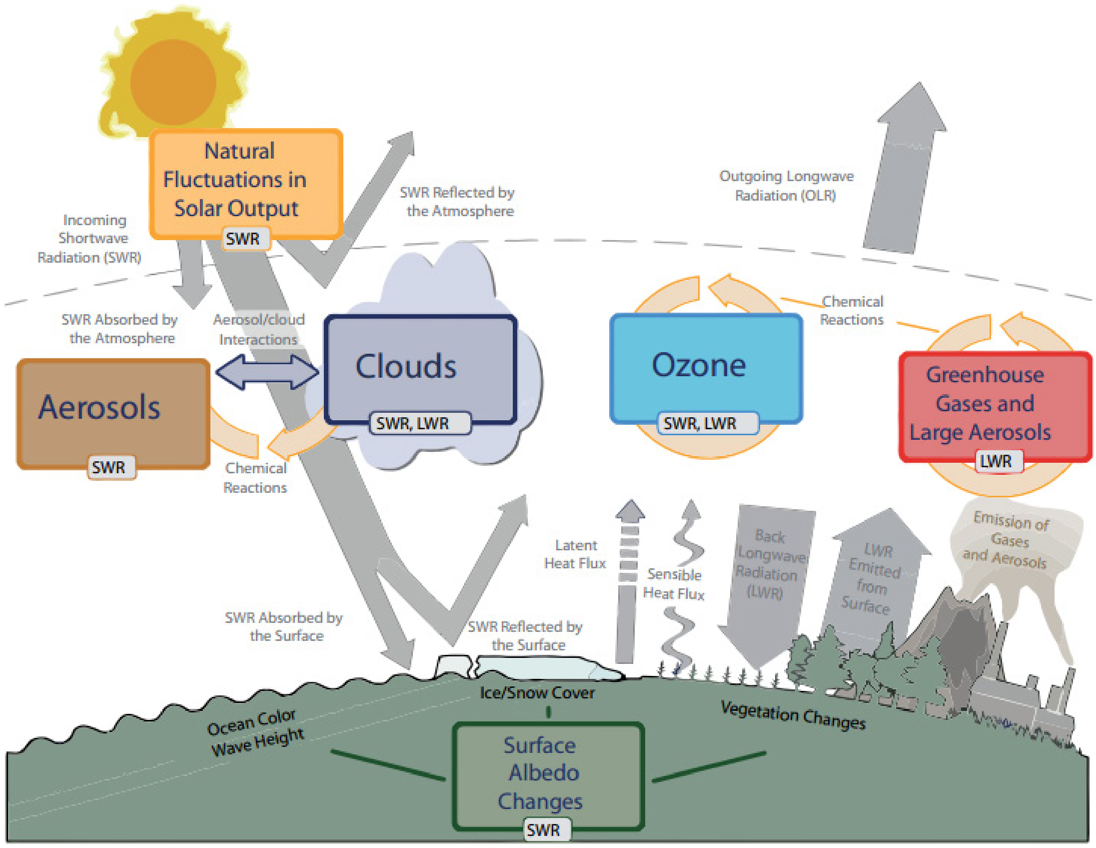
Global climate change refers to long-term (i.e., multi-decadal) trends in global average surface temperature, precipitation, ice cover, sea level, cloud cover, sea surface temperatures and currents, and other climate conditions. Earth absorbs energy from the sun and returns most of this energy to space 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 2021a). IPCC concluded, "it is unequivocal that human influence has warmed the atmosphere, ocean and land. … Overall, the evidence for human influence has grown substantially over time and from each IPCC report to the subsequent one." (IPCC 2021a).

Although the climate system is complex, IPCC AR6 identified the following drivers of climate change (Figure 5.1.2-1). In 2021, IPCC AR6 evaluates observed changes in these climate system drivers and the effective radiative forcing (ERF) they exert.

- **GHGs**. Primary GHGs in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone (IPCC 2021a). Though most GHGs occur naturally, human activities—particularly fossil fuel burning—have significantly increased atmospheric concentrations of these gases (see IPCC 2021a 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). In the past 30 years, the relative importance of aerosol forcing compared to other climate drivers has decreased as the net forcing effect of aerosols has continued to decrease in the 21st century (IPCC 2021a).
- **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). The rapid adjustments implied by clouds are included in the determination of ERF (IPCC 2021a).
- **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). Ozone has the largest positive ERF of all gaseous short-lived climate forcers (IPCC 2021a).
- **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 2021a).
- **Surface changes**. Changes in vegetation or land surface properties, ice or snow cover, and ocean color can affect surface albedo.[6] 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). Changes to land use and land cover have introduced a negative ERF by increasing surface albedo since 1750 (IPCC 2021a).

[6] 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 2021b; 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.[7] Other GHGs, such as the fluorinated gases,[8] 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 2021a) 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 2021a). In 2018, CO_2 emissions accounted for 73 percent of global GHG emissions on a global warming potential (GWP)-weighted basis,[9] followed by CH_4 (18 percent), N_2O (7 percent), and fluorinated gases (2 percent) (WRI 2022).[10] Atmospheric concentrations of N_2O and CH_4 increased approximately 19 and 158 percent, respectively, over roughly the same period (IPCC 2021a).

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 2022). 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 2022).[11]

In general, global GHG emissions continue to increase, although annual increases vary according to factors such as weather, energy prices, and economics. Observed emissions between 2000 and 2010 approximately track the upper half of Representative Concentration Pathway (RCP)[12] projections (RCP8.5), while more recently, the global fossil and industrial CO_2 emissions follow the middle of the projected Shared Socioeconomic Pathway (SSP)[13] scenario ranges, though regional differences exist (IPCC 2021a).

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[7] 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.

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

[9] 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).

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

[11] 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.

[12] The Representative Concentration Pathways (RCPs) were developed for the IPCC AR5 report. They define specific pathways to emission concentrations and ERF 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).

[13] The Shared Socioeconomic Pathways (SSPs) were developed for the IPCC AR6 report. Similar to RCPs, they utilize global socioeconomic projections to derive time-dependent global GHG concentrations and drive general circulation model

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 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 2021c), 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, forestry, waste, and other land use. 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 2021c). In 2019, U.S. GHG emissions were estimated to be 6,558.3 million metric tons carbon dioxide equivalent ($MMTCO_2e$) (EPA 2021c),[14] or approximately 14 percent of global GHG emissions (WRI 2022).[15]

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 2021c) (on a GWP-weighted basis) and accounting for 16 percent of total global CO_2 emissions (WRI 2022).[16] 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 2021c).[17] CO_2 emissions from passenger cars and light trucks have increased 14 percent since 1990 (EPA 2021c) and account for 58 percent of total U.S. CO_2 emissions from transportation (EPA 2021c). 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 2021c; 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 2019c). 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.

simulations of climate change. The SSPs were designed to provide an expanded set of GHG concentration scenarios for CMIP6 based on a range of socioeconomic scenarios, with SSP1 through 5 accounting for various global mitigation and adaption measures. There is a set of five core SSPs used in IPCC reports: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.

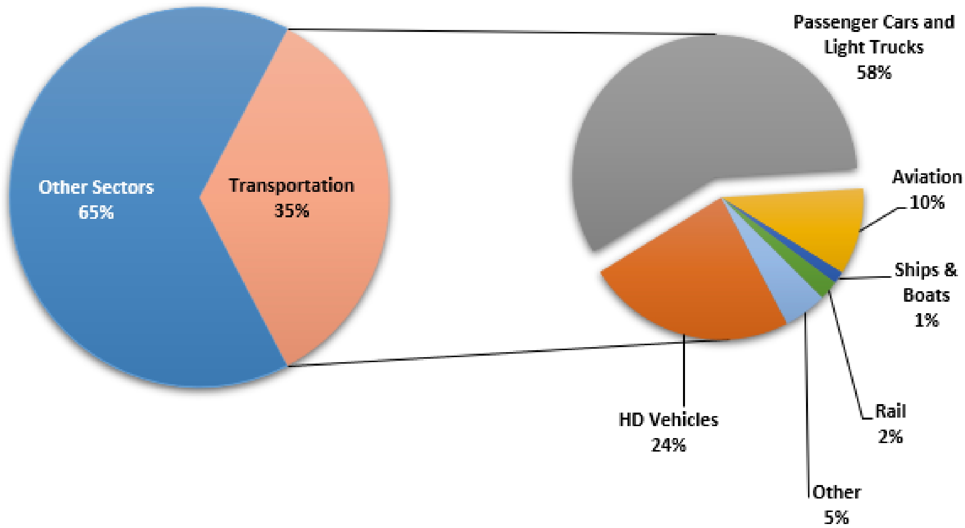
[14] Most recent year for which an official EPA estimate is available, excluding emissions and sinks from land-use change and forestry (EPA 2021c).

[15] 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.

[16] 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.

[17] 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 2021c
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 2021c).

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 2021a; 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 2021a; CCSP 2009). Depending on meteorological conditions and other factors, aerosols typically remain in Earth's atmosphere from days to weeks (IPCC 2021a). Their relatively short lifetimes can create regional areas of high aerosol concentrations nearby as well as some distance downwind from emissions source(s) (IPCC 2021a).

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 (IPCC 2021a; CCSP 2009). In addition, some aerosols attract moisture or water vapor and can affect the lifetime and reflectivity of clouds. Overall, IPCC (2021a) 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. Overall, aerosols can act to intensify precipitation in deep convective clouds or suppress precipitation in shallow cloud regimes through radiative and microphysical processes (IPCC 2021a).

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 IPCC (2021a) integrated the overall indirect cloud effects of black carbon (and other light-absorbing particles) into the estimated ERFs on the earth's energy budget, resulting in a small net positive (i.e., warming) (*low confidence*). Quantifiable estimate shows large uncertainties and 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 AR6), IPCC states, "It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred" (IPCC 2021a). The IPCC also underscored conclusions from the previous assessment (IPCC WGI AR5) that stated, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013a). IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. 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, 2021a; GCRP 2017).
- Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer (IPCC 2014a, 2021a; GCRP 2017).
- Sea level is rising, caused by thermal expansion of the ocean water and melting of snowcaps and ice sheets (IPCC 2013a, 2021a; GCRP 2017).
- More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (IPCC 2021b; 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 2021a; UN 2016; GCRP 2017). Recent assessments 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 2022). 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. During the last decade (2010 through 2019), average annual anthropogenic CO_2 emissions reached the highest levels in human history (*high confidence*) (IPCC 2021a). Current emissions trajectory estimates from the IPCC project global atmospheric CO_2 concentrations between 400 ppm (SSP1-1.9) and 1,100 ppm (SSP5-8.5) by 2100, approximately two to four times preindustrial levels (IPCC 2021a). 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 2021a).

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 ERF, average temperatures, and extreme temperatures as they relate to climate change.

Effective Radiative Forcing

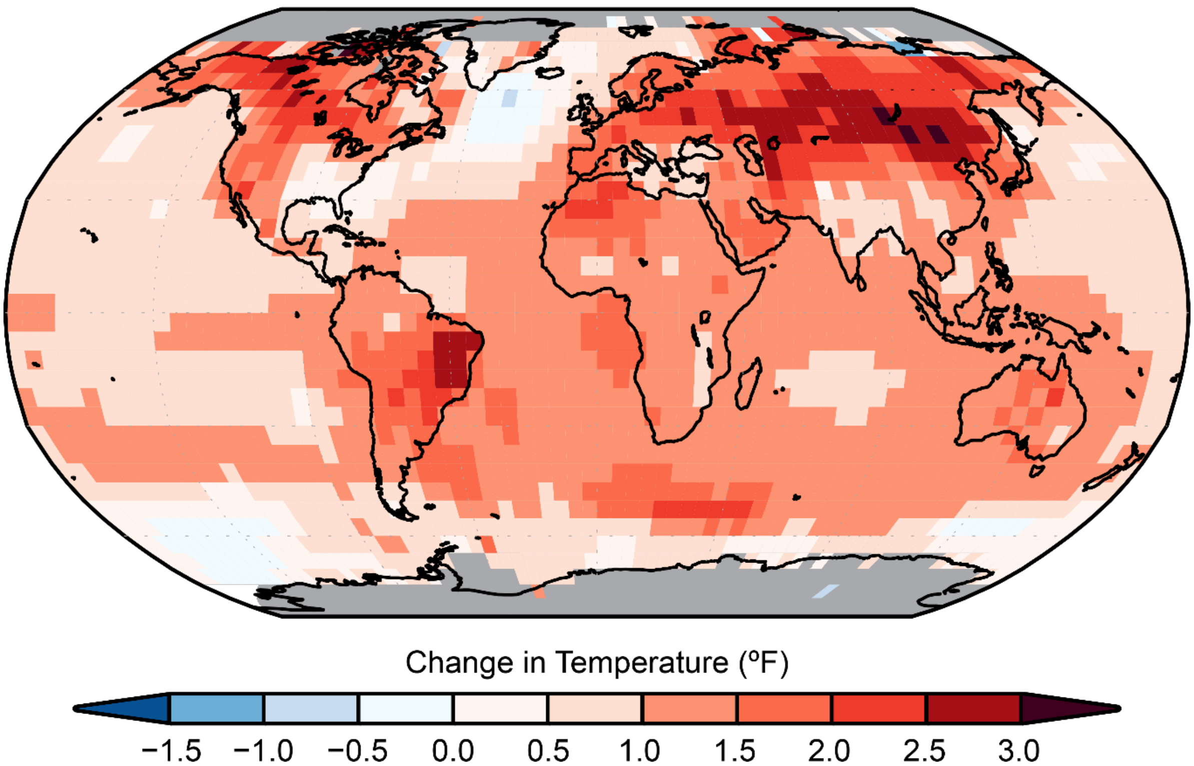
ERF describes the magnitude of change in energy fluxes caused by a specific driver—in this case, anthropogenic GHGs—that can alter the Earth's energy budget. Positive ERF leads to warming while negative ERF leads to cooling (IPCC 2021a). GHGs have a positive ERF. Total anthropogenic ERF has increased by 2.72 watts per square meter (W/m^2) (1.96 to 3.48 W/m^2) since preindustrial times and is responsible for the observed warming (IPCC 2021b). This estimate is a 0.43 W/m^2 increase from the IPCC's previous report (WGI AR5; IPCC 2013a) due to an increase in the GHG ERF. The ERF from increased atmospheric CO_2 concentration alone (from 1750 to 2019) is estimated to be 2.16 W/m^2 (plus or minus 0.26 W/m^2) (IPCC 2021a). Most recently, the net heat uptake rate has been shown to be increasing. From mid-2005 to mid-2019, ERF 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 ERF are captured in the SSPs used to model future climate conditions. SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 are named according to the amount of change in ERF in 2100 relative to preindustrial conditions (i.e., prior to 1750): +1.9, +2.6, +4.5, +7.0, and +8.5 W/m^2. This naming convention is a continuation from the IPCC's Fifth Assessment Report (AR5), where the RCPs were named RCP2.6, RCP4.5, RCP6.0, and RCP8.5 W/m^2 to denote ERF changes (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 degree Celsius (°C) (1.8 degrees Fahrenheit [°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). IPCC (2021b) has also concluded that global surface temperatures have increased faster since 1970 than in any other 50-year period over at least the last 2,000 years (*high confidence*).

IPCC projects continued increases in global mean surface temperature over the course of this century with global average surface temperature in 2081 through 2100 *very likely* to be 1.0 to 1.8°C (1.8 to 3.2°F) greater[18] under a low GHG emissions scenario (SSP1-1.9), 2.1 to 3.5°C (3.8 to 6.3°F) greater under an intermediate GHG emissions scenario (SSP2-4.5), and 3.3 to 5.7°C (5.9 to 10.3°F) greater under a high GHG emissions scenario (SSP5-8.5) (IPCC 2021b). For further information on observed and projected global climate change trends, see IPCC 2021a and GCRP 2018a.

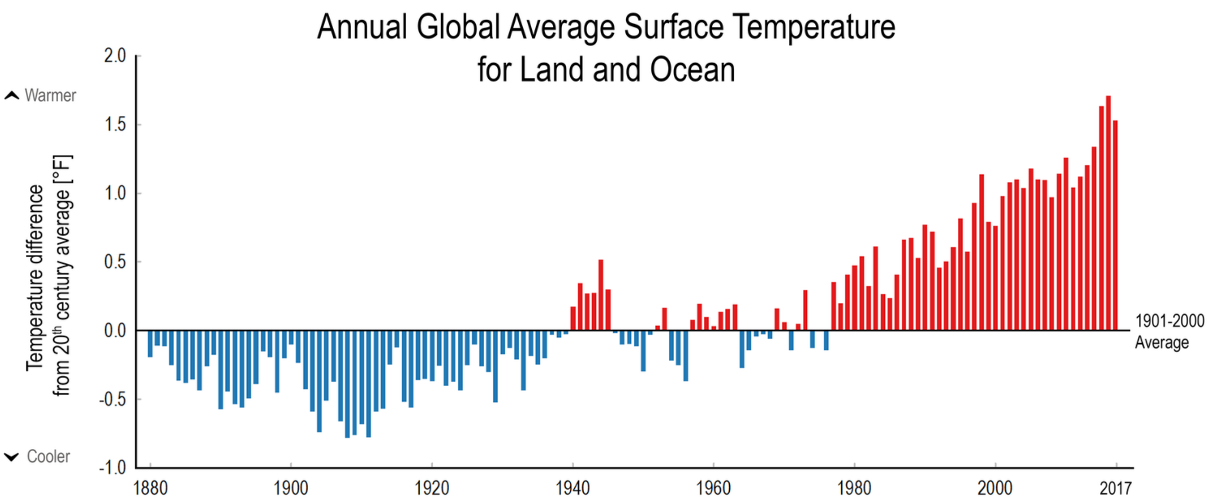
Figure 5.2.2-1. Global Surface Temperature Anomalies in Degrees Fahrenheit from 1986 to 2015 Relative to 1901 to 1960



Source: GCRP 2017
°F = degrees Fahrenheit

[18] This temperature increase is compared to 1850 through 1900 global average temperature values.

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).

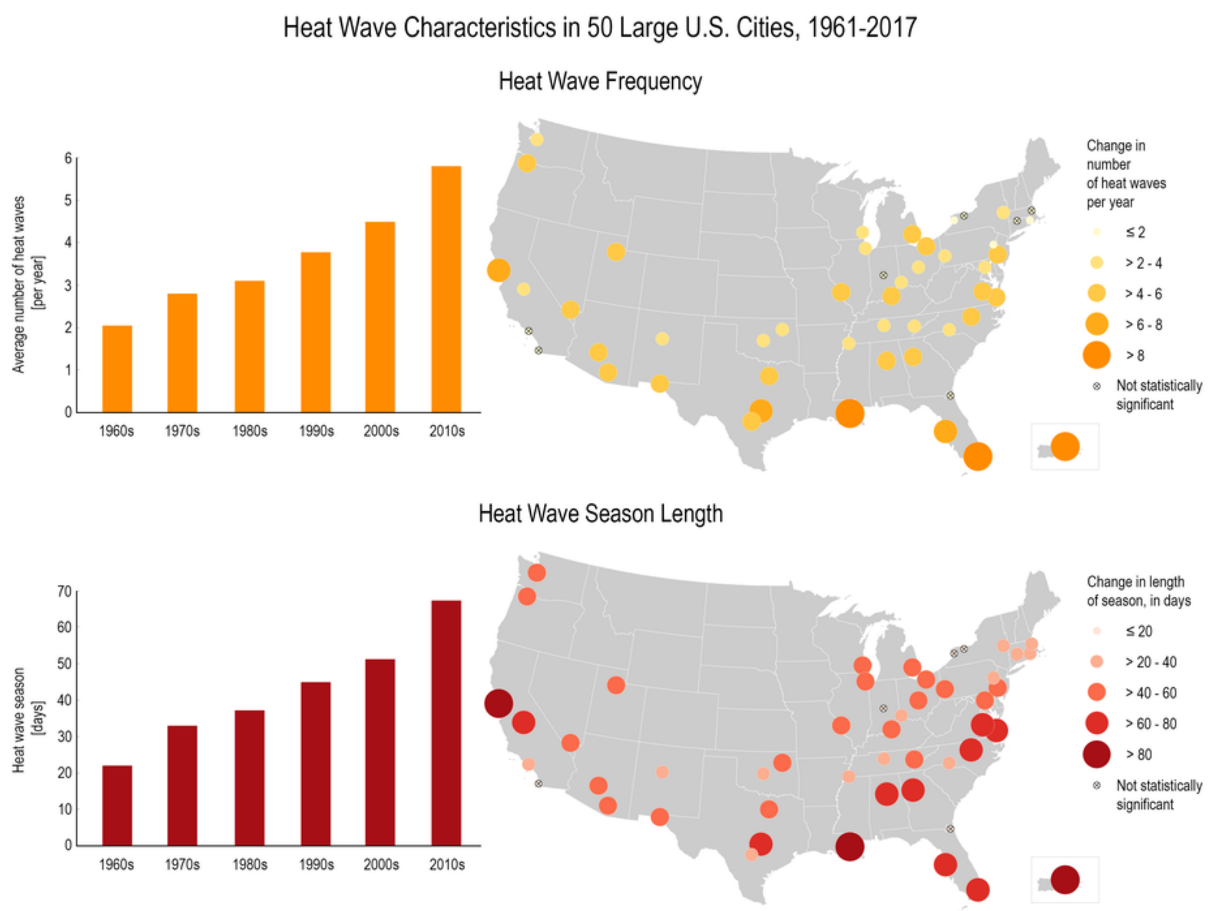
The oceans have a large heat capacity and have been absorbing more than 90 percent of warming caused by anthropogenic GHG emissions (GCRP 2017). Due to Earth's thermal inertia—whereby oceans absorb and dissipate heat to the atmosphere over a long period of time—warming could continue for centuries, even 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 both in frequency and intensity since about 1950 (GCRP 2017). The IPCC concluded it is *virtually certain* that there will be more hot and fewer cold temperature extremes with increases in the frequency, duration, and magnitude of hot extremes along with heat stress; however, occasional cold winter extremes will continue to occur (IPCC 2021a). 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; GCRP 2017; IPCC 2021a). 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 greater extreme heat events since the middle of the 20th century, with higher temperature changes increasing the probability of extreme heat events in some regions (IPCC 2021a). 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 2021a).

At the ocean surface, temperature has, on average, increased by 0.88°C (1.58°F) (0.68 to 1.01°C [1.22 to 1.82°F]) (over the reference period 1850 through 1900 compared to the 2011 through 2020 reference period) with approximately 68 percent of this warming (0.6°C [1.08°F]) having occurred since 1980 (IPCC 2021a). The ocean heat content has increased since at least 1970 (earliest reliable observations) and it is *virtually certain* that heat content will continue to rise over the 21st century, likely continuing until at least 2300, regardless of emissions scenario (IPCC 2021a). Rising ocean heat content leads to thermal heat expansion which contributes, in part, to sea-level rise.

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 from 1992 to 2020 have contributed to 13.5 millimeters (0.5 inch) and 7.4 millimeters (0.3 inch) of global mean sea-level rise, respectively (IPCC 2021a). 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 at least half of the Antarctic and Greenland net mass loss, with the other half coming from melting (IPCC 2021a). Although most of the last century's (1901 through 2018) global mean sea-level rise was caused by ocean thermal expansion (38 percent) and loss from glaciers (41 percent), the contribution of ice mass loss from the Greenland and Antarctic ice sheets increased and accounted for approximately 35 percent of observed global mean sea-level rise between 2006 and 2018 (IPCC 2021a).

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(IPCC 2021b). Projections for sustained warming between 2 and 3°C (3.6 and 5.4°F) result in approximately 50 to 60 percent loss of glacier mass outside Antarctica, and approximately 60 to 75 percent loss for sustained warming between 3 and 5°C (5.4 and 9.0°F).

Under all SSP scenarios, both the Greenland ice sheet (*virtually certain*) and Antarctic ice sheet (*likely*) will continue to lose ice mass, further contributing to global mean sea-level rise. 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 2021a). 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 preindustrial 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).

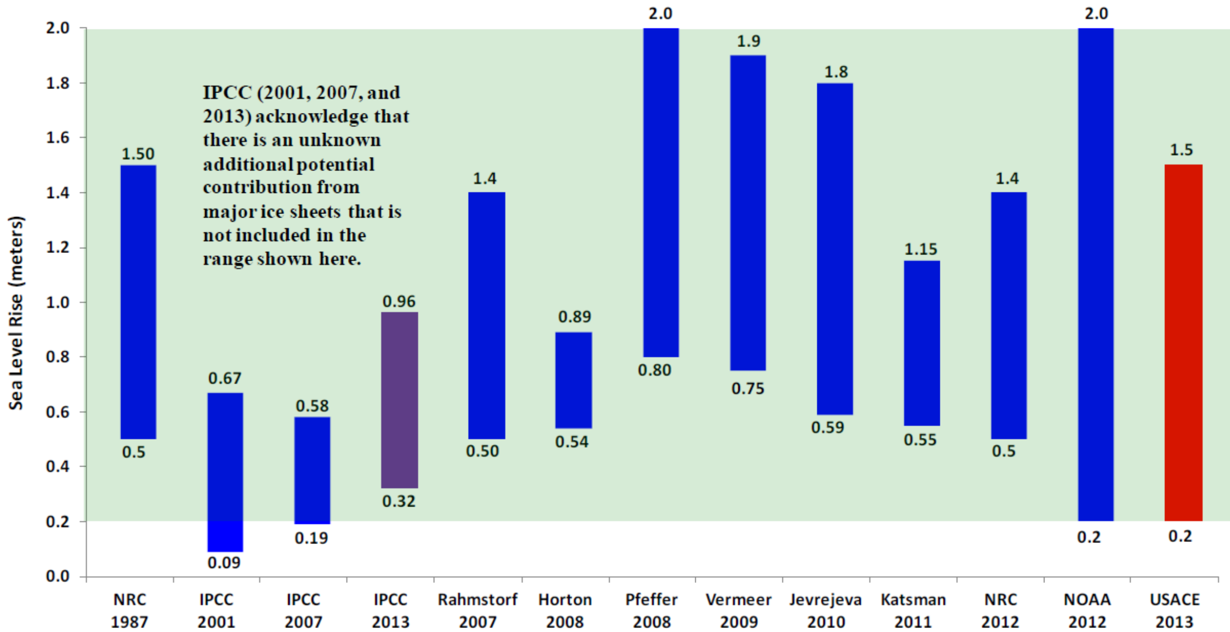
Warming ocean temperatures affect ice sheet stability through submarine melting and altering the dynamics of ice shelves, ice streams, and glaciers. The interconnectedness of the ocean and cryosphere (e.g., glaciers and ice streams that drain the Greenland and Antarctic ice sheets into the ocean) can 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 faster in the 20th century than in any prior century over the last three millennia (IPCC 2021a). The rate of increase has been accelerating since the 1960s, with an average rate of 2.3 millimeters (0.09 inch) per year between 1971 and 2018, and an average rate of 3.7 millimeters (0.15 inch) per year between 2006 and 2018 (IPCC 2021a). 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). Relative to 1995 through 2014, global mean sea level will likely rise by 0.38 meter (1.25 feet) (0.28 to 0.55 meter [0.92 to 1.8 feet]) under SSP1-1.9 and by 0.77 meter (2.3 feet) (0.63 to 1.02 meters [2.07 to 3.35 feet]) under SSP5-8.5 by 2100; these projections are made with *medium confidence* because the uncertainty in ice sheet stability during the 21st century may alter these projections (IPCC 2021a). There is *high confidence* that global mean sea level will continue to rise for centuries past 2100 and remain elevated for thousands of years due to continuing deep ocean heat uptake and committed mass loss from the Greenland and Antarctic ice sheets (IPCC 2021a).

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 was 2.5 to 4°C (4.5 to 7.2˚F) above 1850 through 1900 levels, global mean sea level was 5 to 25 meters (16.4 to 82.0 feet) higher than current levels (IPCC 2021a).

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 because of regional tectonics, subsidence, and isostatic rebound. Throughout the period 1993–2018, sea levels rose fastest in the Western Pacific and slowest in the Eastern Pacific (IPCC 2021a). 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.[19]

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

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

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).[20] 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 2021a). Because of changes in climate, including increased moisture content in the atmosphere, heavy precipitation events have increased in frequency over most land areas (IPCC 2021b; Min et al. 2011).

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

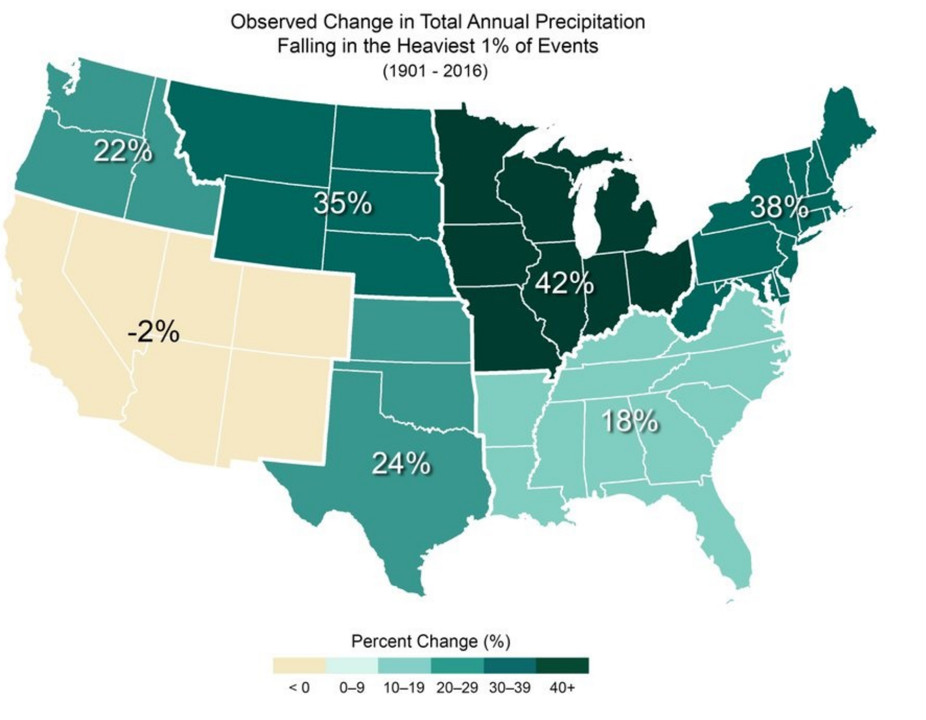
Precipitation

Long-term trends in global precipitation have been observed since 1901. Between 1901 and 2010, increases in precipitation have been observed in the middle and higher latitudes of both the Northern and Southern Hemispheres, specifically in northwestern and eastern parts of North America, parts of Europe and Russia, and southern South America. Drying has been observed in the Sahel region of Africa, the Mediterranean, southern Australia, and parts of Southeast Asia. Spatial and temporal variability for precipitation is high, and data are limited for some regions (IPCC 2021b).

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).

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

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

Increased dryness has been observed in many regions since the 1950s, with intense droughts caused by higher temperatures and decreased precipitation; human-induced climate change is *likely* the main driver of these changes (IPCC 2021b). However, spatial variability for dryness is high and data availability is limited in some regions from which to draw global conclusions. IPCC (2021a) projects increased evapotranspiration and decreased soil moisture, increasing dryness over the Mediterranean, southwestern North America, south Africa, southwestern South America, and southwestern Australia (*high confidence*).

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 2021a). Changes in precipitation have also been identified as a major driver for changing discharge trends across regions (IPCC 2021a).

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) and has been decreasing more rapidly since at least 1978 (*high confidence*) (IPCC 2021a). 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 2021a).

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). Furthermore, the most recent IPCC projections show that Northern Hemisphere spring snow cover extent could decrease by about 8 percent per 1°C (1.8°F) of global surface air temperature increase in the future (IPCC 2021a).

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 2021a). Because pH is measured on a logarithmic scale, this decrease represents about 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 2021a). 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). If global temperatures reach an average increase of 1.5°C (2.7°F), 70 to 90 percent of coral reefs are projected to decline, with even greater losses at 2°C (3.6°F) (IPCC 2021a). At 2°C (3.6°F) above preindustrial levels, mass mortalities of coral reefs are *virtually certain* (IPCC 2021a).

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). Most recent IPCC (2021a) projections under SSP5-8.5 show ocean pH could decrease 0.44 units (a 175 percent increase in the hydrogen ion concentration of seawater) by the end of the century (1870 to 1899 compared to 2080 to 2099 values).

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 2021a). 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 show no trend in the frequency of U.S. landfall events this past century, an increasing trend in intensity since the 1970s is *virtually certain* (IPCC 2021a). 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). This trend has been substantiated by the IPCC (2021a), which shows that globally, major tropical cyclone intensities (Category 3 and above) have increased over the past four decades. Thus overall, IPCC (2021a) projects tropical cyclones to increase in intensity despite a decrease in frequency in most tropical regions (*medium confidence*).

Climate change also causes hurricanes and tropical cyclones to produce heavier precipitation, in part because 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). Globally, the frequency and intensity of heavy precipitation events has increased (*high confidence*) in a majority of land regions, particularly in North America, Europe, and Asia (IPCC 2021a). The IPCC (2021a) states that with increasing temperatures, it is *virtually certain* that heavy precipitation events (including those from tropical cyclones) will become more frequent and intense over all continents.

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). The frequency of weather and climate disasters (including those causing more than $1 billion in damages) has increased in the United States (GCRP 2018a).

There is low confidence in historical trends of hail and severe thunderstorms (IPCC 2021a), which makes their relationship to climate change difficult to resolve. While the IPCC states that climate models consistently project environmental changes that would support an increase in the frequency and intensity of severe thunderstorms that combine tornadoes, hail, and winds, there is *low confidence* in the details of the projected increases. Similarly, GCRP (2017) also indicates *low confidence* for future projections of severe thunderstorms including tornadoes, hail, and extreme winds.

Changes in ocean heat content and freshwater-driven buoyancy as a result of climate change could potentially weaken the Atlantic meridional overturning circulation (AMOC), a mechanism for heat transport in the North Atlantic Ocean that could 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). Models show low agreement in 20th-century AMOC trends (IPCC 2021a). Recent observations show a decline in AMOC since the 2000s; however, this cannot be distinguished from internal variability (IPCC 2021a).

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 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 mass loss from the Greenland ice sheet and the West Antarctic ice sheet (IPCC 2021a; GCRP 2017). Figure 5.2.2-6 shows polar ice sheet mass change from 1992 to 2016.

Since 1979, annual average Arctic sea-ice area has been declining at a rate of 3.5 to 4.1 percent per decade (IPCC 2013a). Average Arctic sea-ice area in August, September, and October has decreased approximately 25 percent in the past 40 years (1979–1988 to 2010–2019) and has decreased to some extent in every month of the year (IPCC 2021a). Warming in the Arctic has proceeded at about twice the rate as the global average, leading to decreases in summer sea ice extent, glacier and ice sheet mass loss, coastal erosion, and permafrost thawing (IPCC 2021a).[21] 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). It is *very likely* that more than half of the observed Arctic sea-ice loss in summer is due to anthropogenic climate change (IPCC 2021a).

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).

While there is low confidence in the quantitative volume and thickness estimates due to poor observations, current analyses show an approximately 72 percent reduction between 1979 and 2016 (IPCC 2021a). 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).

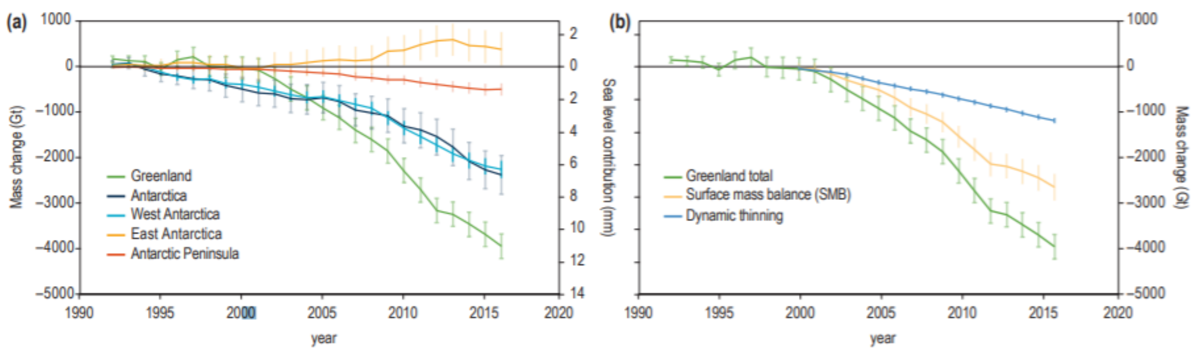
There is *high confidence* that permafrost temperatures have been increasing over the past three to four decades in the permafrost regions (IPCC 2021a). Globally, permafrost has warmed approximately 0.29°C (0.52°F) between 2007 and 2016. The active layer thickness of the permafrost (a layer subject to annual temperature changes) has increased across the entire Arctic region (IPCC 2021a). At lower depths, IPCC (2019a) stated with *very high confidence* that record high permafrost temperatures at the depth of the zero annual amplitude (the depth about 10 to 20 meters [32.8 to 65.6 feet] below the surface where the seasonal soil temperature cycle vanishes) were observed in recent decades in the northern circumpolar permafrost region. They also conclude (*high confidence*) that global warming over the last decades has led to widespread permafrost warming. Complete permafrost thaw in recent decades is a common phenomenon across the permafrost regions (IPCC 2021a). Continued thawing of permafrost over the next century is *virtually certain*, with projections showing the volume of perennially frozen soil within

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

the upper 3 meters (9.8 feet) of the ground decreasing by about 25 percent per 1°C (1.8°F) of global surface air temperature increase (IPCC 2021a).

The loss of Arctic sea ice is projected to continue throughout the 21st century and could *very likely* result in nearly sea-ice-free[22] late summers in the Arctic Ocean by the 2040s (*very high confidence*) (GCRP 2017). The IPCC (2021a) shows that the Arctic Ocean will *likely* become practically sea-ice free during the seasonal sea-ice minimum for the first time before 2050 regardless of SSP scenario. 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



Notes:
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

[22] *Sea-ice free* means sea ice area below 1 million square kilometers (386,102 square miles).

emissions reductions in its Final Regulatory Impact Analysis (FRIA), Chapter 6.5.1. See Chapter 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.[23] 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.

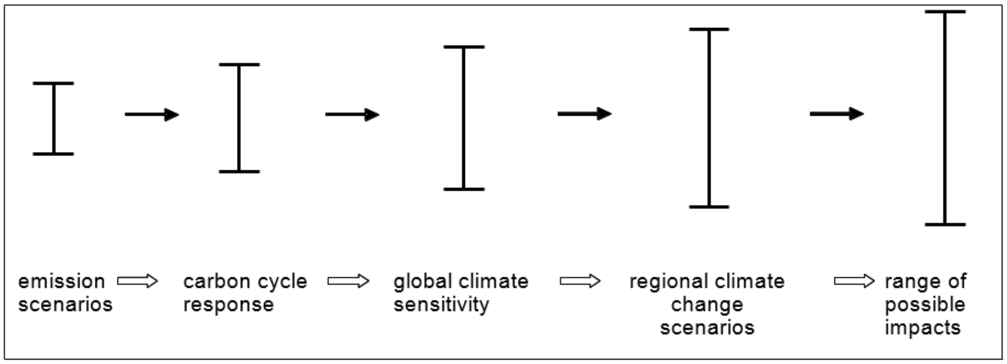
The methods used to characterize emissions and climate impacts consider multiple sources of uncertainty. Sources of uncertainty include the following sources, in addition to many other factors:

- 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.

[23] 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 such as the Model for the Assessment of Greenhouse Gas-Induced Climate Change (MAGICC) 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 1, Framing, context, methods, of IPCC WGI AR6, provides an evaluation of the performance of global climate models. Readers interested in a detailed treatment of this topic will find the Technical Summary and Chapter 1 of IPCC WGI AR6 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).[24] To calculate GHG emissions from upstream processes such as refining and electricity generation, the CAFE Model applies process-specific emission factors specified on

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

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.[25] For 2051 through 2100, the GCAMReference 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.[26] 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).[27] 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 2.5 microns or less in diameter (PM2.5), and volatile organic compounds (VOCs). Air toxics included are acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and diesel particulate matter 10 microns or less 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.[28] Fuel

[25] 2050 is the last year for which the CAFE Model provides estimates of fleet CO_2 emissions for this analysis.

[26] NHTSA anticipates a larger post-2050 decline in passenger car and light truck energy consumption than what is projected in the GCAMReference 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.

[27] 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.

[28] For this rulemaking, NHTSA estimated emissions of vehicular CO_2, CH_4, and N_2O emissions, but did not estimate vehicular emissions of HFCs. HFCs are released to the atmosphere only through air-conditioning system leakage and are not directly related to fuel efficiency. NHTSA's authority under the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, extends only to the regulation of vehicle fuel efficiency. For reference, CH_4 and N_2O account for

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.[29] 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. For this Final SEIS, the Argonne National Laboratory GREET model was updated from the 2020 version to the 2021 version. 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 FRIA characterizes the monetized social value of these estimated changes in emissions. The social cost of 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

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 2021c).

[29] 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).

may consult Section III.G.2 of the preamble to the final rule for a description of how the monetized cost-benefit analysis factors into its decision-making process. The final rule preamble and FRIA 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) and IPCC WGI AR6 (IPCC 2021a) 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 AR6 (IPCC 2021a) and 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).[30]
- 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.
- MAGICC6 uses updated carbon cycle models that can emulate temperature-feedback impacts on the heterotrophic respiration carbon fluxes.

[30] 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 incorporates the latest science from IPCC AR6 and AR5*;* MAGICC6 was used in the *IPCC WGI AR6* (IPCC 2021a).

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).[31, 32] 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[33] 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 GCAMReference 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 ERFs. The regression models for RCP4.5 were used to estimate sea-level rise for the SSP2-4.5 scenario, while the models for RCP6.0 and GCAMReference were used to estimate sea-level rise for SSP3-7.0 and SSP5-8.5 scenarios, respectively. The temperature outputs of the MAGICC RCP and SSP simulations are used as inputs to these regression models to project sea-level rise.[34]

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.[35] The model was developed by Brookhaven National Laboratory and Oak Ridge National Laboratory and is used by both the U.S. Department of Energy and EPA. Orr et al. (2015) compared multiple ocean carbon system models and found that the CO2SYS model was more efficient at analyzing observed ocean chemistry data than other models.

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

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

[32] In this SEIS, the relationship between sea-level rise and global mean surface temperature developed using AR5 is used to estimate sea-level rise using global mean surface temperatures from AR6 for the SSP scenarios.

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

[34] 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.

[35] 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 2021a).

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 scenarios used in the direct and indirect analysis for this SEIS are the GCAMReference scenario (formerly MiniCAM) and SSP3-7.0 scenario, which do not assume comprehensive global actions to mitigate GHG emissions.[36] NHTSA selected the GCAMReference and SSP3-7.0 scenarios for their 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 GCAMReference scenario is the GCAM representation of a scenario that yields an ERF of approximately 7.0 W/m^2 in the year 2100. Similarly, SSP3-7.0 yields an ERF of approximately 7.0 W/m^2 in the year 2100, making it a good comparison to GCAMReference. Like GCAMReference, SSP3-7.0 is noted in the IPCC WGI AR6 as being a scenario "in between RCP6.0 and RCP8.5" (IPCC 2021a).

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.

AR6 uses updated Global Climate Models and GHG concentration scenarios developed for Coupled Model Intercomparison Project Phase 6 (CMIP6). The new GHG concentration scenarios are called SSPs and 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 ERF 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

[36] 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.*

(Riahi et al. 2017). The core set of five SSP scenarios in AR6 (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) were chosen to ensure overlap with the existing RCP levels of ERF in the year 2100, while simultaneously presenting a broader array of potential mitigation and adaptation possibilities.

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 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). For instance, the upper end (95th percentile) of warming through the end of century under the SSP5-8.5 is 5.7°C (10.3°F) (IPCC 2021b), while warming under RCP8.5 is 4.8°C (8.6°F) (IPCC 2013b). 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).

The Final SEIS reflects the action alternatives' climate impacts against the both the RCP and SSP scenarios. The SSP and RCP scenarios are categorized similarly, by reference to approximate ERF reached by the end of the 21st century. However, the SSP scenarios and RCP scenarios are not directly comparable; in general, gas compositions differ, projected 21st-century trajectories differ, and overall ERF may differ (IPPC 2021a). The AR6 provides a description of each SSP scenario coupled with the closest RCP scenario available. NHTSA narrowed down the selection of SSP scenarios to those presented in this AR6 comparison and selected the most similar SSP scenarios to the RCPs presented in this Final SEIS.

The results of the direct and indirect impacts analysis rely primarily on the GCAMReference and SSP3-7.0 scenarios to represent a reference case emissions scenario. The GCAMReference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors. The SSP3-7.0 scenario is considered a medium-high emissions scenario resulting from no additional climate policy and represents continued non-CO_2 GHG emissions. NHTSA chose the GCAMReference and SSP3-7.0 scenarios to present the results of the direct and indirect effects analysis based on the following factors:

- The GCAMReference scenario is a slightly updated version of the scenario developed by the MiniCAM model of the Joint Global Change Research Institute, a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAMReference scenario is based on a set of assumptions about drivers such as population, technology, and socioeconomic changes, in the absence of global action to mitigate climate change.
- In terms of global emissions of CO_2 from fossil fuels and industrial sources, the GCAMReference scenario illustrates a pathway of emissions between the IGSM and MERGE reference scenarios for most of the 21st century. In essence, the GCAMReference scenario is a middle-ground scenario.
- GCAMReference was evaluated in CCSP SAP 2.1.
- Like GCAMReference, SSP3-7.0 is meant to serve as a medium to high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative, which assumes little global cooperation on mitigation efforts.
- SSP3-7.0 has particularly high non-CO_2 emissions, including high aerosols emissions. It also assumes pollutant emissions over the 21st century are comparable to current levels, illustrating a middle-ground scenario.

- The IPCC often refers to SSP3-7.0 (and SSP2-4.5) as “intermediate emission scenarios”, where CO_2 concentrations increase to 2100, but less rapidly than SSP5-8.5, the most extreme scenario.

NHTSA and EPA also used the GCAMReference 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 selected scenarios 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 1,211 million metric tons carbon dioxide ($MMTCO_2$); the emissions in 2040 under Alternative 2.5 (Preferred Alternative) are estimated to be 1,110 $MMTCO_2$. The difference of 101 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global emissions in 2040 are estimated to be 51,701 $MMTCO_2$ for the GCAMReference scenario, and 58,494 $MMTCO_2$ for the SSP3-7.0 scenario. These global emissions 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 101 $MMTCO_2$ less than the reference levels or approximately 51,600 $MMTCO_2$ for GCAMReference and 58,393 $MMTCO_2$ for SSP3-7.0 in 2040. There are some inconsistencies between the overall assumptions that SAP 2.1 and the Joint Global Change Research Institute used to develop the global emissions scenario and the assumptions used in the CAFE Model in terms of economic growth, energy prices, energy supply, and energy demand. However, these inconsistencies affect the characterization of each action alternative in equal proportion, so the relative estimates provide a reasonable approximation of the differences in environmental impacts among the action alternatives.

5.3.3.5 Reference Case Modeling Runs

The modeling runs and sensitivity analysis simulate relative changes in atmospheric concentrations, global mean surface temperature, precipitation, sea-level rise, and ocean pH 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.[37] The approach uses the following five 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.

[37] NHTSA used a climate sensitivity of 3°C (5.4°F), as this is IPCC’s best estimate, with a *likely* range of 1.5 to 4.0°C (2.7 to 7.2°F) (IPCC 2021a).

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 utilized the CO2SYS model to estimate changes in ocean acidification. Changes in global CO_2 concentrations calculated within the MAGICC6 model are parsed to the CO2SYS ocean acidification model to calculate change. This model uses two of four measurable parameters of the ocean 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 years 2040, 2060, and 2100 under the No Action Alternative and each of the action alternatives.
5. NHTSA used the increase in global mean surface temperature to estimate the increase in both global average precipitation and sea-level rise for each alternative using the global emissions scenario.

5.3.3.6 Sensitivity Analysis

NHTSA performed a sensitivity analysis to examine the effect of various equilibrium climate sensitivities on the results. Equilibrium climate sensitivity is the projected responsiveness of Earth's global climate system to increased ERF from higher GHG concentrations and is expressed in terms of changes to global surface temperature resulting from a doubling of CO_2 compared to preindustrial atmospheric concentrations (278 ppm CO_2) (IPCC 2021a). 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 AR6 expresses stronger confidence in some fundamental processes in models that determine climate sensitivity than the AR5 (IPCC 2021a). According to IPCC, the very likely range of equilibrium climate sensitivity is between 2°C (3.6°F) (*high confidence)* and 5°C (9°F) *(medium confidence)*. The assessed best estimate is 3°C (5.4°F) with a *likely* range of 2.5°C (4.5°F) to 4°C (7.2°F) (*high confidence),* compared to 1.5°C (2.7°F) to 4.5°C (8.1°F) in AR5.

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 GCAMReference and SSP3-7.0 scenarios to represent emissions from the No Action Alternative.
2. Starting with the respective scenarios, 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.[38] 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 AR6 (IPCC 2021a) of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0°C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8°F).
4. For each climate sensitivity value in Step 3, NHTSA used MAGICC6 to estimate the resulting changes in CO_2 concentrations and global mean surface temperature, as well as the regression-based analysis to estimate sea-level rise through 2100 for the global emissions scenarios in Steps 1 and 2.

Section 5.4, *Environmental Consequences*, presents the results of the model runs for the alternatives. For the direct and indirect impacts analysis, the sensitivity analysis was performed against the GCAMReference and SSP3-7.0 scenarios (789 ppm and 800 ppm, respectively, 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 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC 2021a) and *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 ERF, 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

[38] 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.

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 2.5 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.[39] 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 80,400 $MMTCO_2$ under Alternative 3 to a high of 89,200 $MMTCO_2$ 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 3,500 to 8,800 $MMTCO_2$. Compared to GCAMReference

[39] Previous NHTSA EISs used the same approaches to quantifying impacts on global atmospheric CO_2 concentrations, temperature change, precipitation change, sea-level rise, and ocean pH. See MY 2011–2015 CAFE standards EIS, MY 2012–2016 CAFE standards EIS, Phase 1 HD standards EIS, MY 2017–2025 CAFE standards EIS, Phase 2 HD standards EIS, and SAFE Vehicles Rule EIS.

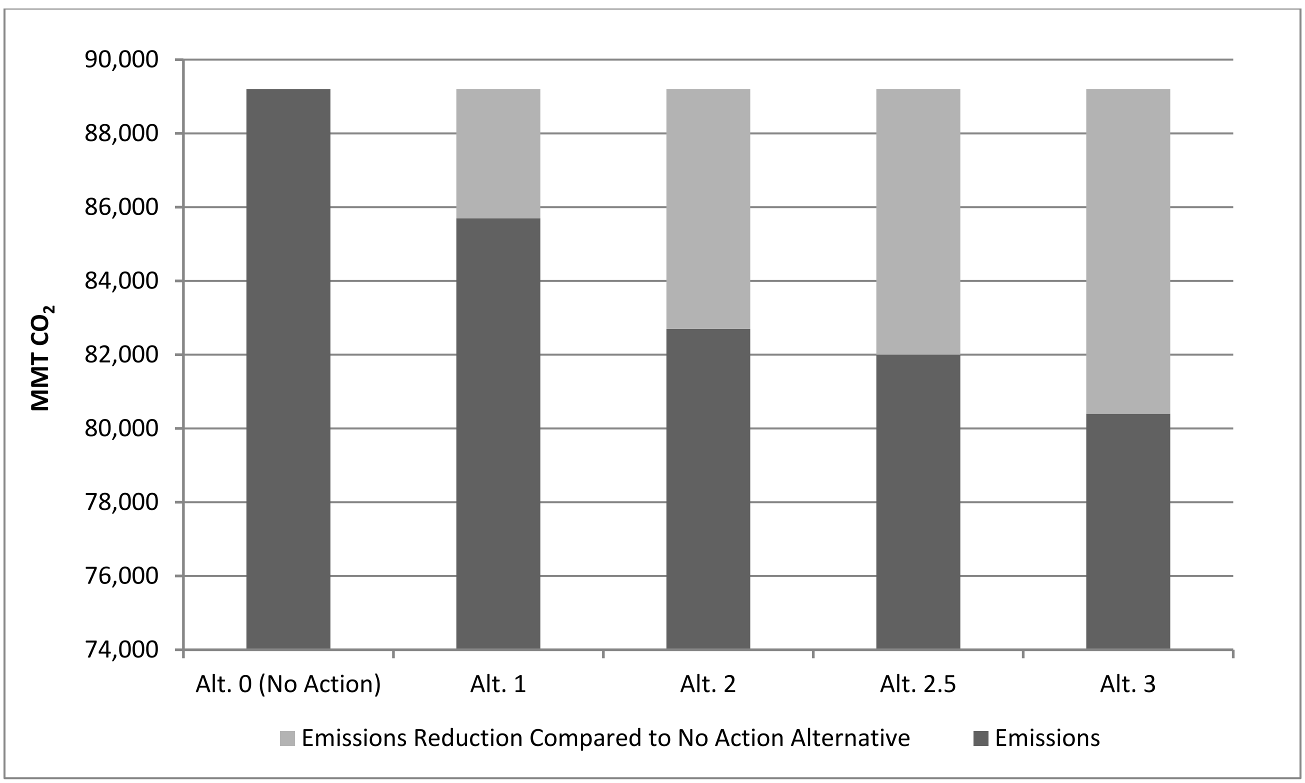
total global emissions projection of 4,950,865 $MMTCO_2$ over this period, this rulemaking is expected to reduce global CO_2 emissions by approximately 0.07 to 0.18 percent from projected levels under the No Action Alternative. Using the SSP3-7.0 total global emissions projection of 5,277,281 $MMTCO_2$ over this period, reductions would range from approximately 0.07 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)	89,200	-	-
Alt. 1	85,700	3,500	4%
Alt. 2	82,700	6,500	7%
Alt 2.5	82,000	7,200	8%
Alt. 3	80,400	8,800	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

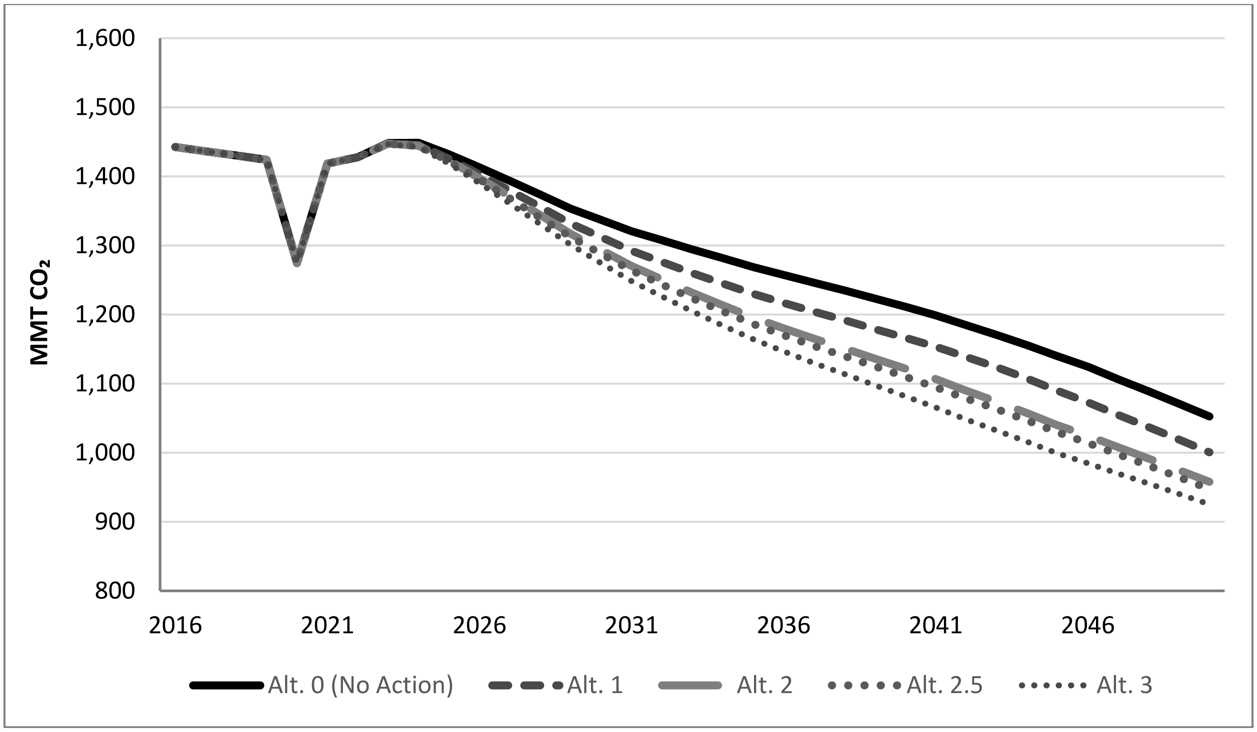
Figure 5.4.1-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All Passenger Cars and Light Trucks, 2021 to 2100, by Alternative



$MMTCO_2$ = 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 4 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 GCAMReference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions in the year 2100 by a range of 0.7 to 1.6 percent.[40] Figure 5.4.1-2 shows the projected annual emissions from U.S. passenger cars and light trucks under the alternatives. Alternatively, using estimated U.S. emissions at the end of the century projected by the SSP3-7.0 baseline scenario (9,477 $MMTCO_2$ from all sources), the action alternatives would reduce total U.S. CO_2 emissions in the year 2100 by a range of 0.4 to 0.9 percent.

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.

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

Table 5.4.1-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All Passenger Cars and Light Trucks by Alternative[a]

GHG and Year	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Carbon dioxide (CO_2)					
2020	1,275	1,275	1,275	1,275	1,275
2040	1,211	1,166	1,122	1,110	1,082
2060	1,047	995	953	943	921
2080	1,040	988	946	936	914
2100	967	919	880	870	850
Methane (CH_4)					
2020	42	42	42	42	42
2040	40	39	37	37	36
2060	36	34	33	33	32
2080	35	34	33	32	32
2100	33	31	30	30	30
Nitrous oxide (N_2O)					
2020	16	16	16	16	16
2040	13	12	12	12	11
2060	11	10	10	10	9
2080	11	10	10	10	9
2100	10	9	9	9	9
Total (all GHGs)					
2020	1,333	1,333	1,333	1,333	1,333
2040	1,264	1,217	1,171	1,159	1,129
2060	1,093	1,040	996	985	962
2080	1,086	1,032	989	978	955
2100	1,010	960	919	910	888

Notes:
[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the GCAMReference scenario. These assumptions project a slight decline over this period.
$MMTCO_2e$ = 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.[41]

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 11.5 percent reduction for the No Action Alternative to an 15.6 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 2040 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 and due to increasing percentages of electric vehicles, which have zero tailpipe emissions and produce lower emissions from a life-cycle perspective. 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.

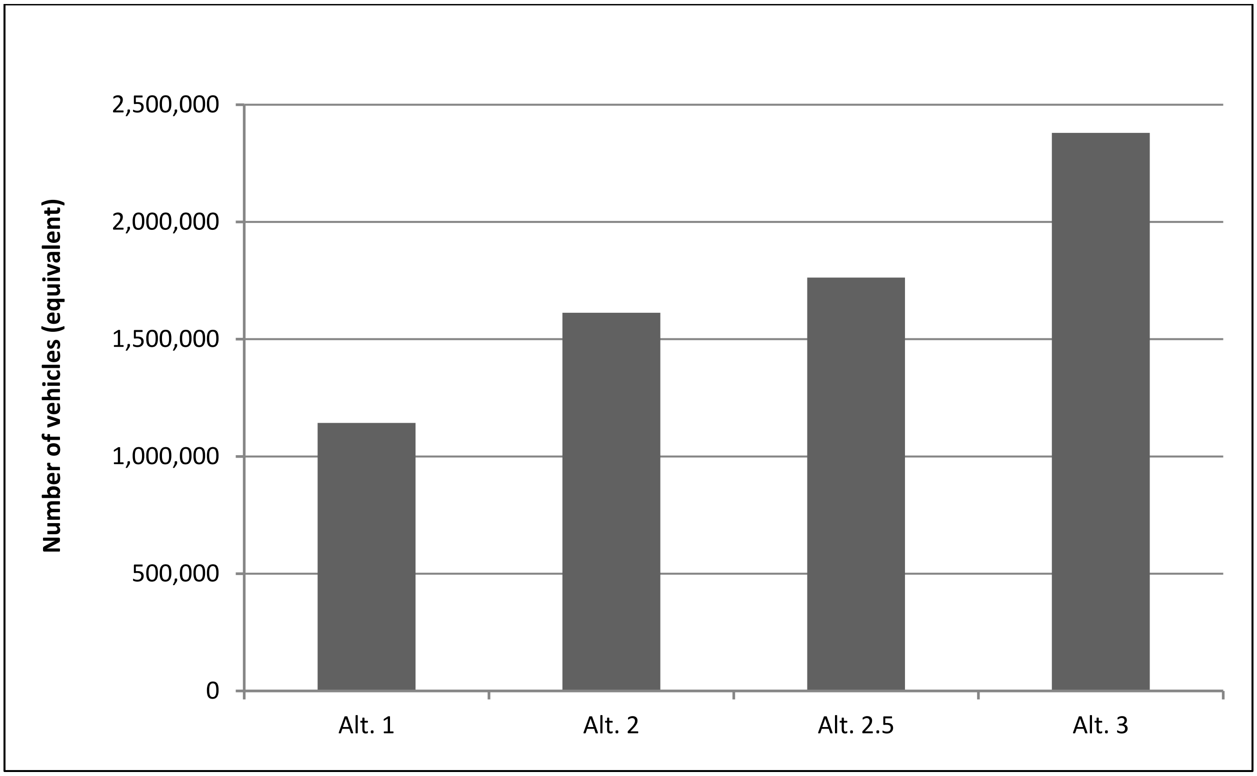
5.4.1.2 Comparison to Annual Emissions from Passenger Cars and Light Trucks

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 1,143,017 passenger cars and light trucks (Alternative 1) to 2,379,681 passenger cars and light trucks (Alternative

[41] 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.

3) in 2025, compared to the annual emissions that would occur under the No Action Alternative. A total number of 253,949,461 passenger cars and light trucks are projected to be on the road in 2025 under the No Action Alternative.[42,43]

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



$MMTCO_2$ = million metric tons of carbon dioxide

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 gigatons (Gt) carbon (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). Most notably, the AR6 detailed the implications of methodological advancements in estimating the remaining carbon budget. The report concluded that, due to a variety of factors, estimates for limiting warming to 2°C (3.6°F) are about 11 to

[42] Values for vehicle totals have been rounded.

[43] 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 5.64 metric tons of CO_2 emissions in 2025 based on MOVES, the GREET model, and EPA analysis.

14 Gt carbon (40 to 50 Gt CO_2) higher (IPCC 2021a) than estimates in AR5. 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.

Using IPCC's estimated carbon budget in AR6, as of 2019, approximately 655 Gt carbon (2,403 Gt CO_2) of this budget has already been emitted, leaving a remaining budget of 358 Gt carbon (1,313 Gt CO_2) (IPCC 2021a). Emissions from 2015 to 2019 alone totaled 210 Gt carbon (771 Gt CO_2). Global emissions in 2020 totaled 34 Gt carbon (125 Gt CO_2). Under the No Action Alternative, U.S. passenger cars and trucks are projected to emit 24 Gt carbon (89 Gt CO_2) from 2021 to 2100, or 7.9 percent of the remaining global carbon budget. Under Alternative 3, this projection decreases to 22 Gt carbon (80 Gt CO_2) or 6.2 percent of the remaining budget.

The emissions reductions necessary to keep global emissions within this carbon budget must include dramatic 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 dramatic 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 11 Gt CO_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 2021).

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 GCAMReference and SSP3-7.0 scenarios. 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 MY 2027 through at least MY 2030, standards that are likely to be more stringent than Alternative 2.5 and produce additional GHG reductions.

MAGICC6 is a reduced-complexity climate model well calibrated to the mean of the multimodel ensemble results for four of the most commonly used RCP emissions scenarios—RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high), and RCP8.5 (high) as well as five of the most widely used SSP scenarios (i.e., SSP1-1.9 [low], SSP1-2.6 [medium-low], SSP2-4.5 [medium], SSP3-7.0 [medium-high], and

SSP5-8.5 [high])—as shown in Table 5.4.2-1 and Table 5.4.2-2.[44] As the tables show, 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 compares the RCP emissions scenarios with CO_2 concentrations and surface temperature estimates from AR5, while Table 5.4.2-2 compares the SSP scenario model results with estimates from AR6.

Table 5.4.2-1. Comparison of MAGICC Modeling Results and Reported IPCC AR5 Results[a]

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

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

Table 5.4.2-2. Comparison of MAGICC Modeling Results and Reported IPCC AR6 Results[a]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
	IPCC WGI (2100)	MAGICC (2100)	IPCC WGI (2081–2100)	MAGICC (2100)
SSP1-1.9	337	384	1.4	1.3
SSP1-2.6	446	434	1.8	1.6
SSP2-4.5	603	582	2.7	2.7
SSP3-7.0	867	828	3.6	4.0
SSP5-8.5	1,135	1,082	4.4	4.9

Notes:
[a] The IPCC values represent the average of the 5 to 95 percent range of global mean surface air temperature.
Source: IPCC 2021a
ppm = parts per million; °C = degrees Celsius; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; IPCC = Intergovernmental Panel on Climate Change; SSP = Shared Socioeconomic Pathway; WGI = Working Group 1.

As discussed in Section 5.3.1, *Methods for Modeling Greenhouse Gas Emissions*, NHTSA used the GCAMReference and SSP3-7.0 emissions scenarios to represent the No Action Alternative in the MAGICC modeling runs. CO_2 concentrations under the GCAMReference scenario for the No Action Alternative are 789.11 ppm and range from 788.80 under Alternative 1 to 788.33 ppm under Alternative 3 in 2100 (Table 5.4.2-3). The CO_2 concentrations under the SSP3-7.0 emissions scenario for the No Action Alternative are 800.39 ppm and range from 800.09 under Alternative 1 to 799.57 ppm under Alternative 3 in 2100 (Table 5.4.2-4). 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

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

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 5.4.2-3. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH (GCAMReference) 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	565.31	788.80	1.287	2.008	3.483	22.87	36.56	76.26	8.4099	8.3477	8.2177
Alt. 2	478.96	565.19	788.53	1.287	2.007	3.482	22.87	36.55	76.23	8.4100	8.3478	8.2179
Alt. 2.5	478.95	565.16	788.47	1.287	2.007	3.481	22.87	36.55	76.23	8.4100	8.3478	8.2179
Alt. 3	478.92	565.10	788.33	1.287	2.006	3.481	22.87	36.55	76.22	8.4100	8.3478	8.2180
Reductions Under Proposed Action and Alternatives												
Alt. 1	0.04	0.13	0.31	0.000	0.001	0.001	0.00	0.01	0.03	0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.57	0.000	0.001	0.002	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 2.5	0.09	0.28	0.64	0.000	0.001	0.003	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 3	0.12	0.34	0.78	0.001	0.002	0.003	0.00	0.01	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 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

Table 5.4.2-4. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH (SSP3-7.0) 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)	488.08	577.31	800.39	1.324	2.068	3.564	23.20	37.38	78.53	8.4030	8.3397	8.2119
Alt. 1	488.04	577.18	800.09	1.324	2.068	3.562	23.20	37.38	78.51	8.4030	8.3398	8.2120
Alt. 2	488.00	577.06	799.80	1.323	2.067	3.561	23.20	37.36	78.47	8.4030	8.3398	8.2122
Alt. 2.5	487.99	577.02	799.73	1.323	2.066	3.560	23.20	37.36	78.45	8.4030	8.3399	8.2122
Alt. 3	487.96	576.95	799.57	1.322	2.066	3.559	23.20	37.35	78.43	8.4030	8.3399	8.2123

	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	0.04	0.13	0.30	0.000	0.001	0.001	0.00	0.00	0.02	0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.59	0.001	0.002	0.003	0.00	0.01	0.06	-0.0001	-0.0002	-0.0003
Alt. 2.5	0.09	0.29	0.67	0.001	0.002	0.003	0.00	0.02	0.07	-0.0001	-0.0002	-0.0003
Alt. 3	0.12	0.36	0.82	0.001	0.003	0.004	0.00	0.03	0.10	-0.0001	-0.0002	-0.0004

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the increases might not reflect the exact difference of the values in all cases.
[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986 to 2005.
[c] Temperature changes reported as 0.000 are more than zero but less than 0.001.
[d] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.
[e] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.
CO_2 = carbon dioxide; °C = degrees Celsius; ppm = parts per million; cm = centimeters; SSP = Shared Socioeconomic Pathway

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 5.4.2-3 and Figure 5.4.2-4, the reduction in CO_2 concentrations by 2100 under Alternative 3 compared to the No Action Alternative is more than double that of Alternative 1 for both the GCAMReference and SSP3-7.0 emissions scenario modeling results.

Figure 5.4.2-1. Atmospheric Carbon Dioxide Concentrations by Alternative—GCAMReference

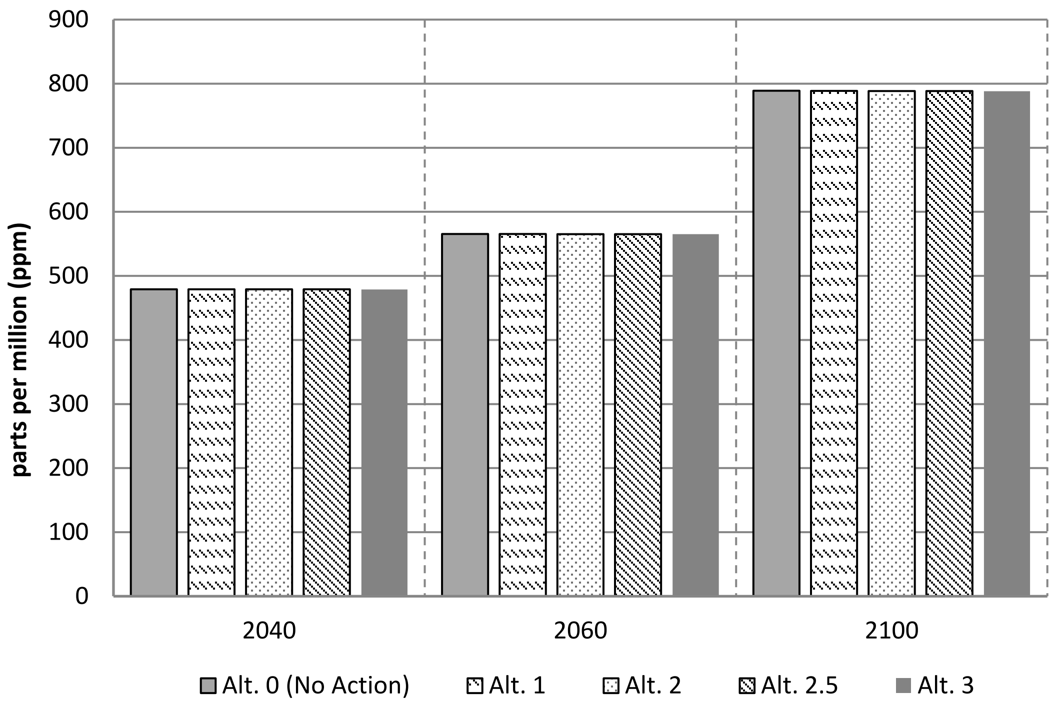


Figure 5.4.2-2. Atmospheric Carbon Dioxide Concentrations by Alternative—SSP3-7.0

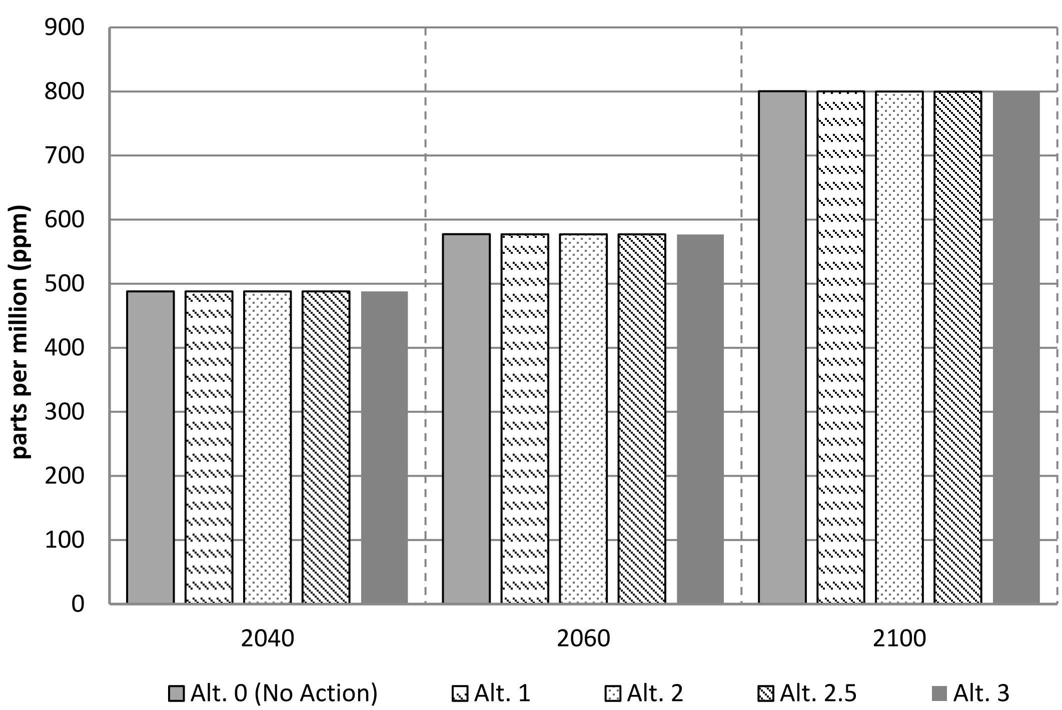


Figure 5.4.2-3. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative—GCAMReference

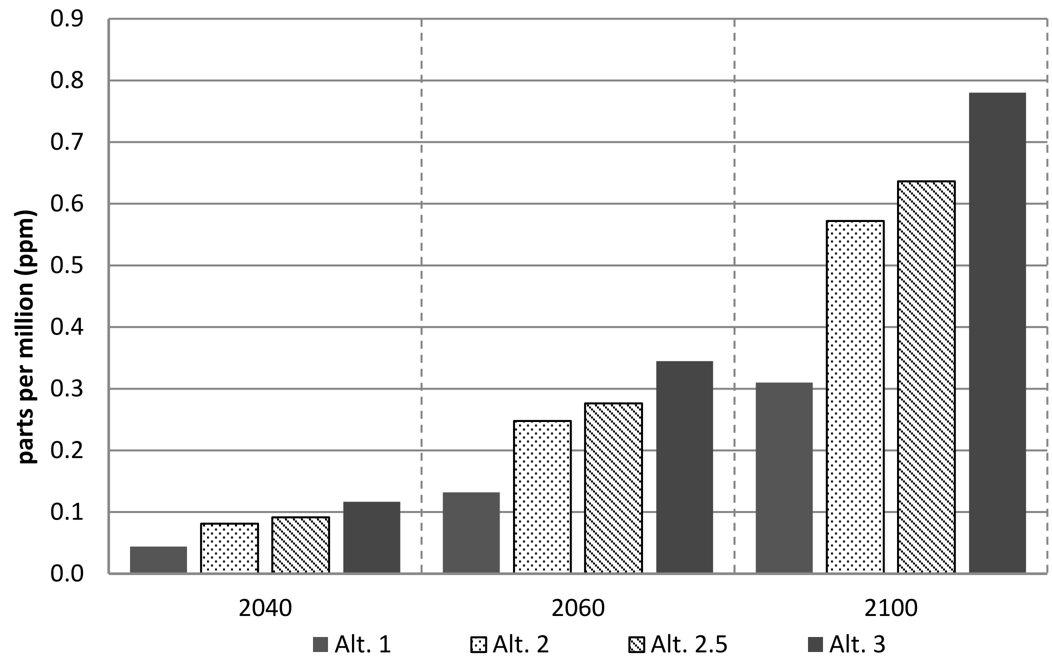
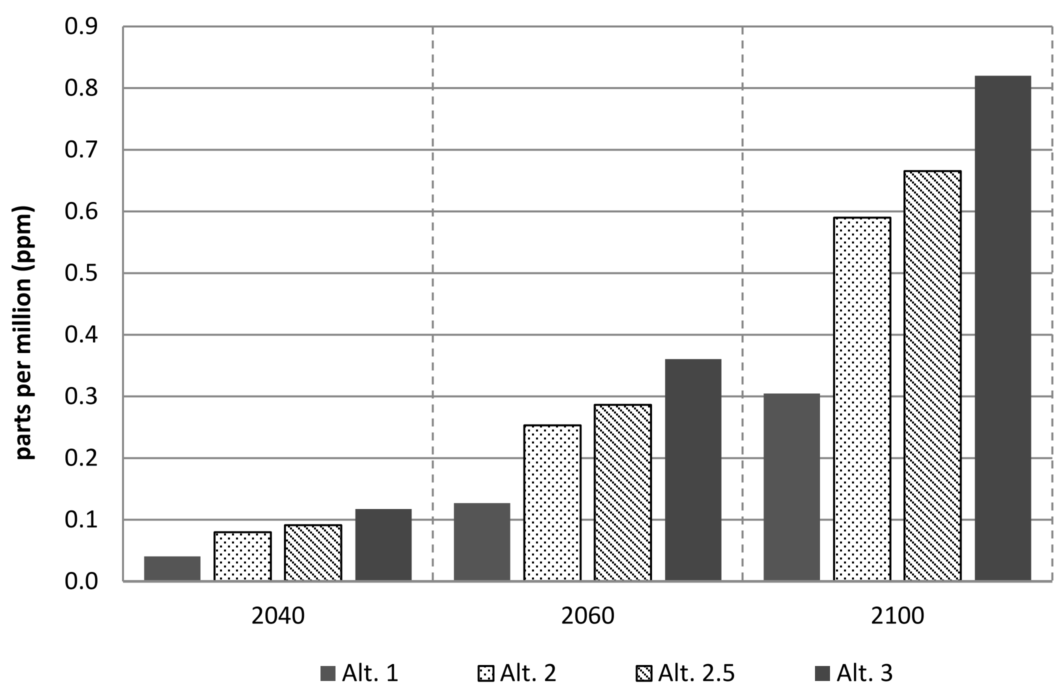


Figure 5.4.2-4. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative—SSP3-7.0

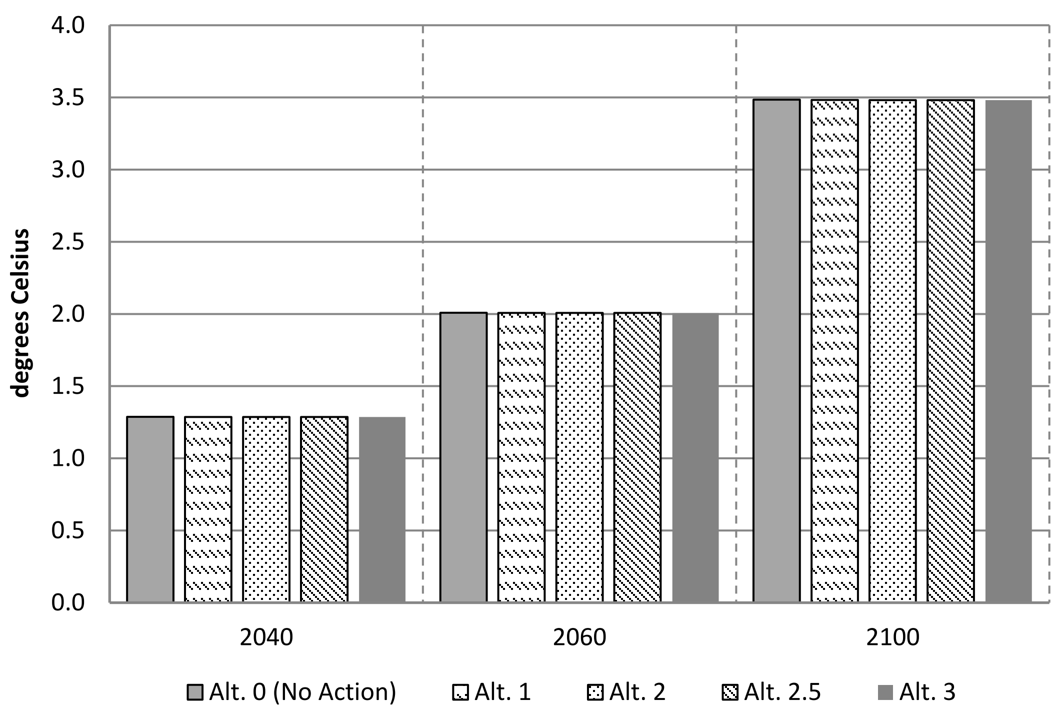


5.4.2.2 Climate Change Attributes

Temperature

Table 5.4.2-1 and Table 5.4.2-2 list MAGICC simulations of mean global surface air temperature increases for the GCAMReference and SSP3-7.0 emissions scenarios. Under the No Action Alternative for the GCAMReference scenario, 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.[45] Under the No Action Alternative for the SSP3-7.0 emissions scenario, global surface air temperature is projected to increase from 1986 to 2005 average levels by 1.32°C (2.38°F) by 2040, 2.07°C (3.73°F) by 2060, and 3.56°C (6.41°F) by 2100. 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 5.4.2-5 and Figure 5.4.2-6 for the GCAMReference and SSP3-7.0 emissions scenarios, respectively. For example, in 2100 the reduction in temperature rise compared to the No Action Alternative for the GCAMReference ranges from 0.001°C (0.002°F) under Alternative 1 to 0.003°C (0.006°F) under Alternative 3. Under the SSP3-7.0 emissions scenario, this temperature reduction range compared to the No Action Alternative is 0.001°C (0.002°F) under Alternative 1 to 0.004°C (0.007°F) under Alternative 3.

Figure 5.4.2-5. Global Mean Surface Temperature Increase by Alternative—GCAMReference



[45] 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 5.4.2-6. Global Mean Surface Temperature Increase by Alternative—SSP3-7.0

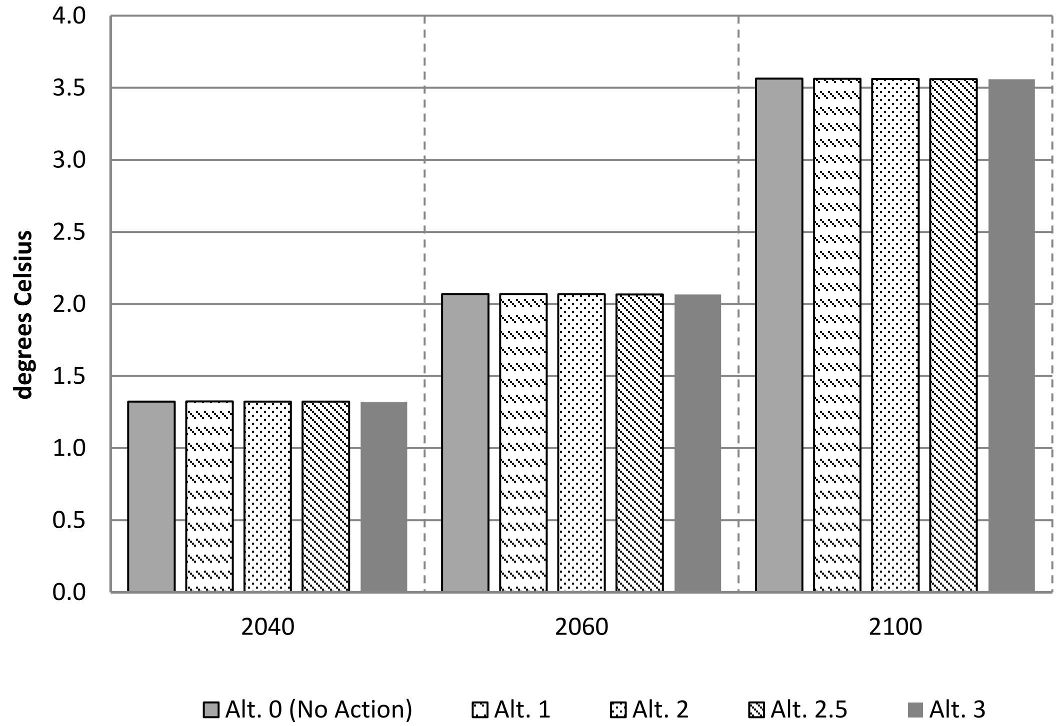


Figure 5.4.2-5 and Figure 5.4.2-6 also illustrate that reduction in the growth of projected global mean surface temperature under the Proposed Action and alternatives compared to the No Action Alternative are anticipated to be small compared to total projected temperature increases. However, the relative 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 5.4.2-7 and Figure 5.4.2-8, the reduction in the projected growth in global temperature under Alternative 3 is more than triple that under Alternative 1 in 2100 for both emissions scenarios.

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 5.4.2-5 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC AR6 from present day through 2100.

Figure 5.4.2-7. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative—GCAMReference

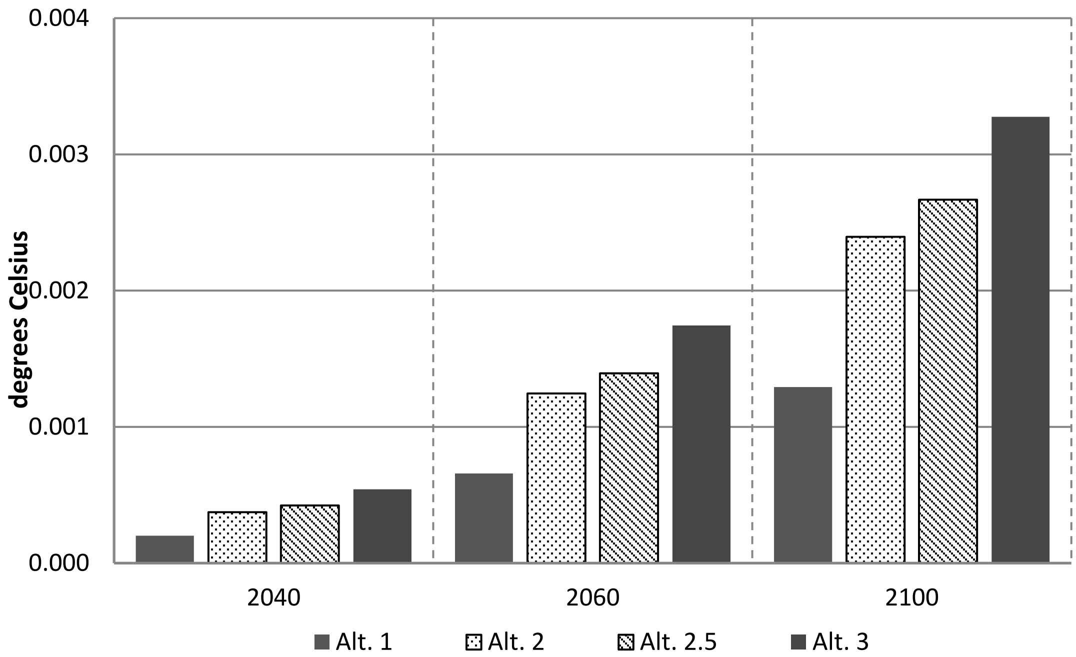


Figure 5.4.2-8. Reductions in Global Mean Surface Temperature Compared to the No Action Alternative—SSP3-7.0

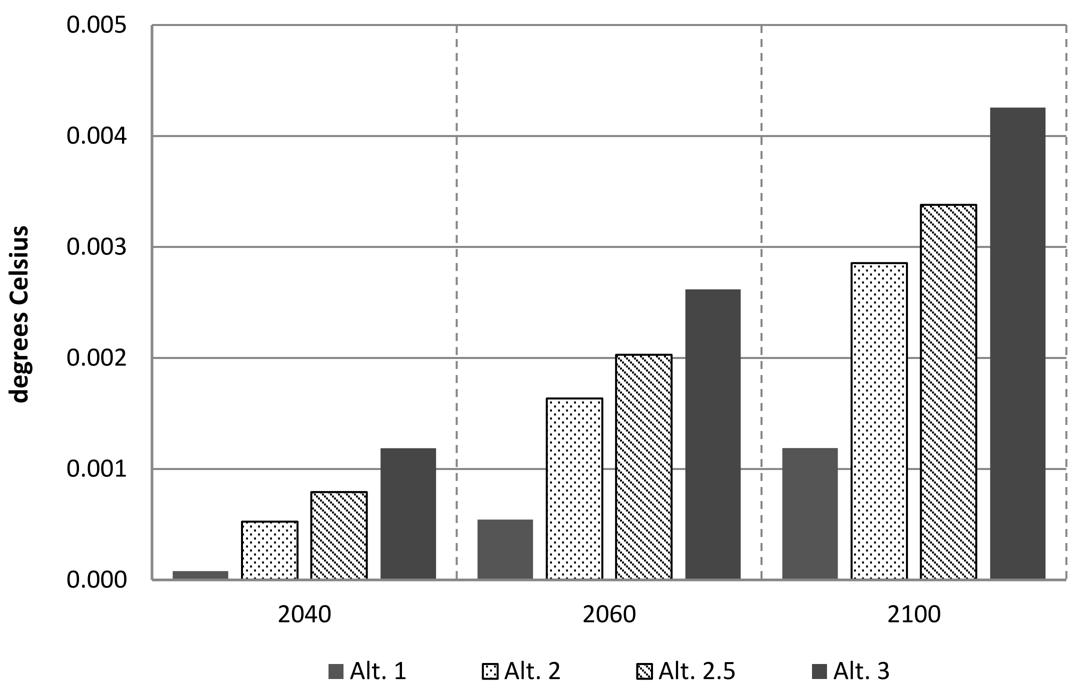


Table 5.4.2-5. Regional Changes to Warming and Seasonal Temperatures in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Sixth Assessment Report

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Africa	Northern Africa and Northern Sahara	*High confidence* of increase in mean annual temperature [a]	*Very likely* to experience a warming larger than 3°C (5.4°F)[c] *High confidence* that cold spells and low target temperatures will decrease in future
	East Africa	*High confidence* of increase in mean annual temperature [a]	*Very likely* to experience a warming larger than 3°C (5.4°F)[c] *High confidence* that cold spells and low target temperatures will decrease in future
	Southern Africa	*High confidence* of increase in mean annual temperature [a]	*Very likely* to experience a warming larger than 3°C (5.4°F)[c] *High confidence* that cold spells and low target temperatures will decrease in future
	Western Africa	*High confidence* of increase in mean annual temperature [a]	*Very likely* to experience a warming larger than 3°C (5.4°F)[c] *High confidence* that cold spells and low target temperatures will decrease in future
Mediterranean and Europe	Northern Europe	*High confidence* of increase in mean annual temperature [a]	*Very likely* decrease in cold spells and frost days [a], more frequent heat waves
	Central Europe	*High confidence* of increase in mean annual temperature [a]	*Very likely* decrease in cold spells and frost days, more frequent heat waves
	Southern Europe and Mediterranean	*High confidence* of increase in mean annual temperature [a]	*Very likely* decrease in cold spells and frost days, more frequent heat waves
Asia	Central Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northern Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Eastern Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	West Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	South Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeast Asia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of 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	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells, with the largest decreases most common in the winter season
	Southwest	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells, with the largest decreases most common in the winter season
Central and South America	Southern Central America	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells by mid-century [b]
	Southeastern South America	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells by mid-century [b]
	Northern South America	*High confidence* of increase in mean annual temperature and extreme heat [a] Largest increases in temperature taking place in the Amazon Basin	*High confidence* of decrease in cold spells [a]
	Southwestern South America	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells [a]
	Northeastern South America	*High confidence* of increase in mean annual temperature and extreme heat [a]	*High confidence* of decrease in cold spells [a]
Australia and New Zealand	Southern Australia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	Southwestern Australia	*High confidence* of increase in mean annual temperature and extreme heat [a]	*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	*High confidence* of increase in mean annual temperature and extreme heat [a]	*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	*High confidence* of increase in mean annual temperature and extreme heat [a]	*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	*High confidence* of increase in mean annual temperature and extreme heat [a] Warming at more than twice the global mean rate	--
	Antarctic	*High confidence* of increase in mean annual temperature [a]	--
Small Islands		*High confidence* of increase in mean annual temperature [a]	*Likely* that the intensity and frequency of hot temperature extremes will increase and cold temperature extremes will decrease

Notes:
Information is omitted from the table where no data was available from AR6.
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] Already emerged in the historical period
[b] RCP2.6
[c] RCP8.5 or SSP5-8.5
[d] RCP4.5
[e] RCP6.0
[f] SRES A1B
Source: IPCC 2021a
No superscripts were used for those findings where the concentration pathways were not identified.

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.

IPCC AR6 further confirms that it is virtually certain that global mean sea level will continue to rise through 2100. In the year 2100, sea level is likely to rise 28 to 55 centimeters (11 to 21.7 inches) under the SSP1-1.9 emissions scenario and 63 to 102 centimeters (24.8 to 40.2 inches) centimeters for the SSP5-8.5 emissions scenario. Higher amounts of global mean sea-level rise before 2100 could be caused by earlier than projected disintegration of the marine ice shelves (IPCC 2021a).

Table 5.4.2-3 lists the impacts of the Proposed Action and alternatives on sea-level rise under the GCAMReference scenario and Table 5.4.2-4 lists the impacts under the SSP3-7.0 scenario. This analysis under the GCAMReference scenario 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 76.26 centimeters (30.02 inches) under Alternative 1. This represents a maximum reduction of 0.07 centimeter (0.03 inch) by 2100 under Alternative 3 compared to the No Action Alternative. Alternative 2.5, the Preferred Alternative, would lead to sea-level rise of 76.23 centimeters (30.01 inches) in 2100, or a reduction of 0.05 centimeter (0.020 inch) compared to the No Action Alternative. Analysis under the SSP3-7.0 scenario shows sea-level rise in 2100 ranging from 78.53 centimeters (30.92 inches) under the No Action Alternative to between 78.43 centimeters (30.88 inches) under Alternative 3 and 78.51 centimeters (30.91 inches) under Alternative 1. This represents a maximum reduction of 0.10 centimeter (0.04 inch) by 2100 under Alternative 3 compared to the No Action Alternative. Projected sea-level rise under Alternative 2.5 in 2100 would be 78.45 centimeters (30.89 inches), or a reduction of 0.07 centimeter (0.028 inch) 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, 2021a), 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, 2021a) 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 RCP and SSP emissions scenarios (IPCC 2013a, 2021a) is given as the scaled change in precipitation (expressed as a percentage change from 1980 to 1999 averages for RCP emissions scenarios and from 1995 to 2014 averages for SSP emissions scenarios) divided by the increase in global mean surface warming for the same period (per °C), as shown in Table 5.4.2-6 and Table 5.4.2-7. 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 an ERF in 2100 of 6 W/m^2, similar to the GCAMReference scenario's ERF of 7 W/m^2) in the analysis of RCP emissions scenarios because MAGICC does not directly estimate changes in global mean precipitation. Similarly, in the analysis of SSP emissions scenarios, NHTSA used the scaling factor for the SSP3-7.0 scenario as it also yields an ERF of approximately 7.0 W/m^2 in the year 2100, making it a good comparison to GCAMReference. Table 5.4.2-7 describes the mean change in precipitation for each SSP emissions scenario, ranging from an increase of 1.83 percent per °C (SSP5-8.5) to 3.05 percent per °C (SSP1-2.6).

Table 5.4.2-6. Rates of Global Mean Precipitation Increase over the 21st Century, per Representative Concentration Pathways Emissions Scenario

Scenario	Percent per °C
RCP8.5	1.58
RCP6.0	1.68
RCP4.5	1.96
RCP2.6	2.39

Source: IPCC 2013b: Figure 12-7
°C = degrees Celsius

Table 5.4.2-7. Rates of Global Mean Precipitation Increase over the 21st Century, per Shared Socioeconomic Pathways Emissions Scenario

Scenario	Percent per °C [a,b]
SSP5-8.5	1.83
SSP3-7.0	1.71
SSP2-4.5	2.16
SSP1-2.6	3.05

Notes:

[a] Global percent precipitation anomalies are calculated relative to model averages over 1995 through 2014 for 2081 through 2100 from Table 4.3 in IPCC 2021a.

[b] Percent per °C is calculated using average changes in global annual surface temperature presented in Table 5.4.2-2 scaled to the new reference time period of 1995 through 2014 by subtracting 0.85°C (IPCC 2021a).

°C = degrees Celsius

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 5.4.2-8 (GCAMReference scenario) and Table 5.4.2-9 (SSP3-7.0 scenario)(based on the scaling factor from the RCP6.0 and SSP3-7.0 scenarios respectively).

Table 5.4.2-8. Global Mean Precipitation (Percent Increase) Based on GCAMReference 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 GCAMReference Scenario by Alternative			
Alt. 0 (No Action)	1.287	2.008	3.484
Alt. 1	1.287	2.008	3.483
Alt. 2	1.287	2.007	3.482
Alt. 2.5	1.287	2.007	3.481
Alt. 3	1.287	2.006	3.481
Reductions in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative) [b]			
Alt. 1	0.000	0.001	0.001
Alt. 2	0.000	0.001	0.002
Alt. 2.5	0.000	0.001	0.003
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. 2.5	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. 2.5	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

Table 5.4.2-9. Global Mean Precipitation (Percent Increase) Based on SSP3-7.0 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)	1.71%		
Global Temperature Above Average 1986–2005 Levels (°C) for the SSP3-7.0 Scenario by Alternative			
Alt. 0 (No Action)	1.324	2.068	3.564
Alt. 1	1.324	2.068	3.562
Alt. 2	1.323	2.067	3.561
Alt. 2.5	1.323	2.066	3.560
Alt. 3	1.322	2.066	3.559
Reductions in Global Temperature (°C) by Alternative (Compared to the No Action Alternative)[b]			
Alt. 1	0.000	0.001	0.001
Alt. 2	0.001	0.002	0.003
Alt. 2.5	0.001	0.002	0.003
Alt. 3	0.001	0.003	0.004
Global Mean Precipitation Increase by Alternative (%)			
Alt. 0 (No Action)	2.26%	3.54%	6.09%
Alt. 1	2.26%	3.54%	6.09%
Alt. 2	2.26%	3.53%	6.09%
Alt. 2.5	2.26%	3.53%	6.09%
Alt. 3	2.26%	3.53%	6.09%
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. 2.5	0.00%	0.00%	0.01%
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 increases might not reflect the exact difference of the values in all cases.
[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.
[c] The increase in precipitation is less than 0.005%, and thus is rounded to 0.00%.
SSP = Shared Socioeconomic Pathway; 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.[46] 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

[46] 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."

models typically are used to provide results among scenarios with very large changes in emissions, such as the selection of the RCP and SSP scenarios; very small changes in emissions profiles (such as those resulting from the Proposed Action and alternatives) would produce results that would be difficult to resolve among scenarios. In addition, the multiple AOGCMs produce results regionally consistent in some cases but inconsistent in others.

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 5.4.2-10 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC AR6 from the present day through 2100.

Table 5.4.2-10. Regional Changes to Precipitation in the Year 2100 Compared to Current Conditions, Summarized from the IPCC Sixth Assessment Report

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
Africa	Northern Africa and Northern Sahara	*High confidence* in decreases in mean annual precipitation [b]	--
	Eastern Africa	*Likely* increase in mean annual precipitation over the Ethiopian Highlands *Medium confidence* of drying in western portions and wettening in eastern portions	
	Central Africa	*High confidence* that the intensity of extreme precipitation will increase [e]	
	Southern Africa	*Medium to high confidence* in decreases in mean annual precipitation beginning mid-century [b]	
	Western Africa	*Medium confidence* of drying in western portions and wettening in eastern portions *High confidence* that the intensity of extreme precipitation will increase [e]	
Mediterranean and Europe	Northern Europe	*High confidence of* increase in annual precipitation [b] *High confidence* in extreme precipitation increase	*High confidence* in decrease of snow cover extent and seasonal duration
	Central Europe	*High confidence* in extreme precipitation increase	--
	Southern Europe and Mediterranean	*High confidence of* decrease in annual precipitation [c]	--
Asia	Central Asia	*High confidence* of increase in annual precipitation	*High confidence* of decrease in snow
	Northern Asia	*High confidence* of increase in annual precipitation by mid-century [b]	

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
	Eastern Asia	*High confidence* of increase in annual precipitation	
	West Asia	*Medium confidence* of precipitation decreasing in summer and increasing in winter	*High confidence* of decrease in snow
	South Asia	*High confidence* of increase in annual precipitation	*High confidence* of decrease in snow
	Southeast Asia	*Medium confidence* of increase in annual precipitation *High confidence* of decrease in precipitation in Indonesia	--
North America	Northern regions/Northern North America	*High confidence* of increase in precipitation by end-of-century [c], higher confidence of increase in northern regions and lower confidence toward south	*High to medium confidence* in decrease of snow season length and snow depth [c] Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
	Southwest	Increasing precipitation in northern regions and decreasing toward south	*High confidence* in decrease of snow season length and snow depth [b]
	Northeast USA	*High confidence* of increase in precipitation by end of century, higher confidence in increase in northern regions and lower confidence toward south	*High confidence* in decrease of snow season length and snow depth [b] Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
Central and South America	Southern Central America	*Medium confidence* of decrease in precipitation	--
	Southeastern South America	*High confidence* of increase in precipitation	
	Northern South America	*Medium confidence* of decrease in precipitation	
	Southwestern South America	*High confidence* of decrease in precipitation	
	Northeastern South America	*High confidence* of decrease in precipitation	

Land Area	Subregion	Precipitation	Snow Season and Snow Depth
Australia and New Zealand	Southern Australia	*Medium confidence* of decrease in precipitation [c]	*High confidence* of decrease in snow
	Southwestern Australia	*High confidence* of decrease in precipitation	--
	New Zealand	*Medium confidence* of decrease in precipitation in north and east and increase in south and west	*High confidence* of decrease in Glacier volume, *medium confidence* of decrease in snow
Polar Regions	Arctic	*High confidence* of increase in precipitation	*High* confidence of decrease in snow Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
	Antarctic	*High confidence* of increase in precipitation	*Medium confidence* of decrease in snow Snow may increase in some high elevations and during the cold season and decrease in other seasons and at lower elevations
Small Islands	--	*High confidence* in precipitation decrease in the Caribbean region, *Low confidence* in decrease in eastern Pacific and southern Pacific subtropics and increase in parts of western and equatorial Pacific	--

Notes:
Information is omitted from the table where no data was available from IPCC AR6.
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] Already emerged in the historical time period
[b] Emerging by 2050 at least in scenarios RCP8.5/SSP5-8.5 with *medium to high confidence*
[c] Emerging after 2050 and by 2100 at least in scenarios RCP8.5/SSP5-8.5 with *medium to high confidence*
[d] RCP2.6
[e] RCP8.5
Source: IPCC 2021

Ocean pH

Table 5.4.2-3 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative under the GCAMReference scenario. 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. Table 5.4.2-4 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative under the SSP3-7.0 scenario. Ocean pH under the alternatives ranges from 8.2119 under the No Action Alternative to 8.2123 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 GCAMReference and SSP3-7.0 scenarios.

Table 5.4.2-11 lists the results from the sensitivity analysis under the GCAMReference scenario while Table 5.4.2-12 details the sensitivity results for the SSP3-7.0 scenario, both of 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 5.4.2-11. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for Selected Alternatives[a]—GCAMReference

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm) [b]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0 (No Action)	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05	8.2445
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74	8.2350
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52	8.2260
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28	8.2176
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93	8.1952
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70	8.1759
Alt. 1	1.5	469.57	545.97	737.20	0.741	1.128	1.889	41.03	8.2447
	2.0	473.05	552.96	755.19	0.941	1.445	2.450	52.73	8.2351
	2.5	476.17	559.39	772.39	1.122	1.738	2.980	64.50	8.2261
	3.0	478.99	565.31	788.80	1.287	2.008	3.483	76.26	8.2177
	4.5	485.95	580.49	833.94	1.699	2.706	4.866	110.89	8.1954
	6.0	491.30	592.74	874.51	2.019	3.278	6.169	144.64	8.1761

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	469.49	545.76	736.76	0.740	1.127	1.888	41.01	8.2449
	2.0	472.98	552.75	754.75	0.941	1.444	2.449	52.70	8.2353
	2.5	476.10	559.18	771.93	1.122	1.737	2.978	64.47	8.2264
	3.0	478.92	565.10	788.33	1.287	2.006	3.481	76.22	8.2180
	4.5	485.88	580.27	833.45	1.698	2.705	4.864	110.83	8.1956
	6.0	491.22	592.51	874.00	2.019	3.277	6.165	144.55	8.1763
Reductions Under Alternative 1 Compared to No Action Alternative									
Alt. 1	1.5	0.04	0.13	0.29	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.29	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.04	0.13	0.30	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.31	0.000	0.001	0.001	0.03	-0.0002
	4.5	0.04	0.13	0.34	0.000	0.001	0.002	0.04	-0.0002
	6.0	0.04	0.14	0.37	0.000	0.001	0.003	0.06	-0.0002
Reductions Under Alternative 3 Compared to No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.72	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.12	0.34	0.74	0.000	0.001	0.002	0.04	-0.0004
	2.5	0.12	0.34	0.76	0.000	0.002	0.003	0.05	-0.0004
	3.0	0.12	0.34	0.78	0.001	0.002	0.003	0.07	-0.0004
	4.5	0.12	0.35	0.82	0.001	0.002	0.005	0.10	-0.0004
	6.0	0.12	0.36	0.88	0.001	0.003	0.006	0.15	-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 through 2005.

ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters

Table 5.4.2-12. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for Selected Alternatives[a]—SSP3-7.0

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	478.50	557.44	746.90	0.764	1.164	1.934	42.07	8.2395
	2.0	482.04	564.64	765.59	0.970	1.491	2.508	54.17	8.2297
	2.5	485.22	571.24	783.41	1.155	1.791	3.050	66.36	8.2205
	3.0	488.08	577.31	800.39	1.324	2.068	3.564	78.53	8.2119
	4.5	495.12	592.82	847.00	1.743	2.784	4.976	114.38	8.1891
	6.0	500.49	605.26	888.66	2.070	3.369	6.297	149.24	8.1696

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. 1	1.5	478.46	557.32	746.61	0.764	1.163	1.933	42.06	8.2396
	2.0	482.00	564.52	765.29	0.970	1.490	2.507	54.15	8.2298
	2.5	485.18	571.12	783.11	1.155	1.791	3.049	66.34	8.2206
	3.0	488.04	577.18	800.09	1.324	2.068	3.562	78.51	8.2120
	4.5	495.08	592.69	846.70	1.744	2.784	4.974	114.35	8.1892
	6.0	500.45	605.13	888.28	2.070	3.369	6.294	149.20	8.1697
Alt. 3	1.5	478.39	557.10	746.16	0.763	1.162	1.932	42.02	8.2399
	2.0	481.93	564.29	764.82	0.969	1.489	2.505	54.11	8.2301
	2.5	485.10	570.89	782.61	1.154	1.789	3.046	66.28	8.2209
	3.0	487.96	576.95	799.57	1.322	2.066	3.559	78.43	8.2123
	4.5	495.00	592.44	846.10	1.742	2.781	4.970	114.22	8.1895
	6.0	500.38	604.87	887.67	2.068	3.365	6.288	149.03	8.1700
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.13	0.28	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.29	0.000	0.000	0.001	0.01	-0.0002
	2.5	0.04	0.13	0.30	0.000	0.000	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.30	0.000	0.001	0.001	0.02	-0.0002
	4.5	0.04	0.13	0.30	0.000	0.001	0.002	0.03	-0.0001
	6.0	0.04	0.13	0.37	0.000	0.001	0.002	0.04	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.34	0.74	0.001	0.002	0.002	0.04	-0.0004
	2.0	0.12	0.35	0.77	0.001	0.002	0.003	0.06	-0.0004
	2.5	0.12	0.36	0.79	0.001	0.002	0.004	0.08	-0.0004
	3.0	0.12	0.36	0.82	0.001	0.003	0.004	0.10	-0.0004
	4.5	0.12	0.37	0.90	0.001	0.003	0.006	0.15	-0.0004
	6.0	0.12	0.38	0.98	0.002	0.004	0.009	0.22	-0.0005

Notes:

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

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986 through 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 5.4.2-11 and Table 5.4.2-12 show, projected future atmospheric CO_2 concentrations differ with varying climate sensitivities even under the same alternative, despite the fact that CO_2 emissions are fixed under each alternative.

Simulated atmospheric CO_2 concentrations in 2040, 2060, and 2100 are a function of changes in climate sensitivity. The small changes in concentration are due primarily to small changes in the aqueous solubility of CO_2 in ocean water: slightly warmer air and sea surface temperatures lead to less CO_2 being dissolved in the ocean and slightly higher atmospheric concentrations.

The response of simulated global mean surface temperatures under the GCAMReference scenario to variation in the climate sensitivity parameter varies among the years 2040, 2060, and 2100, as shown in Table 5.4.2-11. In 2040, the impact of assumed variation in climate sensitivity is low, due primarily to the limited rate at which the global mean surface temperature increases in response to increases in ERF. 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 under the GCAMReference scenario to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.2-11. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, sea-level rise is lower under the 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 0.15 centimeter (0.016 to 0.059 inch), depending on the assumed climate sensitivity.

The response of simulated global mean surface temperatures under the SSP3-7.0 scenario to variation in the climate sensitivity parameter similarly varies among the years 2040, 2060, and 2100, as shown in Table 5.4.2-12. 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 0.009°C (0.016°F) for the 6.0°C (10.8°F) climate sensitivity.

The sensitivity of the simulated sea-level rise under the SSP3-7.0 scenario to change in climate sensitivity and global GHG emissions mirrors that of global temperature and follows the same pattern under the SSP3-7.0 scenario as it does under the GCAMReference scenario. The reductions of sea-level rise under Alternative 3 compared to the No Action Alternative ranges from 0.04 to 0.22 centimeter (0.016 to 0.087 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 internal combustion engine (ICE) passenger car and light truck use based on literature reviewed. 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 various levels of CAFE 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 the different types of fuels used by passenger cars and light trucks.
- Section 6.3, *Vehicle 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.

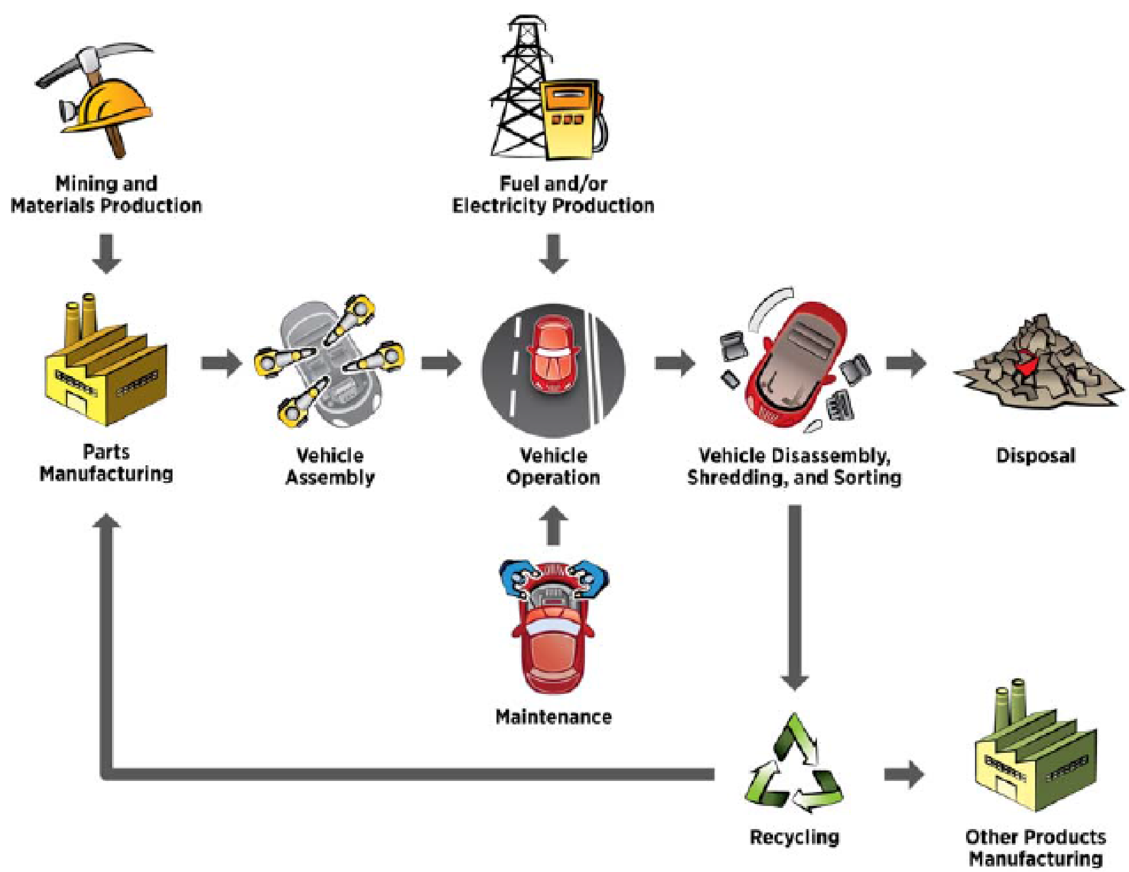
6.1.1 Life-Cycle Assessment for Vehicles

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

[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 2021). 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). NHTSA included additional studies in this Final SEIS based on comments received on the Draft SEIS.

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.[3] 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.[4]

According to the AEO 2021, gasoline (including ethanol used in gasoline blending) 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.[5]

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

Fuel	2020 (%)	2050 (%)
Gasoline (including ethanol blending)	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[6] and increased investment in the expansion of vehicle charging

[3] The Docket for the SEIS includes an Excel workbook that shows how values reported in this chapter reflect separate AEO 2021 tables for Energy Supply and Disposition, Energy Consumption by Sector and Source, and Renewable Consumption by sector and source (NHTSA-2021-0054-007, file name "Draft SEIS Energy Figures based on 2021 AEO"). The data presented in this chapter do include electricity losses, again in order to provide supply and demand values that are comparable. The British thermal unit (Btu) amounts used in electricity generation include electricity losses because those losses are part of the supply Btus (coal, natural gas, etc.) used to deliver electricity for consumption.

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

[5] 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 final rule and in Section III.C of the final 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.

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

infrastructure.[7] NHTSA's CAFE Model projects that the share of total light-duty vehicles running on electricity only (i.e., dedicated EVs) will increase from 5.7 percent in the No Action Alternative to 11.9 percent in Alternative 3 in 2050.

This section synthesizes life-cycle findings on fuel sources for passenger cars and light trucks in Section 6.2.1, *Diesel and Gasoline*; Section 6.2.2*, Natural Gas*; Section 6.2.3, *Electricity*; Section 6.2.4, *Biofuels*; and Section 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 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).

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[7] 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/.

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[8] per megajoule of energy (g CO_2e/MJ), respectively, from *in situ* extraction of oil sands in Alberta. For comparison, emissions related to soil carbon stock changes and biomass removal are 50 percent and 5 percent lower, respectively, for crude oil extraction in Alberta (Yeh et al. 2010).

Additionally, oil sands extraction, production, and transport can present other environmental impacts. For example, open pit mining of oil sands can lead to water contamination, referred to as oil sands process-affected water (OSPW). Release of OSPW is not permitted in Alberta and many studies have attempted to evaluate the toxicity levels of OSPW, identifying the most toxic compounds to be naphthenic acids and acid-extractable organics (Li et al. 2017). Studies have shown these compounds to have damaging effects on fish and crustaceans, and a chemical study of an aged OSPW sample (i.e., OSPW that had been stored in a constructed pond since 1993) found chloride and copper levels above Canadian Council of Minister of the Environment and EPA water quality guidelines (Bauer et al. 2019). Transportation of crude oils extracted from oil sands via pipeline, rail, or barge also can present serious threats of fire, death, and damage to the environment when incidents of spills occur given the toxic and flammable qualities of these oil sands-derived crude oils (Walker et al. 2016).[9] While emissions from accidents are impactful, they are infrequent and are not usually considered in an LCA (EPA 2006); however, these risks should be considered when assessing oil sands extraction and production.

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 (65.8 percent), totaling 7.54 million barrels per day (EIA 2021a).

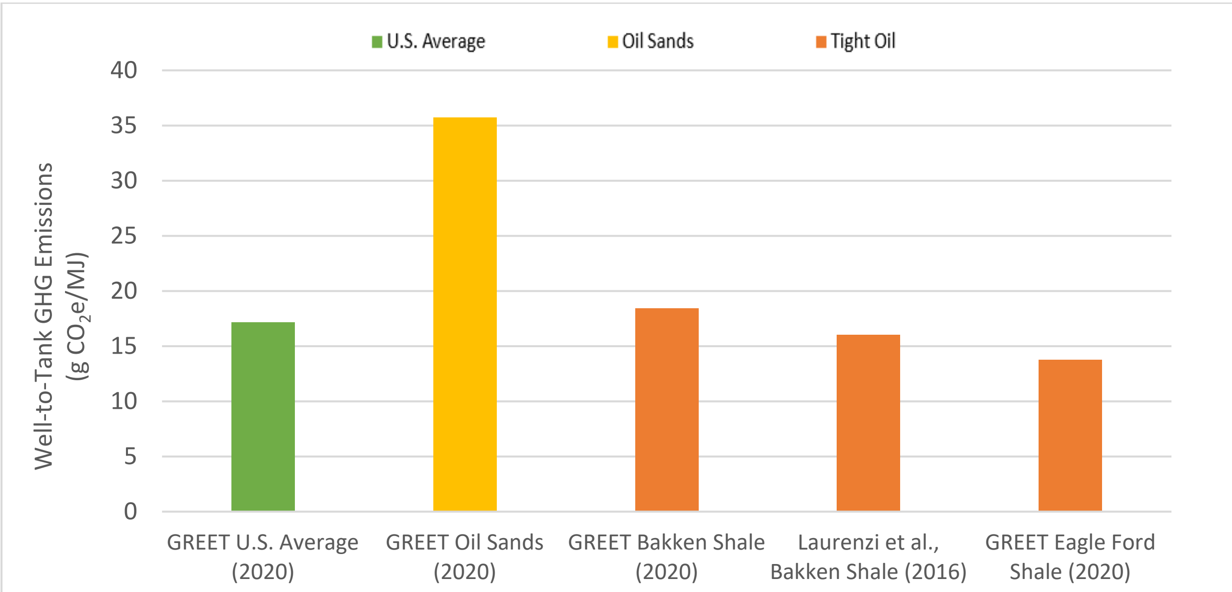
Argonne National Laboratory's GREET model provides a snapshot of life-cycle GHG impacts associated with international and domestic conventional petroleum-based fuel pathways. In the model's updates in 2015 and 2020, researchers updated the refinery efficiencies and included values for Canadian oil sands and domestic tight oil from shale based on research at Stanford University and the University of California, Davis (ANL 2021; Englander and Brandt 2014; Ghandi et al. 2015; Brandt et al. 2015). GREET's 2021 version uses EIA projections for crude oil supplies to generate a default average (77 percent

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

[9] ExxonMobil's "Pegasus Pipeline" that transported heavy crude oil from sands in Alberta ruptured near Mayflower, Arkansas, in 2013, leading to the evacuation of 62 homes and devastation to the surrounding wildlife. Possibly the worst example of the risks of heavy crude oil transport is the tragedy in Lac-Megantic, Quebec, when a runaway transport train derailed and led to a massive fire, leading to 47 deaths in 2013 (Walker et al. 2016).

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).[10]

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

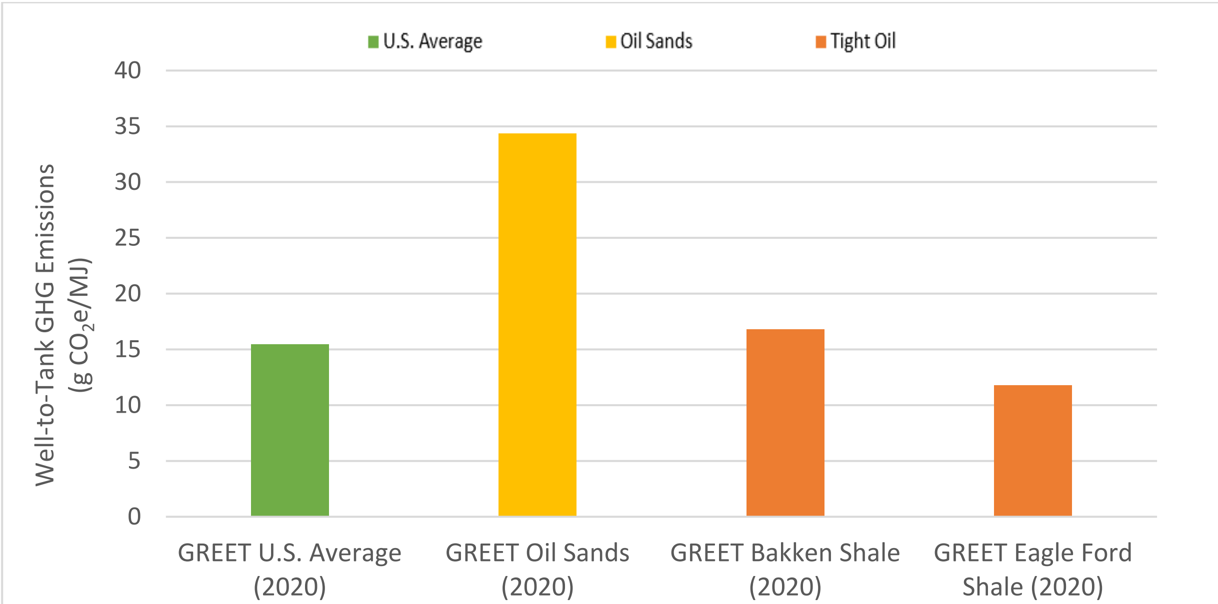


Source: ANL 2021; Laurenzi et al. 2016
GHG = greenhouse gas; g CO_2e/MJ = grams of carbon dioxide equivalent per megajoule; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

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 2021 simulation of refining processes.

[10] 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.

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



Source: ANL 2021

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	<0.001	75.0
Gasoline	72.7	0.003	0.001	73.0

Notes:

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

Source: ANL 2021

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 2021; 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

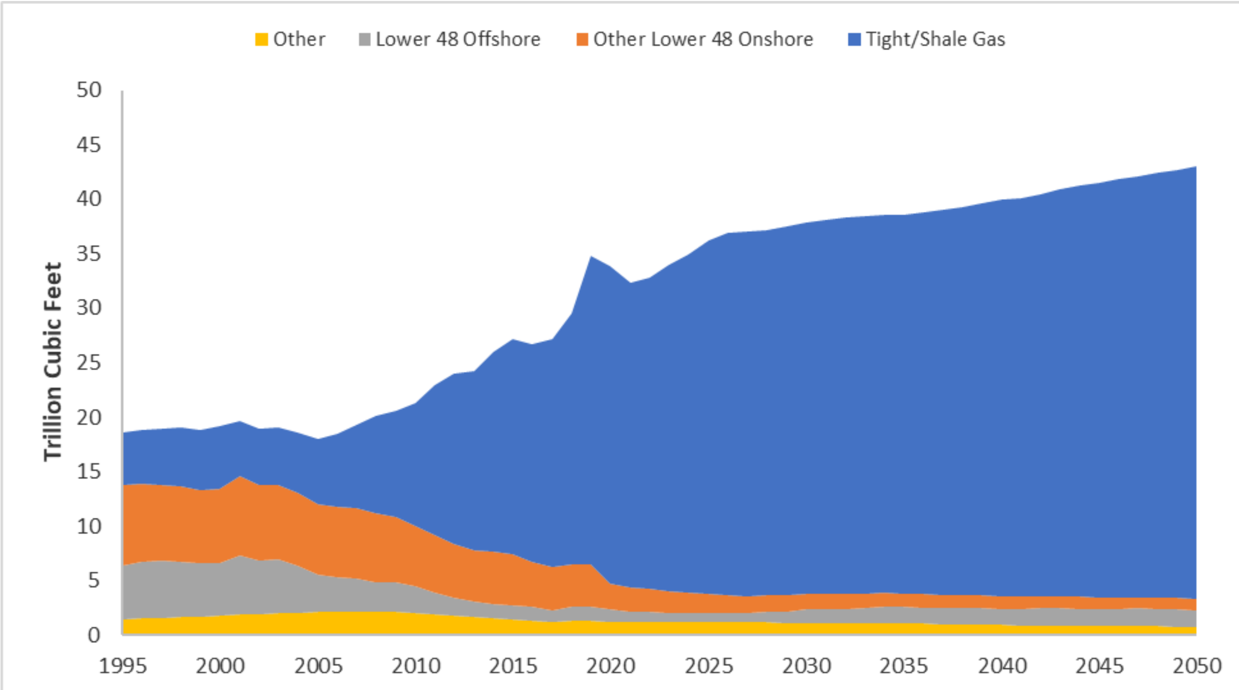
Natural gas can be used in vehicles in compressed or liquid forms. It is also a fuel used for electricity generation that in turn can power EVs. In 2020, natural gas represented 0.02 percent of the total fuel supplied for direct use in passenger cars and light trucks. This share is projected to remain steady through 2050 (EIA 2021a).[11] However, natural gas has recently become a significantly larger portion of U.S. electricity generation—reaching 40.3 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 (final rule preamble, Tables V-19 through V-36), 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).

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 (final rule preamble, Section III.C.7). When substituted for coal to produce heat or electricity, natural gas has lower emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Moore et al. 2014).

[11] 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.

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



Source: EIA 2021a

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 2021c). 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 2021c). Natural gas systems are currently the largest source of anthropogenic methane emissions in the United States (EPA 2021c). 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 2021c). 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[12] 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 2021c).
- **Processing (natural gas).** Raw natural gas is composed of methane as well as other impurities. To prevent pipeline corrosion, these impurities must be removed before the natural gas can be transported and serve its end-use purpose. At processing facilities, the natural gas is separated from the other constituents of the raw gas. This requires maintaining certain levels of pressure during processing, and during the processing stage methane emissions arise mainly from compressors (EPA 2021c).
- **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 2021c).
- **Distribution (natural gas).** During distribution, natural gas is emitted mainly from the gate stations and pipelines (EPA 2021c).

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 2021c).

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

[12] 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).

about 5.4 percent of total production and 6.1 percent of transmission and distribution (EPA 1995a, 2021a; IPCC 2006; EIA 2019a, 2019b).

The GREET model used to evaluate emissions from vehicles that use natural gas in their production or use phases also incorporates two other sources of methane emissions related to vehicle use. First, GREET includes the natural gas used during the process of crude oil production and refining, especially in the processes of heating refineries and providing the energy necessary to produce the hydrogen gas needed to transform oil hydrocarbons into the preferred hydrocarbon form for use, called "cracking" (EPA 2015b; EIA 2021e). In 2020, domestic oil refineries used over 972 billion cubic feet of methane, which was a 14 percent increase from 2015 (EIA 2021e). The GREET model also includes emissions from escaped methane from pipeline leaks in its calculations (Burnham 2021).

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 ICE vehicles. 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 emissions 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.[13] Note that the low and high results for Heath et al. (2014) reflect the 25th and 75th percentiles and maximum and minimum values for Weber and Clavin (2012). A more recent LCA of shale gas produced from the Marcellus shale formation found upstream GHG emissions to be 28 g CO_2e/MJ, or about 20 percent of total life-cycle emissions, similar to the results of Heath et al. (2014) (Laurenzi 2015).

Table 6.2.2-1. Results Summary for Upstream Shale Gas LCA Literature Reviews

LCA Literature Review	Shale Gas (g CO_2e/MJ Generated)			Conventional Gas (g CO_2e/MJ Generated)		
	Low	**Median**	**High**	**Low**	**Median**	**High**
Heath et al. (2014)	18	25	39	11	19	22
Weber and Clavin (2012)	8	15	27	5	16	18

LCA = life-cycle assessment; g 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, NO_X, sulfur oxides, and particulate matter 2.5 or 10 microns or less 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).

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

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 2021, 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

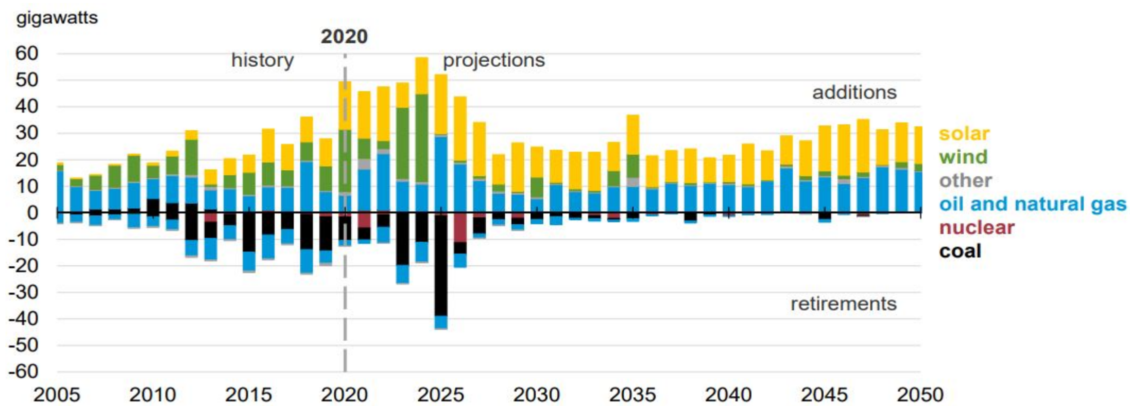
Electricity currently makes up 0.1 percent of light-duty vehicle fuel use, but the AEO 2021 projects this proportion to increase to 2.8 percent by 2050, representing the largest share of fuel consumption outside of gasoline (EIA 2021a). Current U.S. policies expanding the federal EV fleet and improving vehicle charging infrastructure are anticipated to drive this number higher. NHTSA's CAFE Model projects that by 2050, the share of total light-duty vehicles running on electricity only (i.e., dedicated EVs) will increase from 5.7 percent in the No Action Alternative to 11.9 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, *Electric 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 (Bieker 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).

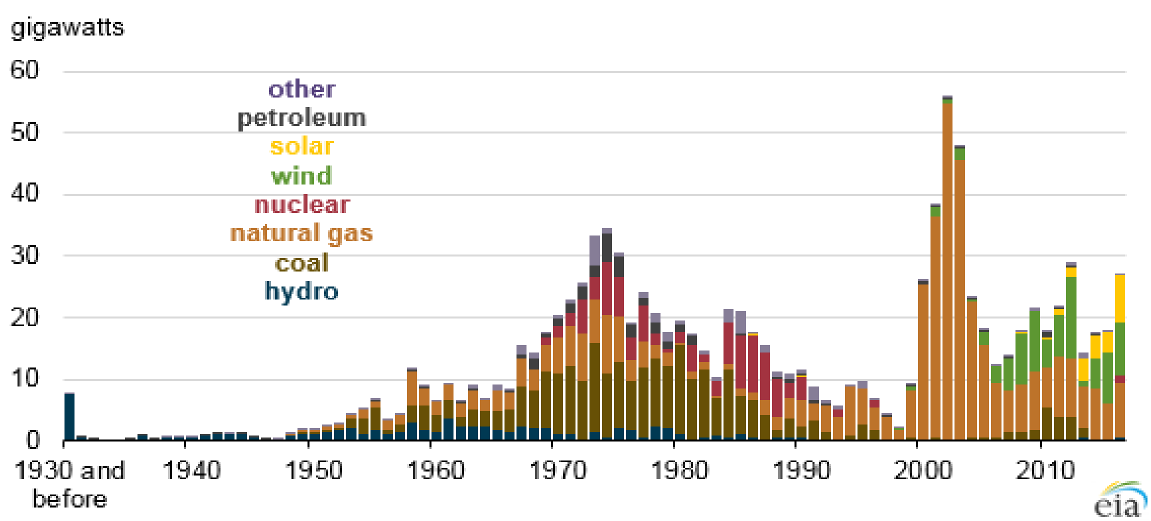
Figure 6.2.3-1 shows that oil, natural gas, wind, and solar power accounted for most electricity capacity additions from 2005 through 2020, and coal power plants accounted for most power plant retirements. Figure 6.2.3-2 shows that natural gas power plants also accounted for most of the capacity additions 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.

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



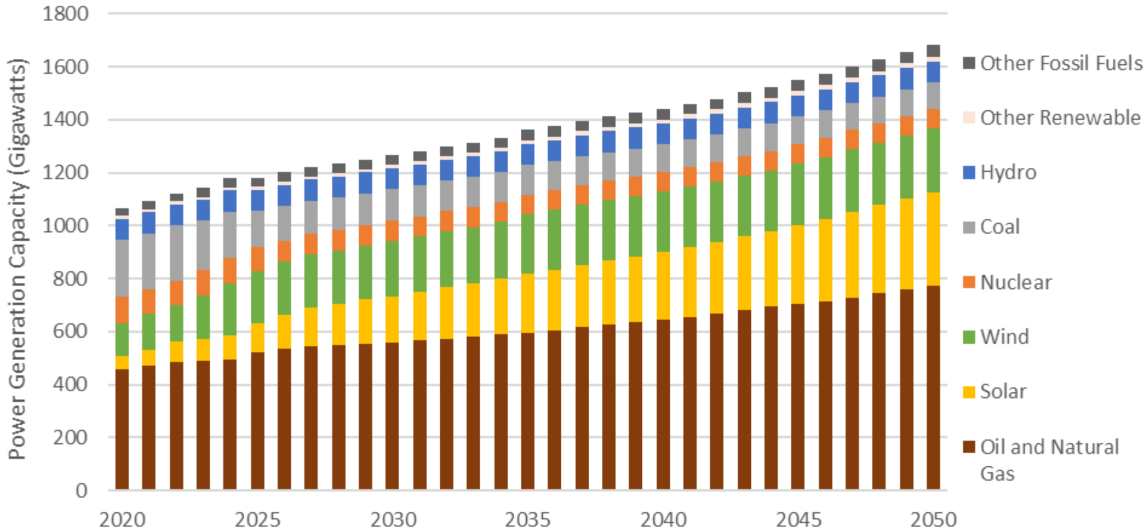
Source: EIA 2021a

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 CAFE Model projects that EVs will comprise a growing share of manufacturers' vehicle fleets in future years and particularly in Alternatives 2, 2.5, and 3. As shown in Table 6.2.3-1, Alternatives 2, 2.5, and 3 would result in significantly higher penetration of EVs in the light-duty vehicle fleet (9.6, 10.6, and 12.2 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. 2.5	Alt. 3
PHEVs	**0.18%**	**0.32%**	**0.28%**	**0.32%**	**0.32%**
PHEV20: 20-mile PHEV with HCR Engine	0.11%	0.22%	0.22%	0.26%	0.25%
PHEV20T: 20-mile PHEV with Turbo Engine	0.06%	0.09%	0.07%	0.07%	0.07%
Dedicated EVs	**5.7%**	**6.8%**	**9.3%**	**10.3%**	**11.9%**
BEV200: 200-mile EV	2.8%	3.5%	3.7%	3.8%	4.0%
BEV300: 300-mile EV	2.6%	3.1%	5.3%	6.2%	7.6%
BEV400: 400-mile EV	0.3%	0.3%	0.3%	0.3%	0.3%
Total for PHEVs and Dedicated EVs	**5.9%**	**7.1%**	**9.6%**	**10.6%**	**12.2%**

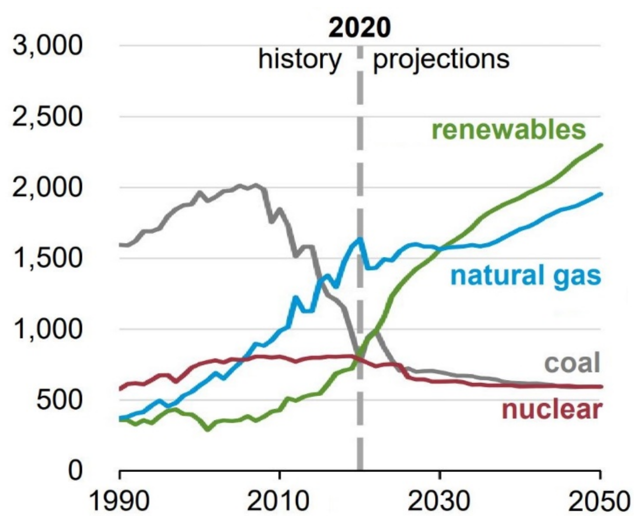
Notes:
For BEV200, BEV300, and BEV400, the number refers to the EV's mileage driving range.
PHEV = plug-in hybrid electric vehicle; EV = electric vehicle; BEV = battery electric vehicle

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 (EIA 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 2007 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).

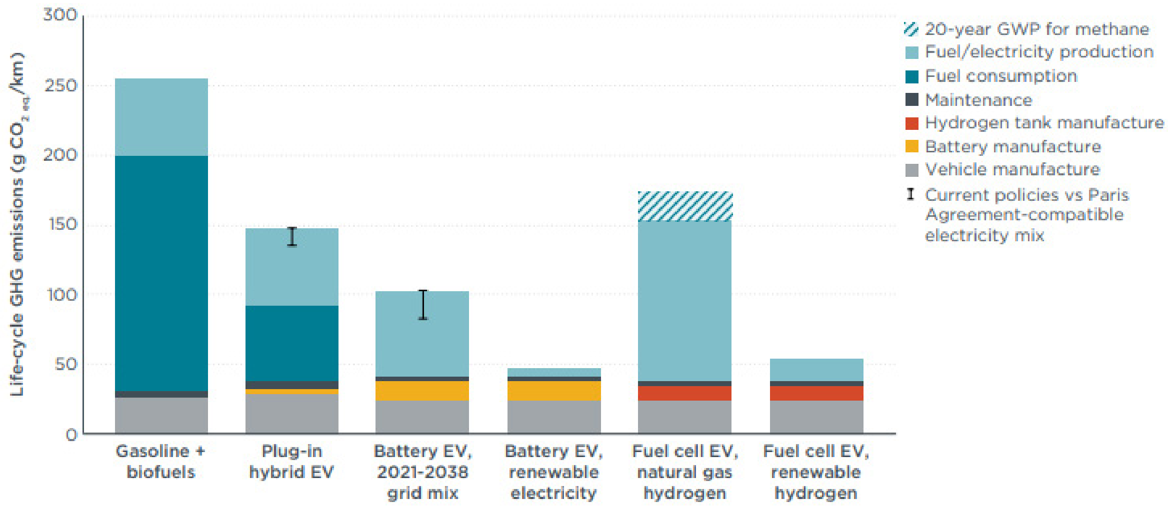
Figure 6.2.3-4. Net Electricity Generation by Source (1990 to 2050)



Source: EIA 2021a

Figure 6.2.3-5 shows the relative contributions of these phases to life-cycle EV GHG emissions for cars operating in the United States in 2021, including variations for PHEVs and BEVs, and hydrogen fuel cells made using both natural gas and renewable sources from a report by the International Council on Clean Transportation (Bieker 2021). 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 (Bieker 2021; Gaines et al. 2011; Notter et al. 2010).

Figure 6.2.3-5. Life-Cycle GHG Emissions of Electric Vehicles Registered in the United States in 2021



Source: Bieker 2021
GHG = greenhouse gas; GWP = global warming potential; CO_2 = carbon dioxide; EV = electric vehicle;.

Increased market penetration of EVs also likely offer 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 significant reductions in 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.

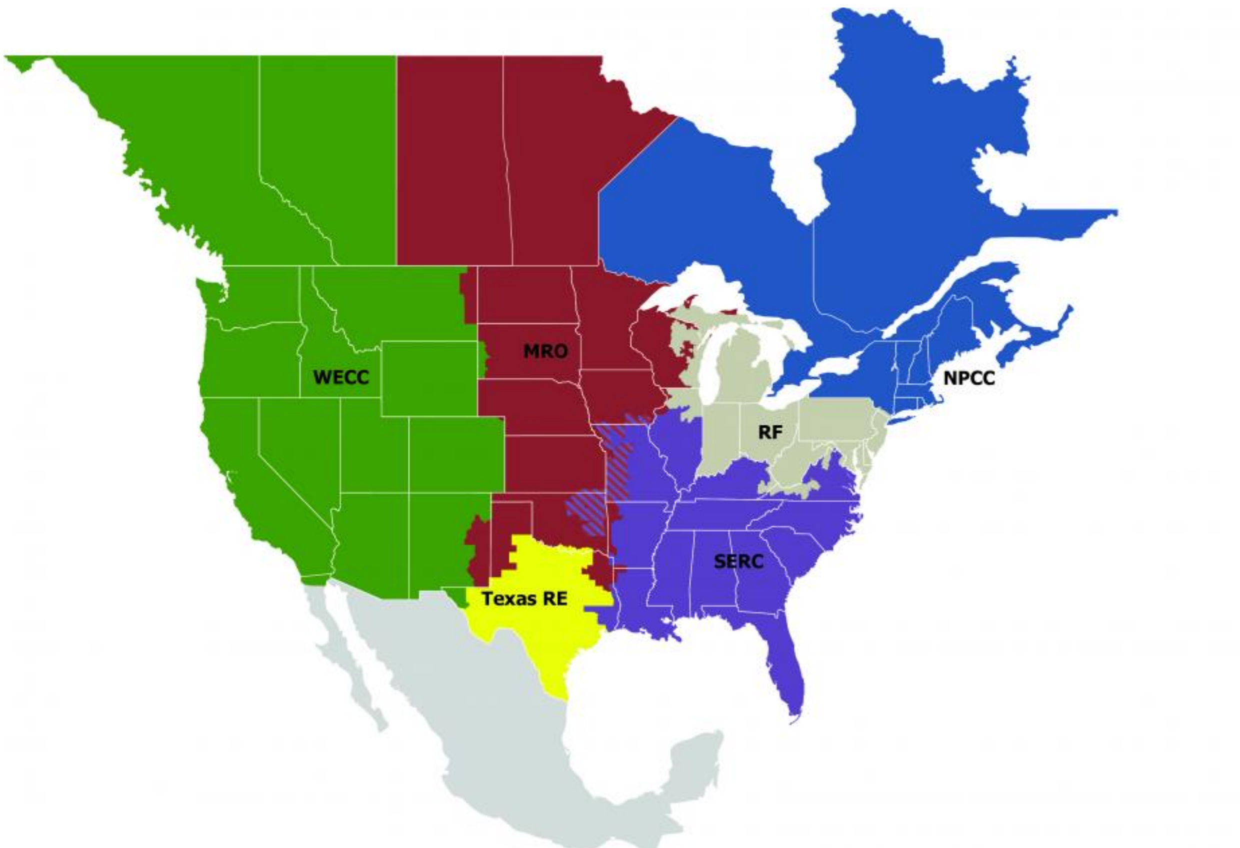
This section focuses on EV operations (i.e., use phase) and the associated life-cycle environmental impacts. This primarily consists of examining the dynamics of EV electricity consumption, including location and time of consumption. Electricity generation sources are the drivers of EV operation impacts. 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, *Electric 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, *Electric Vehicle Batteries*.

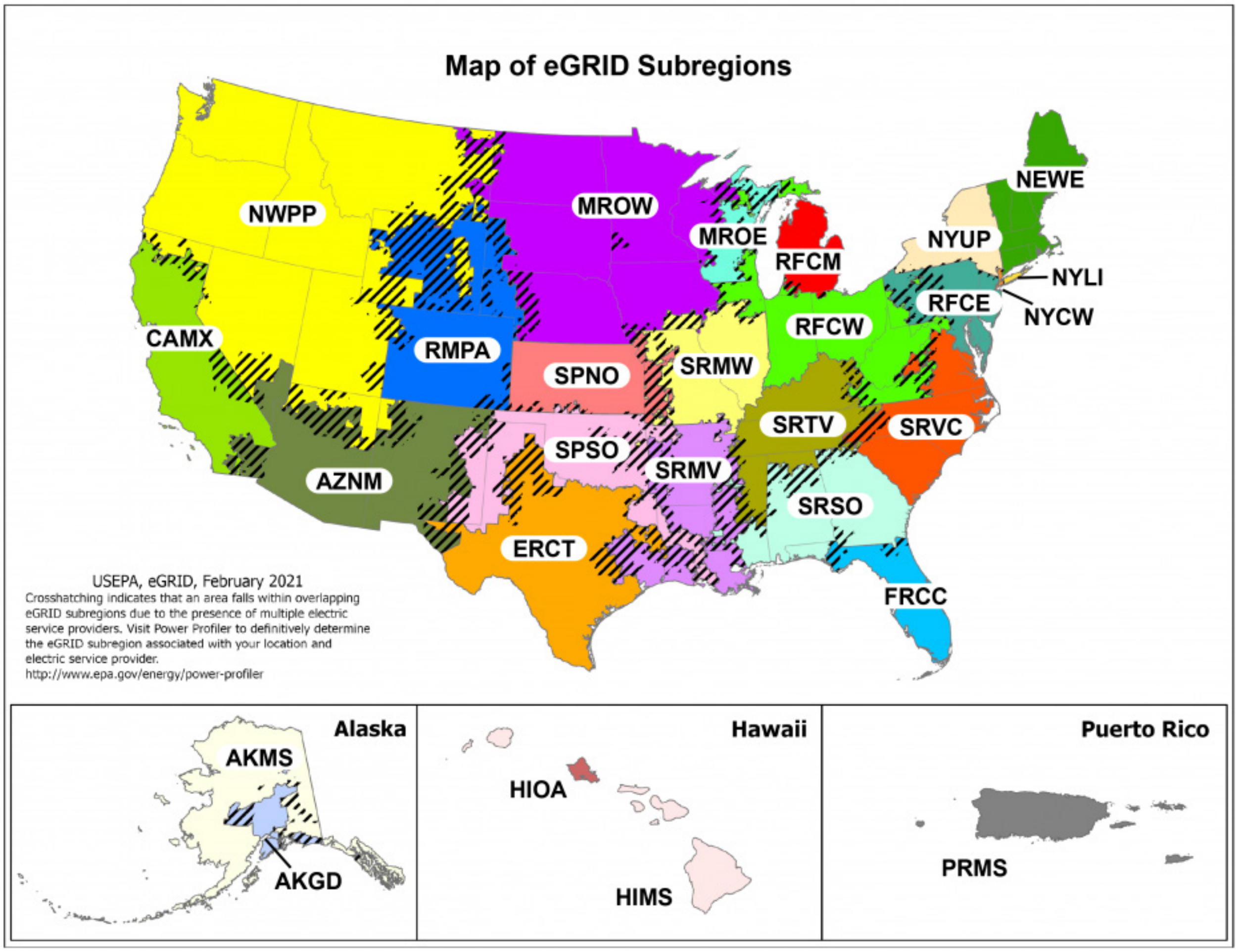
In the United States, the grid mix consists of coal, natural gas, nuclear, hydroelectric, oil, and renewable energy sources. The relative proportions of these components can be analyzed by regions, including National Electricity Reliability Commission (NERC) regions (Figure 6.2.3-6) and EPA Emissions & Generation Resource Integrated Database (eGRID) subregions (Figure 6.2.3-7), which are based on energy transmission, distribution, and utility territories to analyze the environmental aspects of power generation. 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, as of 2019, 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

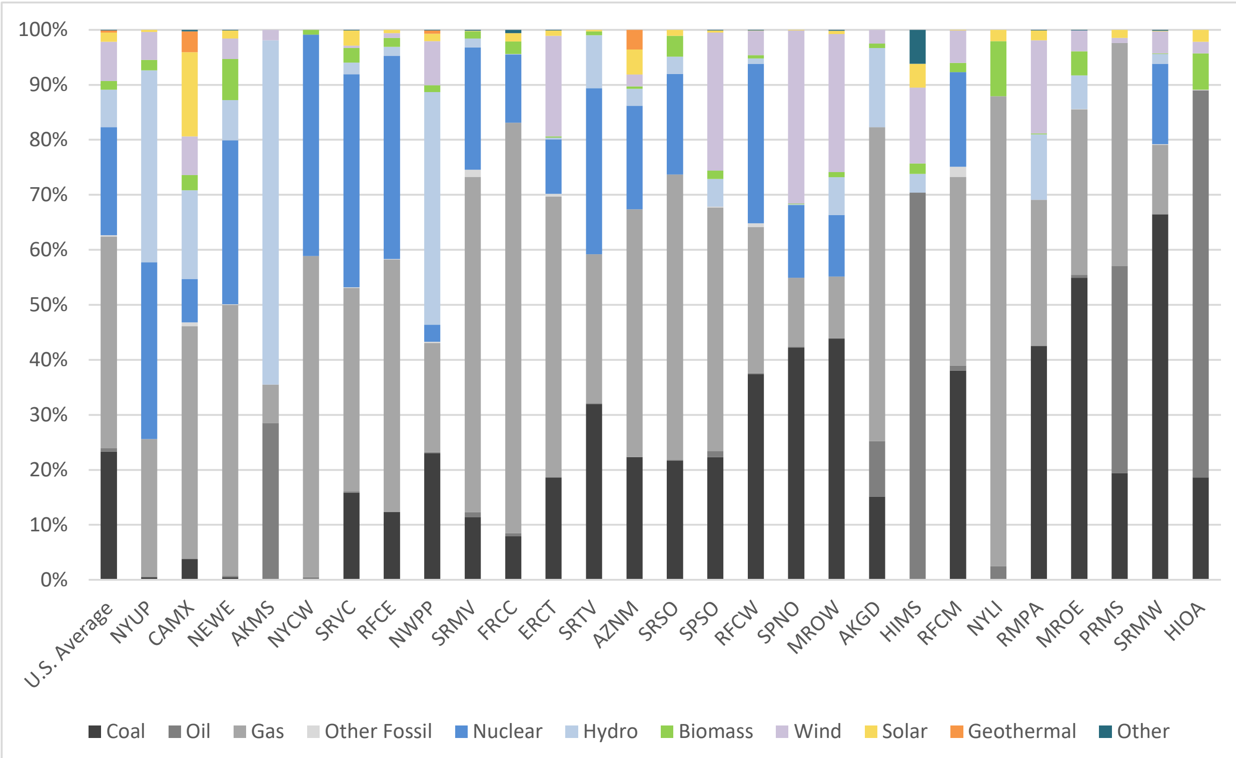
Figure 6.2.3-7. Environmental Protection Agency eGRID Subregions



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

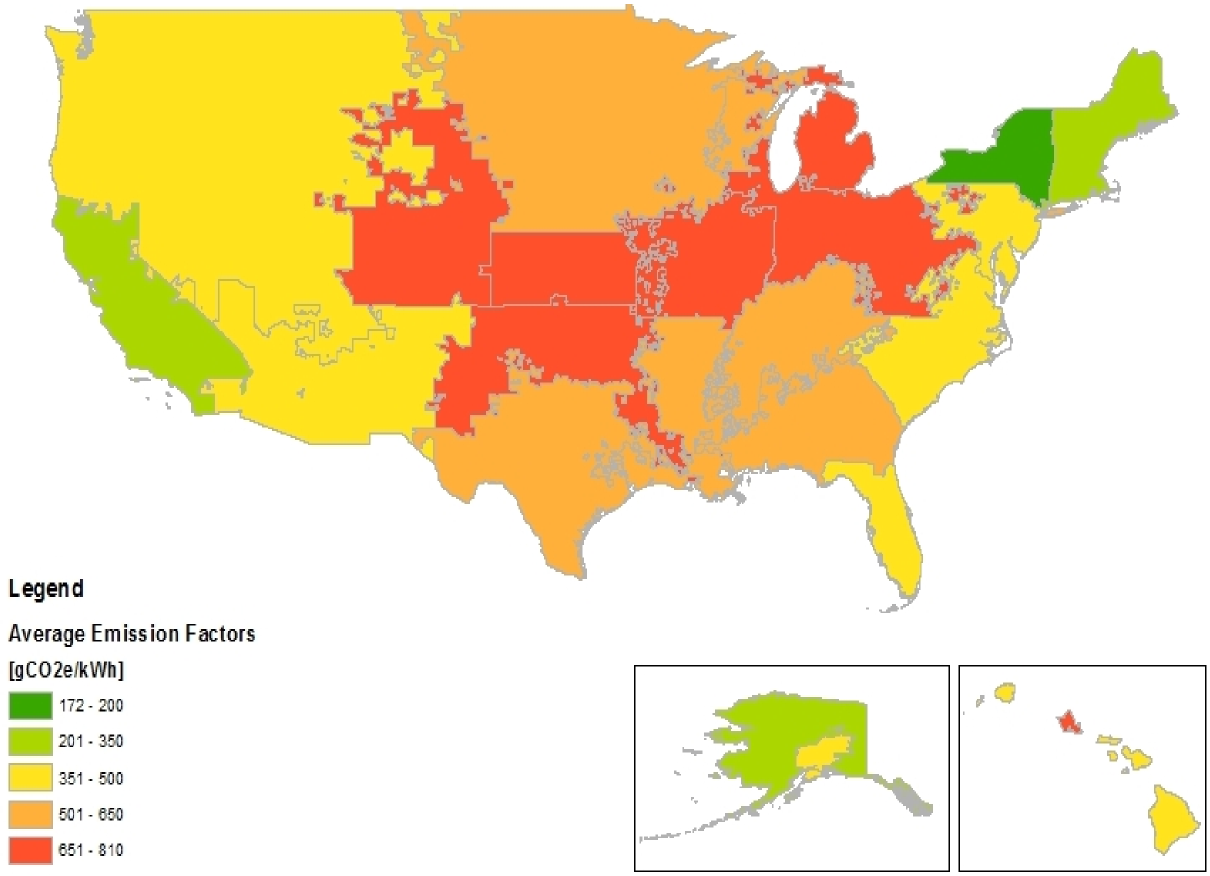


Source: EPA 2021g

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. In recent years, the U.S. electricity grid has become much less carbon-intensive overall. The CO_2 emission rates for most eGRID subregions have declined by more than 20 percent between 2012 and 2019 (EPA 2015c, 2021g).

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

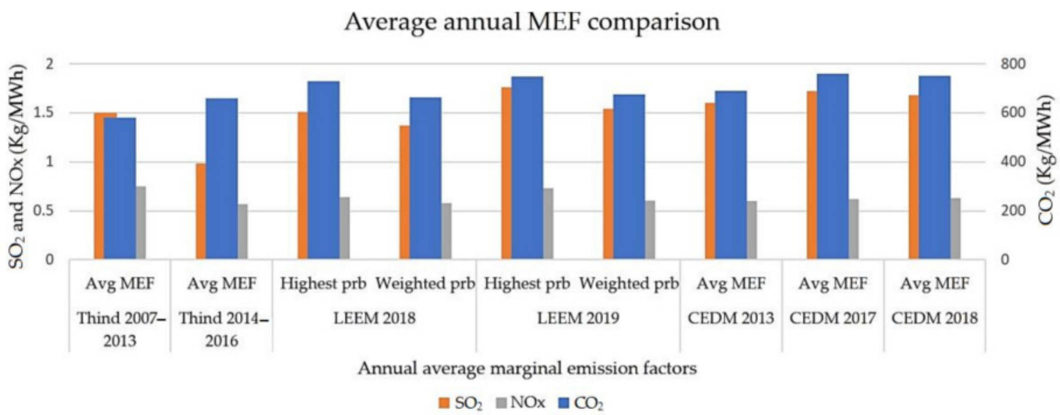


Source: EPA 2021h
eGRID = Emissions & Generation Resource Integrated Database; g CO_2e/kWh = grams of carbon dioxide equivalent per kilowatt –hour

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 emissions 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), as potentially resulting from additional EV penetration. 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. There is a lack in recent (2018 or later) LCA studies projecting MEFs in the upcoming years. A recent study by Kamjou et al. (2021), however, illustrates average annual MEF comparisons, using different methodologies, for the U.S. electrical grid data in 2013, as shown in Figure 6.2.3-10. In this figure, different MEF calculations methodologies are compared to demonstrate the fluctuation in the concept of an MEF, and this fluctuation, along with the unreliability of MEF projections in future years, is part of the reason why recent LCA studies have moved away from using MEFs as a standard indicator.

Figure 6.2.3-10**. Methodological Differences in Calculating MEFs for 2013 U.S. Electric Grid**



Source: Kamjou et al. 2021

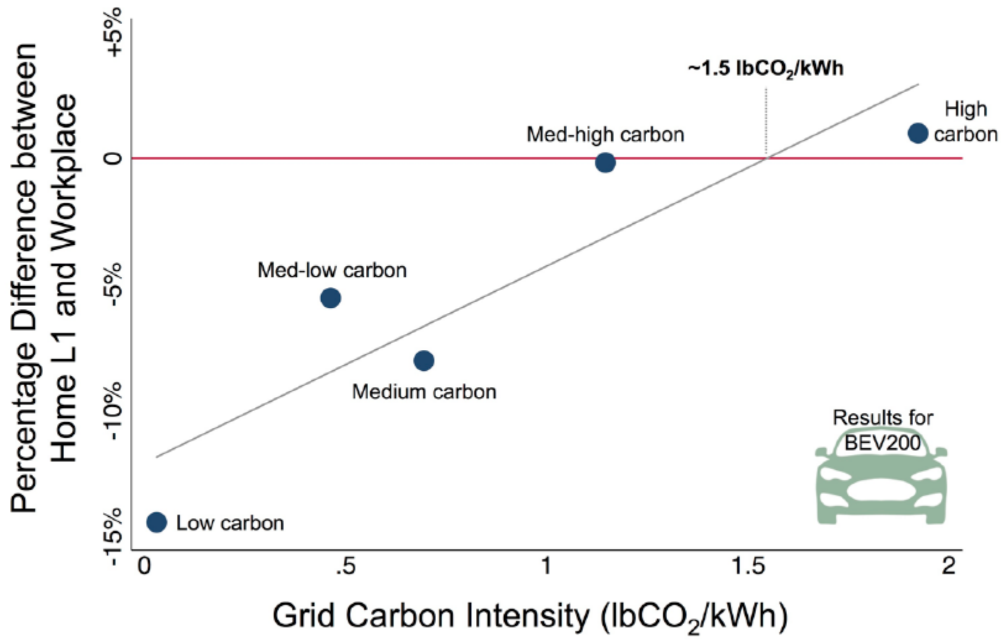
Electricity grid mix also plays a substantial role in EV life-cycle air pollution outside of GHG emissions. EV electricity consumption is a main driver of life-cycle particulate matter, sulfur oxides, and NO_X emissions, as well as ozone formation (Weis et al. 2016; Tessum et al. 2014; Hawkins et al. 2013). Carbon-intensive grid mixes, primarily those that are reliant on coal, create significantly higher particulate emissions and ozone formation potential than conventional 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, NO_X, 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).

A 2016 NREL study performed an analysis of anticipated emissions resulting from BEVs and PHEVs for four charging scenarios and five electricity profiles, and the main conclusion of the study was that vehicle use-phase emissions are highly dependent on the percentage of fossil fuels in the grid, and that restricting charging to off-peak time results in higher total emissions for all vehicle types, in comparison to other charging scenarios (NREL 2016). The methodological approach used in the NREL study presents a more comprehensive LCA study by accounting for owner behavioral change assumptions relating to using the different vehicle categories (ICE, BEVs, and PHEVs) in different scenarios. The NREL methodology takes into account the most probable composition of the total on-road fleet, and their apportioned shares of the total vehicle miles traveled.

This 2016 NREL study concludes that regions with grids that are more carbon intensive will experience greater emissions reductions associated with EVs by focusing on reducing the carbon intensity of the electricity grid, rather than focusing efforts on charging behaviors, as illustrated in Figure 6.2.3-11.

Figure 6.2.3-11. Percentage Difference in Emissions between Home and Workplace Charging Scenarios as a Function of Grid CO_2 Intensity

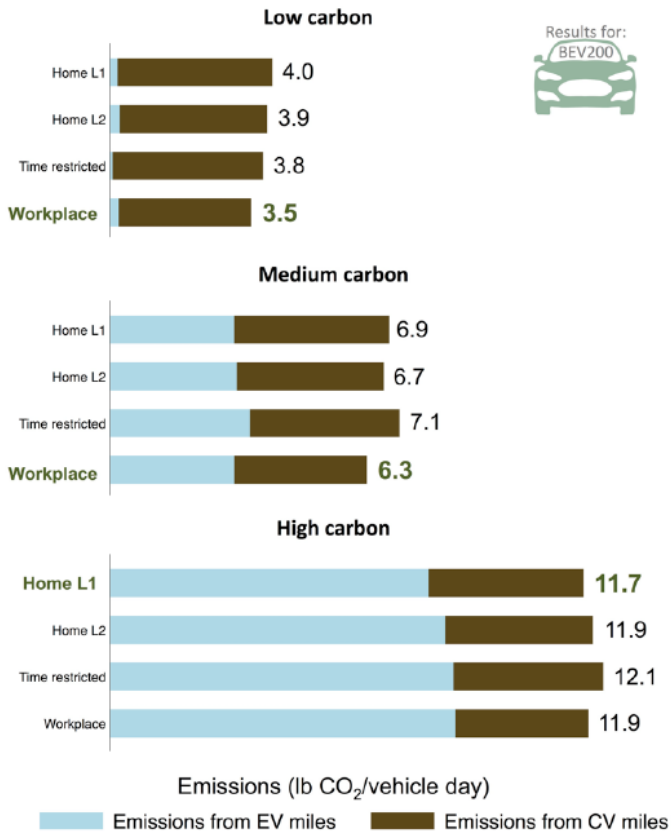


Source: NREL 2016

Another factor emphasized by the 2016 NREL study on EV charging emissions variability is that the availability of daytime charging increases the percentage of miles that PHEVs drive on electricity and results in greater petroleum displacement. However, emissions reduction benefits of workplace charging diminish as the CO_2 intensity of the grid increases. Of all charging scenarios evaluated, the time-restricted charging results in the lowest number of electric miles and the highest level of emissions for most grids and vehicle types. Emissions savings can be greater for PHEVs (than for BEVs) when the grid carbon intensity is high, due to the relative efficiencies of the vehicles. BEVs have more electric miles overall; however, the efficiency of the ICE vehicle used by BEV owners when they are unable to use their EV is 40.8 miles per gallon (NREL 2016) compared to a PHEV efficiency of 66.8 miles per gallon in gasoline mode. In other words, the carbon intensity of the BEV non-electric miles is higher than the intensity of the PHEV non-electric miles. These conclusions are based on the assumption that the non-electric miles calculated in the study are made by EV owners driving ICE vehicles for trips unable to be made in a BEV.

Based on the 2016 NREL Study, a BEV using time-restricted charging on a high-carbon grid results in the highest level of emissions, and a BEV using workplace charging on a low carbon grid provides the greatest emissions reductions (Figure 6.2.3-12). Reducing grid mix carbon intensity reduces both GHG and criteria pollutant emissions for the EV use phase.

Figure 6.2.3-12. Total Emissions for a BEV200 for All Charging Scenarios and Three Electricity Grids



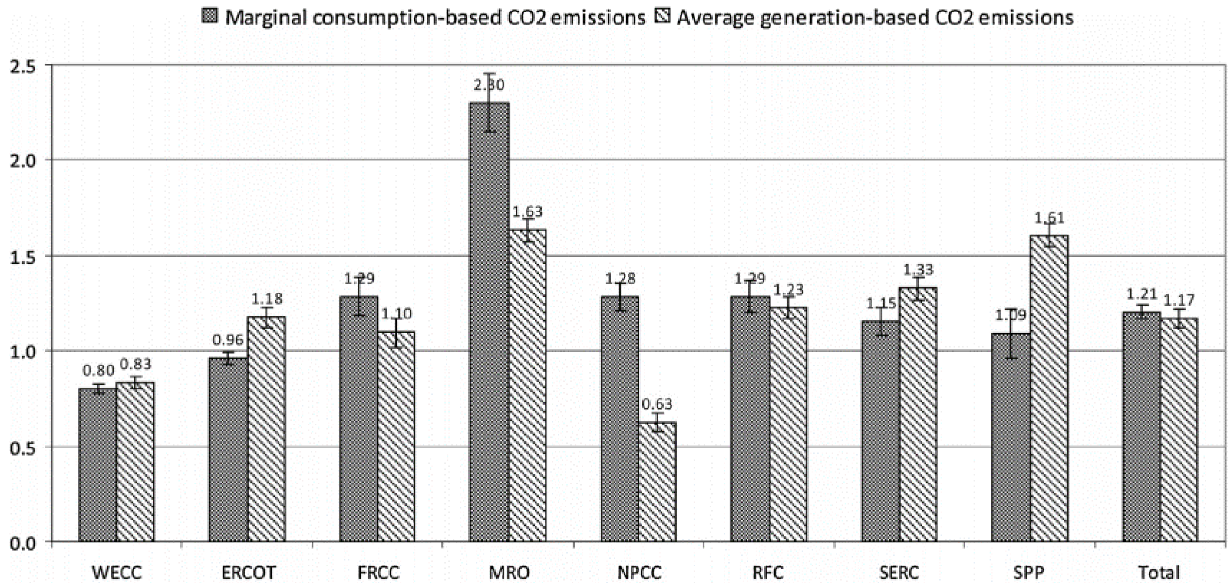
Source: NREL 2016

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 emissions 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 6.2.3-13 (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 6.2.3-13. Marginal Emission Factors and 95 Percent Confidence Intervals versus Average Emission Factors by National Electricity Reliability Commission Region

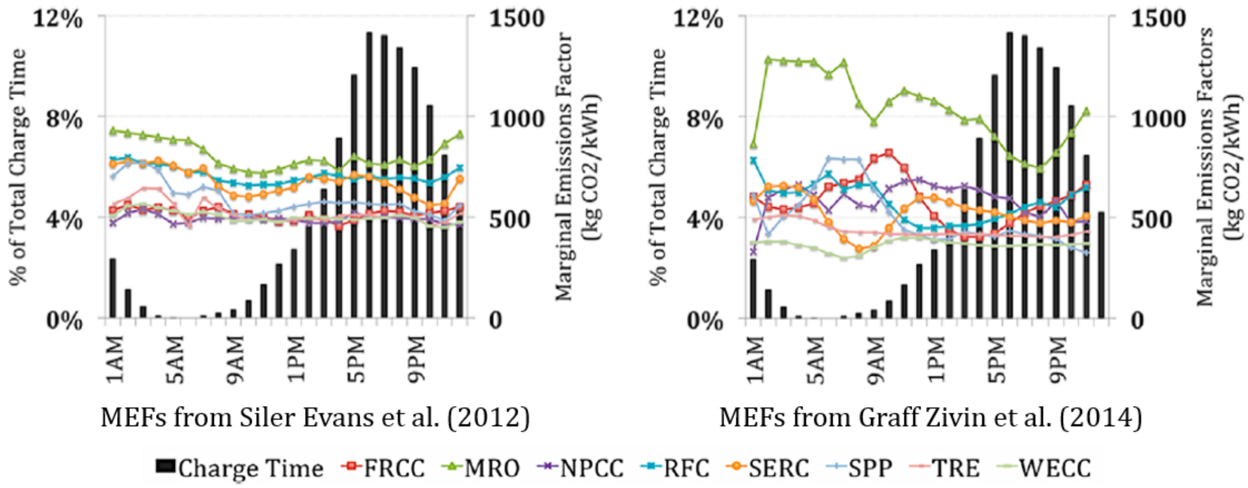


Source: Zivin et al. 2014

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 6.2.3-14). 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 6.2.3-14) with diurnal MEF estimates for NERC regions (colored plots in Figure 6.2.3-14) 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.

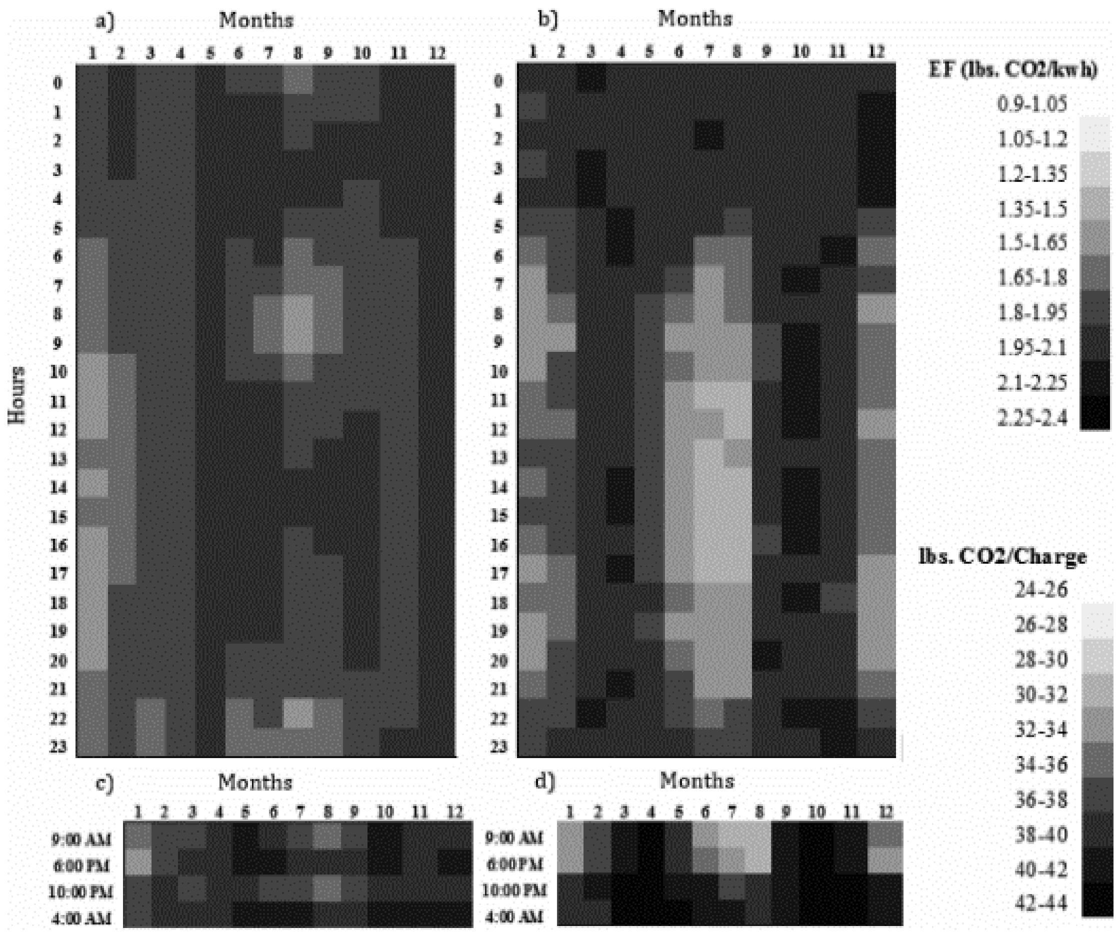
Figure 6.2.3-14. Convenience Charging Profile [a] and Hourly Marginal Emission Factors [b] by National Electricity Reliability Commission Region [c]



Notes:
[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)
Source: Tamayao et al. 2015
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 6.2.3-15 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 6.2.3-15. Hourly and Monthly Carbon Dioxide Emission Factors and Emissions from Electric Vehicle Charging [a, b, c, d]



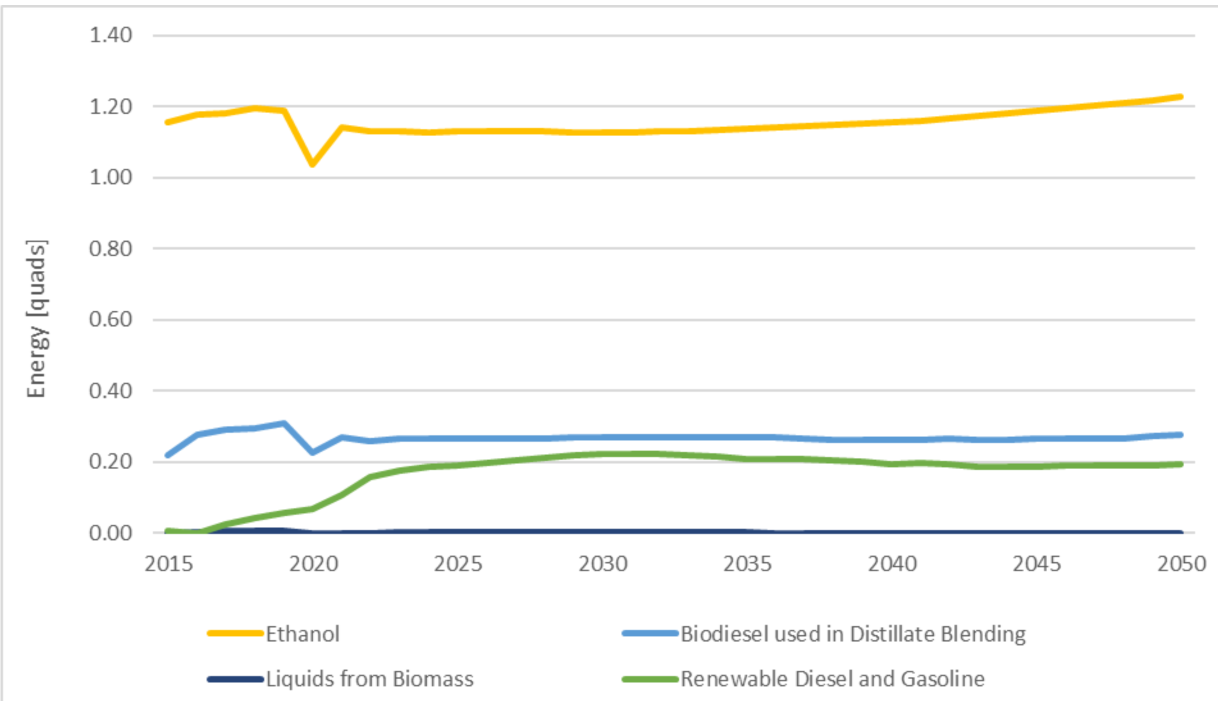
Notes:
[a] MISO MOIL region emission factors estimated through PLEXOS
[b] Upper Midwest (WMW) region emission factors estimated through AVERT
[c] MISO MOIL emissions per charge (PLEXOS)
[d] Upper Midwest (WMW) emissions per charge (AVERT)
Source: Ryan et al. 2016
EF = emission factor; lbs/CO_2/kWh = 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[14] established the Renewable Fuel Standard, which was expanded by the Energy Independence and Security Act of 2007.[15] The Renewable Fuel Standard requires that transportation fuel contain a certain volume of four categories of biofuel: biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel. By 2022, the program mandates the production of 36 billion gallons of total renewable fuel. 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, renewable diesel, gasoline, and liquids from biomass.

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.

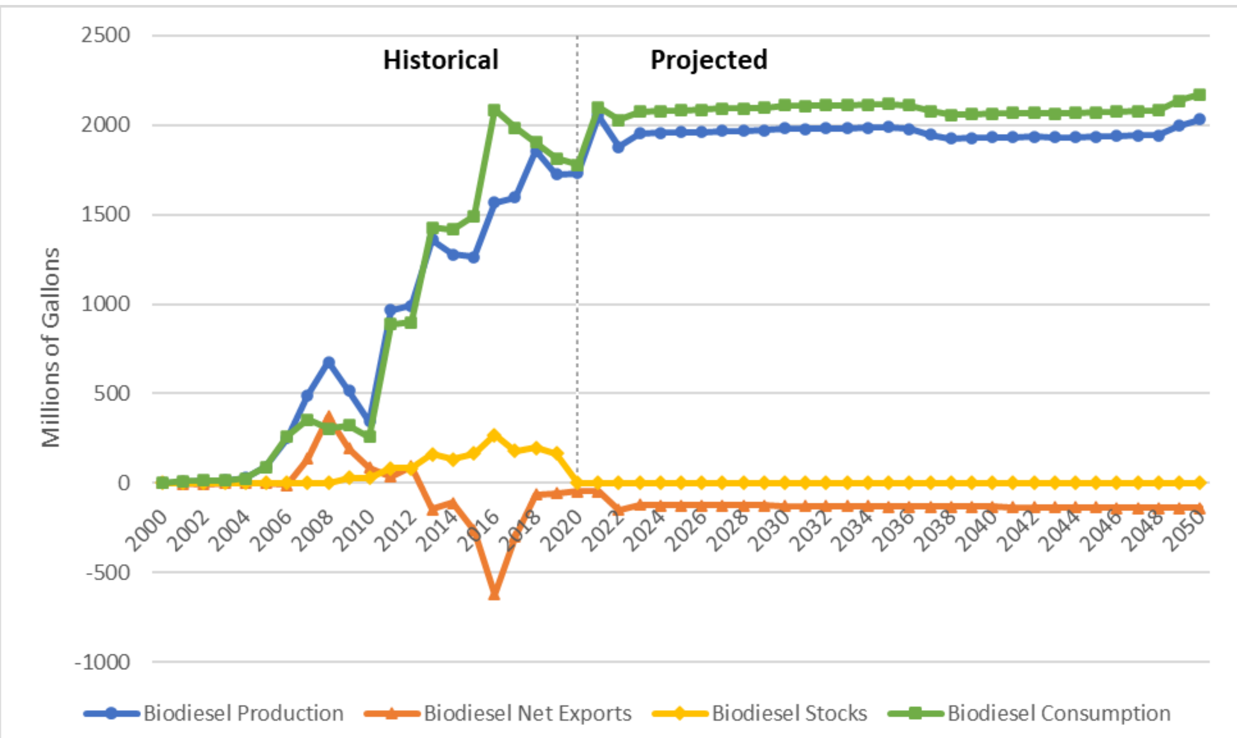
[14] Pub. L. No 109–58, 119 Stat. 594 (Aug. 8, 2005).

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

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



Notes:
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.
Source: EIA 2021a, 2021f

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).

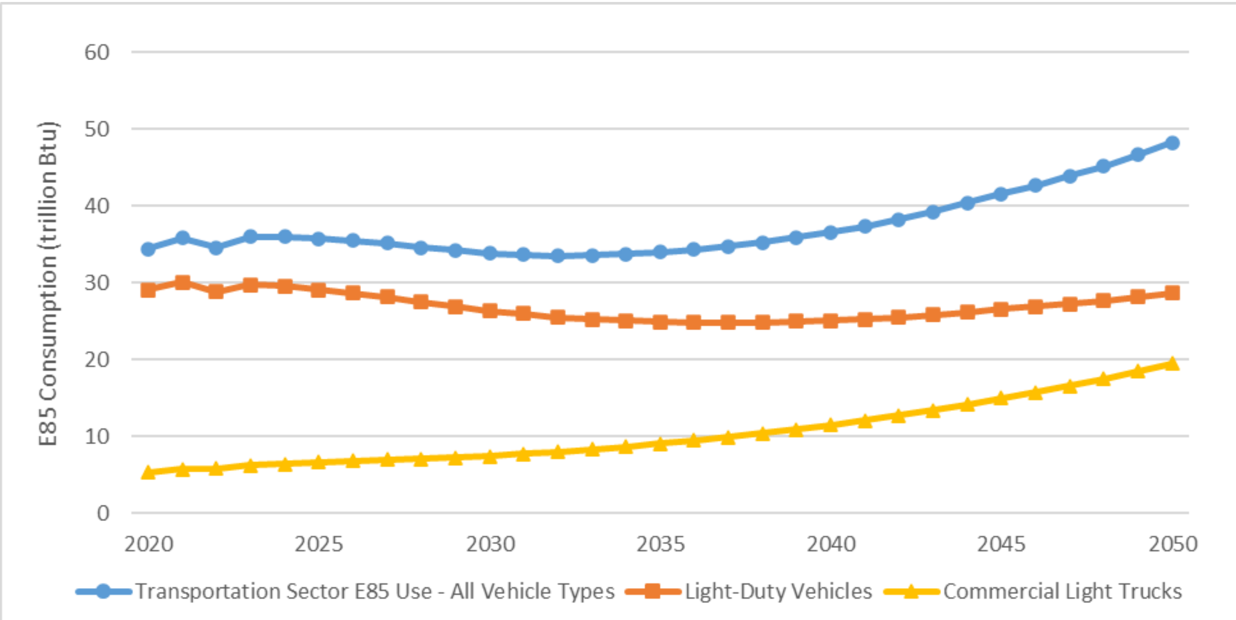
Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool shows that replacing one diesel passenger car with a comparable model running on B20 reduces GHG emissions from 3.6 to 3.1 metric tons CO_2e annually, and replacement with a B100 vehicle 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). For the Renewable Fuel Standard, EPA's life-cycle analysis of soybean oil–based biodiesel produced from transesterification showed similarly sizeable reductions in emissions—57 percent lower net emissions relative to those for a baseline petroleum fuel (EPA 2016c).

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, a pilot program in Nebraska to study the use of E30 in conventional vehicles owned by the state demonstrated that higher ethanol blends do not adversely affect vehicle performance or fuel economy (Saha et al. 2021). 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



Notes:
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).
Source: EIA 2021a
Btu = British thermal units

Recent studies and LCA models have found that corn ethanol has declined in carbon intensity over time, revealing increased GHG emissions 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).

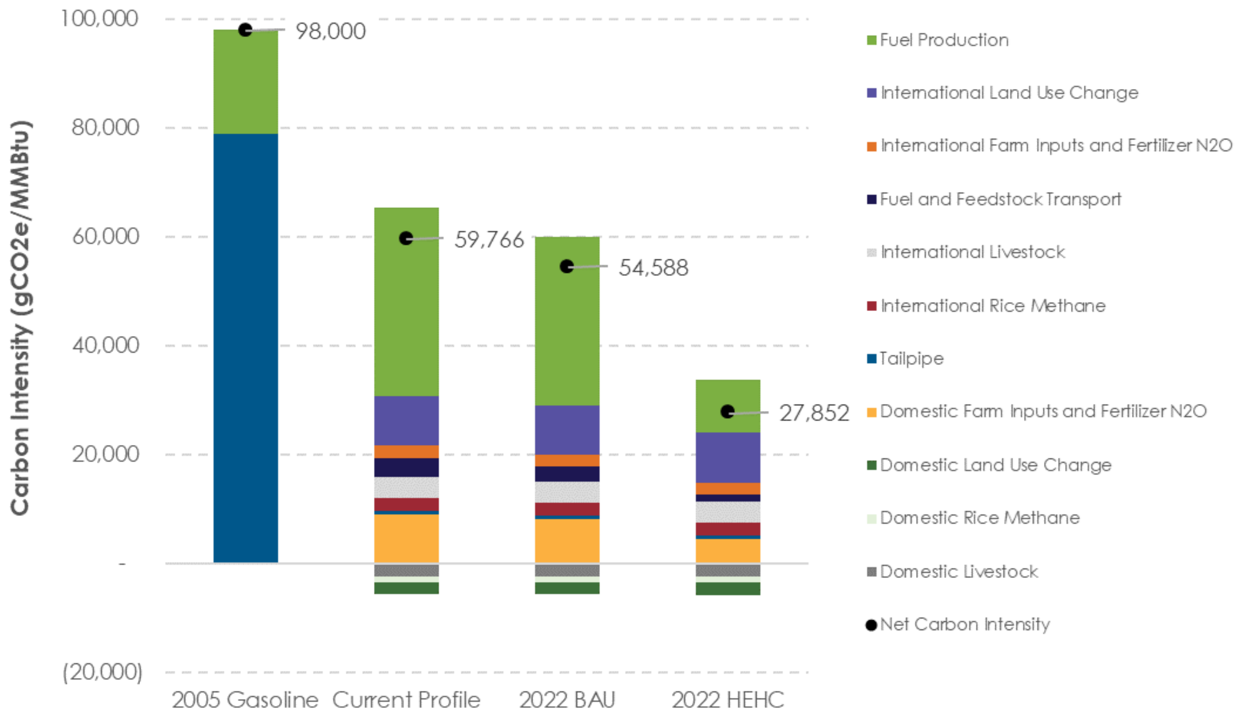
Table 6.2.4-1. Well-to-Wheels GHG Emissions Reductions in Vehicles Fueled by High-Octane Fuels with Different Ethanol Blending Levels Relative to Regular Gasoline (E10) Baseline Vehicles

	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 a small percentage 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 emissions 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). For the Renewable Fuel Standard, EPA's life-cycle analysis, completed in 2010, found that net emissions for corn starch ethanol produced in dry mill plants using natural gas were 21 percent lower relative to those for a baseline petroleum fuel (EPA 2016c). The more recent studies described above have shown a larger percentage differential between corn ethanol and gasoline life-cycle GHG emissions as newer data and information have become available (Lewandrowski et al. 2020).

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



Notes:
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
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

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). EPA's study reported comparatively higher GHG emissions for corn ethanol agricultural impacts (17 kilograms CO_2e/MMBtu) and land use change (28 kilograms CO_2e/MMBtu) (EPA 2010e, 2016c). 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 via clean pathways, such as water electrolysis using clean electricity or steam methane reforming with carbon capture and sequestration. 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 cradle-to-gate GHG emissions for a fuel-cell vehicle to be about 40 percent lower than those of traditional ICE vehicles, and over 80 percent lower when the hydrogen is supplied by renewables, assuming gaseous hydrogen delivery and use of grid electricity to power the hydrogen fueling station (Elgowainy et al. 2021; ANL 2020b).

Numerous factors limit fuel-cell vehicle 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 industry (including chemicals manufacturing, steel manufacturing, biofuels, and synthetic fuels), which are being explored by DOE's H2@Scale initiative (DOE 2018). Recent studies have also shown that hydrogen fuel cells can be a cost-competitive option in the future to decarbonize medium- and heavy-duty vehicles, particularly where long range and fast fill times are required (Hunter et al. 2021).

6.3 Vehicle 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 road load technologies including those affecting vehicle mass reduction (Section 6.3.1, *Road Load Technologies—Mass Reduction*), tires (Section 6.3.2, *Road Load Technologies—Tires*), and EV batteries (Section 6.3.3, *Electric Vehicle Batteries*).

6.3.1 Road Load Technologies—Mass Reduction

Material substitution in vehicles and material joining technologies that offer mass reduction can improve passenger car and light truck fuel efficiency. This section examines the LCA impacts for 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. The studies to date suggest that changing vehicle mass using material substitution offers higher GHG emissions 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 6.3.1-1, 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 with the exception of the 5 percent mass reduction under Alternative 1. However, the CAFE Model projects an increase in higher levels of mass reduction (10 and 15 percent reductions in glider weight) under Alternatives 1, 2, and 2.5 as well as under Alternative 3 for the 15 percent reduction 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 13 percent under No Action Alternative to 39 percent under Alternative 3. The life-cycle implications discussed in Section 6.3.1.1, *Vehicle Mass Reduction by Material Substitution*, and Section 6.3.1.2, *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 6.3.1-1. Mass Reduction Technology Penetration Rates for Model Year 2029

Technology Type	Alt. 0 (No Action)	Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Baseline Mass	8%	2%	2%	4%	2%
Mass Reduction, Level 1 (5% Reduction in Glider Weight)	26%	27%	22%	19%	19%
Mass Reduction, Level 2 (7.5% Reduction in Glider Weight)	17%	6%	6%	6%	6%
Mass Reduction, Level 3 (10% Reduction in Glider Weight)	36%	50%	43%	42%	33%
Mass Reduction, Level 4 (15% Reduction in Glider Weight)	13%	15%	27%	27%	39%

6.3.1.1 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.[16]

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 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

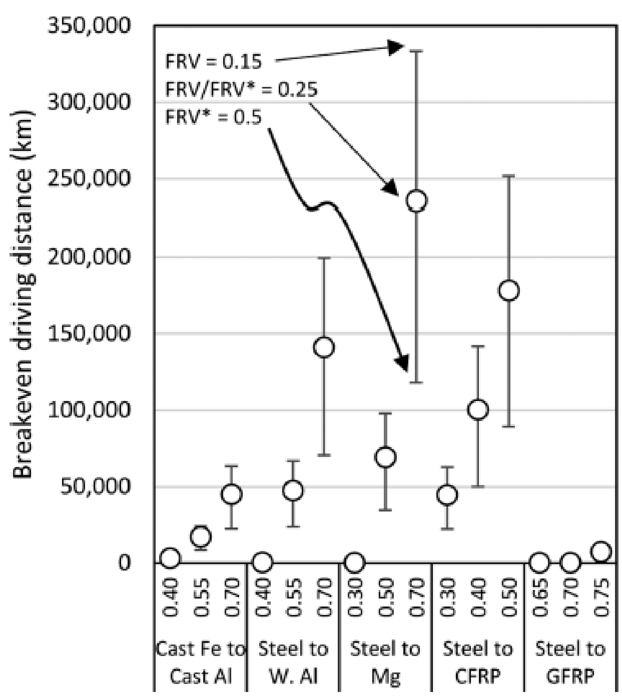


Figure 5. Breakeven driving distance for different material substitution pairs and substitution ratios, assuming different FRV/FRV* values.

Source: Kelly et al. 2015

[16] 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.

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).

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[17] 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

[17] 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).

production phase; thus, a net energy reduction ensues.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 GHG emissions 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).[18]

- **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,[19] and location of aluminum production.

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). Another 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.[20] The 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 (Zhu et al. 2021).

[18] Another study used a fleet-based life-cycle model to estimate the GHG emissions savings from 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 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).

[19] 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.

[20] 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 automotive body sheet within the 2020 U.S. light-duty vehicle fleet. This production is projected to result in approximately 125 kt per year of aluminum automotive body sheet scrap in 2035 and approximately 246 kt per year in 2050 if the current volumes of production are maintained.

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).[21]

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[22] (Kelly and Apelian 2016).

GHG emissions savings from vehicles using lightweight materials might or might not depend on the materials recycling rates achieved. Estimates range from lower life-cycle GHG emissions only under scenarios with very high recycling levels for aluminum components, to significantly lower life-cycle GHG emissions compared to comparable mild-steel components, even with an unrealistic recycling rate of 0 percent (Bertram et al. 2009; Birat et al. 2003). One study found that an aluminum chassis substituted for a steel chassis resulted in net GHG savings under all recycling scenarios. The recycling scenarios ranged from *pessimistic*, where 75 percent of aluminum parts are open-loop recycled and 25 percent landfilled, to *optimistic*, where 90 percent of aluminum parts are closed-loop recycled (Raugei et al. 2015). Another study noted that replacing conventional steel with recycled aluminum for various frame components reduced life-cycle emissions of CO_2 by 7 percent within 1 year and 11 percent after 10 years of use (Ungureanu et al. 2007).

[21] The authors examined the impact on life-cycle GHG emissions for aluminum substitution scenarios when the aluminum displacement rate falls below the one-to-one displacement assumed under the avoided burden method. In this context, displacement is taking into account the benefits of aluminum recycling and 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. The results show that lower aluminum displacement rates can significantly affect 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).

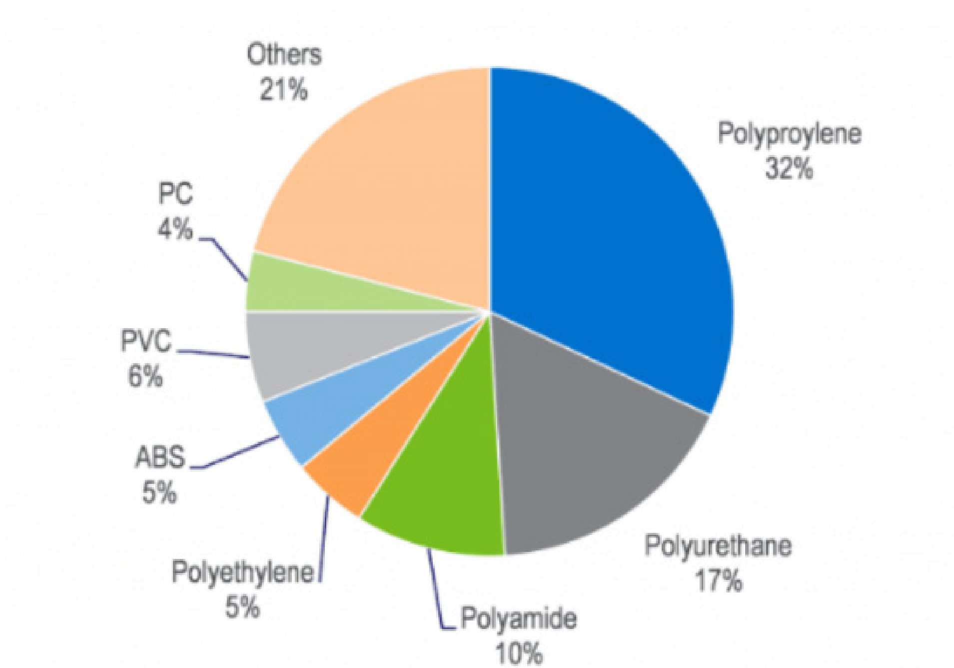
[22] Open-loop recycling systems are characterized by recycled materials being converted into both new (raw) material, such as aluminum, and waste product. Materials recycled through this system are typically used for applications that vary from their former (pre-recycled) purpose, whereas a closed-loop 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 automotive body sheets, scrap is not easily recycled into original aluminum automotive body sheet 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.

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).

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). One 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 found that the plastic fender resulted in up to 47 percent lower carbon footprint than its steel counterpart (Baroth et al. 2012). These emissions reductions predominantly occurred during the use phase, where the emissions from the vehicle with the plastic fender (92 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.[23] 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).[24]

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.

[23] 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).

[24] At the nano scale, carbon fibers offer additional tensile strength and provide other functionalities such as electrical conductivity and antistatic properties, which are useful properties for automobile components such as body panels and casings for electronic equipment (Khanna and Bakshi 2009) 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 percent 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).

- 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;[25] 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[26] energy required for carbon nanofiber polymer composites range from nearly 2 to 12 times greater than the energy requirements for steel[27] (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;[28] 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

[25] 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.

[26] 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.

[27] Standard steel plate used in this study.

[28] 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).

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[29] (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 kilograms [163.2 pounds] CO_2e/part) (Koffler and Provo 2012).

In general, the studies that examine multiple environmental impact categories conclude that these lightweight composite materials offer overall environmental benefits compared to mild steel—and in most cases, compared to aluminum—across the vehicle life cycle. Carbon-fiber-reinforced polymer composite used in vehicle closure panels[30] 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.[31] 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).[32] When carbon-fiber-reinforced polymer replaces a much larger share of the steel in the vehicle body panel (i.e., beyond the closure panels), the environmental benefits of carbon fiber lessen (Overly et al. 2002). When a nylon composite manifold was compared to two similar aluminum parts (sand-cast and multi-tubed brazed), the composite manifold showed lower life-cycle impacts across certain metrics (energy use and GHG, carbon monoxide, nonmethane hydrocarbons, and NO_X

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

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

[31] These results vary based on the substitution ratios used and whether powertrain resizing is considered (Kelly et al. 2015).

[32] 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.

emissions), but increases among others (methane, PM10, and SO_2) 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). 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 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.

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.[33]

- Magnesium is more energy- and GHG-intensive to produce than steel or aluminum.
- Significant reductions in vehicle weight and GHG emissions can be achieved in the future by substituting magnesium for heavier components currently in use. However, breakeven distances can be relatively high in relation to other materials (Kelly et al. 2015). For example, examining only mass reduction of the engine block, use of coal-based Pidgeon process magnesium could result in a breakeven distance of from approximately 20,000 kilometers (12,500 miles) to 236,000 kilometers (147,000 miles) compared to other materials ranging from iron to aluminum produced from different production processes and locations (Tharumarajah and Koltun 2007). The use of coal-based Pidgeon process magnesium decreases the life-cycle energy and GHG benefits of magnesium. The greater the amount of GHG-intensive Pidgeon process magnesium incorporated into the vehicle, the longer the break-even distance becomes (Cáceres 2009). The substitution ratio used for magnesium substituting steel can vary the breakeven distance by as much as 225,000 kilometers (140,000 miles) (Kelly et al. 2015).
- 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). SO_2 is also used as a protective gas to cover molten magnesium during production (i.e., cover gas) (Dubreuil et al. 2010).

[33] 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.

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[34] and might be phased out of manufacturing in the near future in most countries. At present, SF_6 is used as a cover gas (i.e., a protective gas to cover molten magnesium during production). To lower GHG emissions, SO_2 can also be used to treat magnesium, but it is toxic (Johnson and Sullivan 2014). The inclusion of SF_6 as part of the emissions impacts from manufacturing can increase the vehicle breakeven point to approximately 200,000 kilometers (124,000 miles) (Sivertsen et al. 2003). The inclusion of SO_2 as part of the emissions 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).

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

- **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.

6.3.1.2 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 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.

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.

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 *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.

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.

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.

6.3.2 Road Load Technologies—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 (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 6.3.2-1 (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 6.3.2-1. Percent of Energy Input for Powering Wheels and Overcoming Rolling Resistance

Vehicle Type	Percent of Vehicle Energy Input Powering Wheels	Percent of Vehicle Energy Input 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 these 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 SO_2, NO_X, and ammonia released as well. Partially substituting silica for carbon black as filler can reduce the cumulative energy input over the entire life of the tire by up to 9.3 percent. In total, a reduction of approximately 8.7 percent in the consumption of resources is achieved, due to petroleum savings of approximately 9.8 percent (Continental 1999).

Another LCA compared a carbon black tire to a silica/silane tire (which has lower rolling resistance). The primary energy demand for the production of the carbon black tire was 197 megajoule and for the silica/silane tire was 84 megajoule. This corresponded to emissions of 9.2 kilograms (20 pounds) of CO_2 from the production phase of the carbon black tire and 6.0 kilograms (13 pounds) of CO_2 from the production phase of the silica/silane tire. Because of increases in the quantities of solid and liquid waste and of ash and slag, a silica tire would produce approximately 3.4 percent more waste than a carbon black tire. Additionally, production of filler silica increases the negative impact on wastewater (Continental 1999). Given the limited availability of LCAs in recent literature, further research is needed to better quantify environmental impacts of low-rolling-resistance tires across the entire life cycle.

NHTSA subjected five tire models to on-vehicle tread wear testing and found no clear relationship between tread wear and rolling resistance levels (NHTSA 2009). For six tire models subjected to significant wear during indoor tests (i.e., in a laboratory setting when not attached to a vehicle), the results did show a trend toward faster wear for tires with lower rolling resistance. Other anecdotal and qualitative sources indicate that production and use of tires designed to reduce rolling resistance may affect tire manufacturing energy, durability, and opportunities for retread. A reduction in durability and retread opportunities could decrease the effective life of the tires, creating more waste and requiring additional tire manufacturing; however, improving technologies for tire design and rubber compounds are reducing concerns over tread life with each new tire model (NACFE 2015).

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 Organisation for Economic Co-operation 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 expend less energy to overcome rolling resistance and therefore consume 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.

6.3.3 Electric Vehicle Batteries

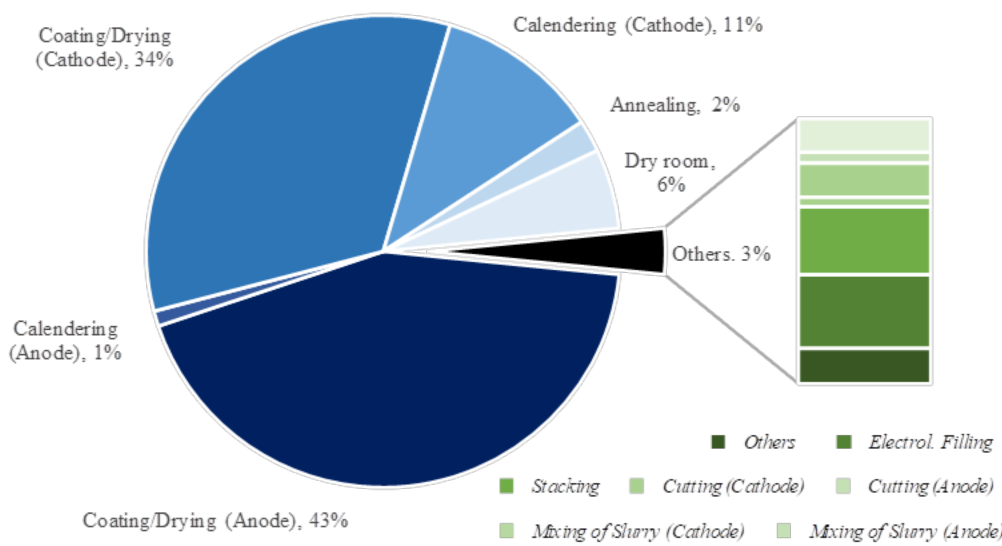
6.3.3.1 Lithium-Ion Batteries

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 compared to other battery chemistries (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 NMC (Nealer and Hendrickson 2015). The manufacturing of lithium-ion batteries is an energy-intensive process, particularly with the coating and drying phases[35] 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 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 emissions 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

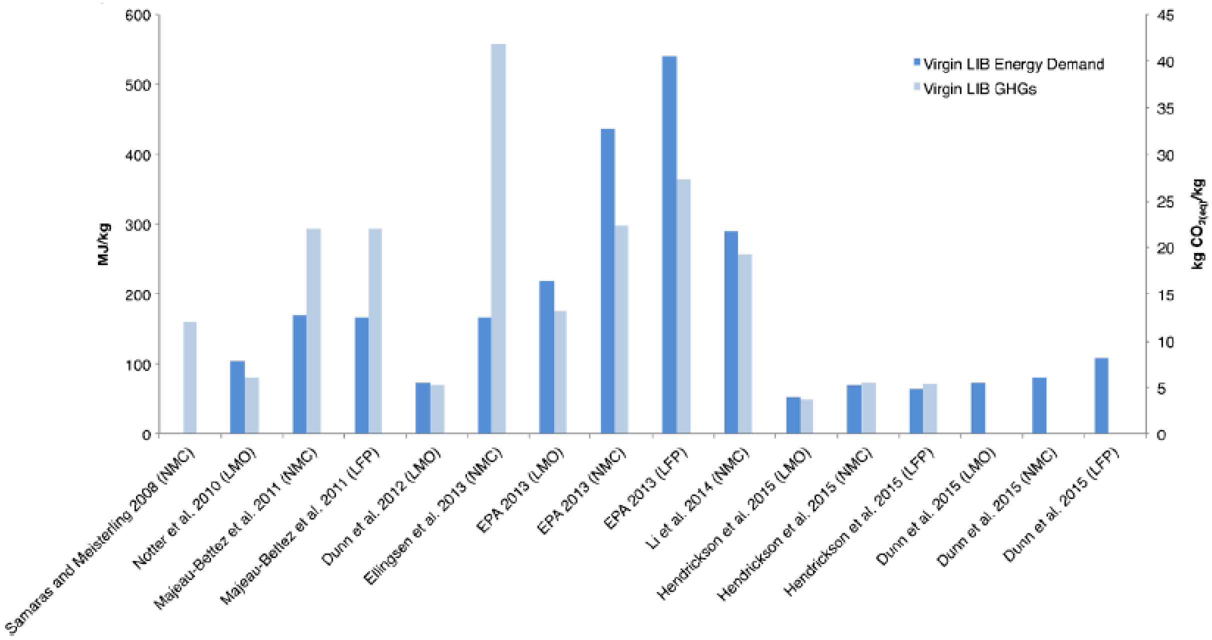
[35] The drying phase involves application of heat to remove the flammable solvent in the cathode after the coating process. Drying is an important step in the manufacture of Lithium-ion batteries as it helps ensure the stability of the lithium salts used as electrolytes under least humidity conditions.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

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.

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 SO_2 emissions, respectively, primarily due to battery production and the electricity generation source used to charge the batteries (Congressional Research Service 2020).

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

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,[36] 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

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

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 emissions standards, primarily Mexico (Commission for Environmental Cooperation 2013).

Rapid expansion of EV adoption would create large battery waste flows for solid waste infrastructure and the expansion and increased efficiency of the recovery of lithium-ion battery materials will be needed. 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). Most of the recycling techniques and methodologies are still at the laboratory scale, and there is a need to gain a full understanding of both their environmental and their economic impact before they are adapted to industry-scale recycling processes. Sambamurthy et al. (2021) conducted an LCA study comparing the environmental impact for one hydrometallurgical recycling method. The recovery of cobalt was estimated as 89 percent in the form of cobalt hydroxide, and about 77 percent of lithium was recovered in its carbonate form (i.e., lithium carbonate).

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 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).

Depending on the cell chemistry, recycling can significantly reduce the potential environmental impacts of battery production. Based on a 2021 LCA study (Mohr et al. 2020), the highest benefits are obtained via the advanced hydrometallurgical treatment for lithium nickel manganese cobalt oxide and lithium nickel cobalt aluminum oxide batteries, mainly due to cobalt and nickel. Additionally, to obtain optimal environmental benefits, the hydrometallurgical treatment needs to be adapted to the specific cell chemistry. This study also concluded that the GHG benefits achievable from recycling cannot offset even half of the GHG emissions from cell manufacturing (in the optimal cell-specific recycling conditions), which limits the GHG benefits of recycling.

There is an economic interest to focus the recovery of lithium-ion batteries on recycling highly valuable metals, including cobalt, iron, and nickel, from cathode materials. In the recycling of lithium-cobalt batteries, hydrometallurgical processes have been seen as an effective recycling approach because they achieve high recycle efficiencies for both lithium and cobalt ions. The hydrometallurgical process also offers lower energy consumption, low air toxic emissions, low cost, and convenience of operations (Sambamurthy et al. 2021).

One additional consideration that could increase the sustainability of lithium-ion batteries' life cycle is the systematic implementation of coordinated planning in closed-loop supply chains (Scheller et al. 2021). In other words, in an economy where recyclers become suppliers for manufacturers, recycling would be optimized for business considerations. For example, transportation costs can be reduced if the location of the recycling plant is near the production plant. Additionally, the upfront planning would require the production and the recovery technologies to be compatible, along with the exchange of materials.

At this time, many vehicle manufacturers and battery recyclers have started long-term cooperation and a coordinated planning approach. Some manufacturers, including Volkswagen and Nissan, are implementing their own recycling facilities, but most efforts are conducted through partnerships and collaboration, which are all dependent on the region, cooperation needs, recycling technology, etc. (Scheller et al. 2021).

Furthermore, recycling and production technologies need to be compatible. Current recycling processes for lithium-ion batteries contain a hydrometallurgical process to regain cobalt, nickel, and further materials. However, the actual composition of the materials regained from recycling varies. For example, lithium can be regained as lithium carbonate or lithium hydroxide. Additionally, the production process usually necessitates a specific composition and quality of materials in the battery. Furthermore, recycling processes vary regarding their recoverable materials. For example, it is more difficult to regain lithium using a pyrometallurgical than using a mechanical preparation. These circumstances need to be considered in the strategic planning between the forward and reverse supply chain (Scheller et al. 2021).

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 emissions 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 emissions 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 Chapter 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 22, 24, and 29 percent, respectively, in Alternatives 2, 2.5, 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. 2.5	Alt. 3
Strong Hybrid EVs	**5.9%**	**9.0%**	**12.1%**	**13.3%**	**16.6%**
SHEVP2: P2 Strong Hybrid/Electric Vehicle	1.6%	3.6%	2.8%	3.0%	4.3%
SHEVPS: Power Split Strong Hybrid/Electric Vehicle	3.9%	4.7%	8.4%	9.4%	11.2%
P2HCR1: Special P2 Strong Hybrid/Electric Vehicle with HCR1 Engine	0.4%	0.8%	0.9%	0.9%	1.1%
PHEVs	**0.18%**	**0.32%**	**0.28%**	**0.32%**	**0.32%**
PHEV20: 20-mile PHEV with HCR Engine	0.11%	0.22%	0.22%	0.26%	0.25%
PHEV20T: 20-mile PHEV with Turbo Engine	0.06%	0.09%	0.07%	0.07%	0.07%
Dedicated EVs	**5.7%**	**6.8%**	**9.3%**	**10.3%**	**11.9%**
BEV200: 200-mile EV	2.8%	3.5%	3.7%	3.8%	4.0%
BEV300: 300-mile EV	2.6%	3.1%	5.3%	6.2%	7.6%
BEV400: 400-mile EV	0.3%	0.28%	0.28%	0.28%	0.28%
Total for Strong Hybrid EVs, PHEVs, and Dedicated EVs	**12%**	**16%**	**22%**	**24%**	**29%**

Notes:
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

6.3.3.2 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).

6.4 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 nearly three times as many strong hybrid EVs (i.e., approximately 17 percent of the fleet vs. 6 percent under the No Action Alternative), about three times as many PHEVs and dedicated EVs (i.e., 12 percent of the fleet vs. 6 percent under the No Action Alternative), about three times the penetration of the highest level of mass reduction (i.e., 39 percent of the fleet vs. 13 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 triple for strong hybrid EVs, be about twice as high for PHEVs and dedicated EVs, and about three 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 6.4-1. 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. 2.5	Alt. 3
Strong Hybrid EVs	6%	9%	12%	13%	17%
PHEVs and Dedicated EVs	6%	7%	10%	11%	12%
Mass Reduction, Level 4 (15% Reduction in Glider Weight)	13%	15%	27%	27%	39%
Low-Rolling-Resistance Tires, Level 2 (20% Reduction)	97%	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 emissions 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 emissions 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 final rule in Section VIII.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 final 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 final rule in Section III.H.3 and Chapter 5.4 of the Final Regulatory Impact Analysis (FRIA).

[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), plug-in HEVs, dedicated EVs (or fully electric powertrains), electrified accessories, micro-hybrid stop-start systems, belt-mounted integrated starter generators, and alternative fuel/hybrid combinations. 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, *Electric 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 41 billion gasoline gallon equivalents (GGE) under Alternative 1 to 138 billion GGE under Alternative 3 from 2020 to 2050 across all light-duty vehicles (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, *Electric 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, 2016d).

[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 3.3, *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

[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 6.3.1.1, *Vehicle Mass Reduction by Material Substitution,* and Section 6.3.1.2, *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, plug-in HEVs, dedicated EVs (or fully electric powertrains), electrified accessories, micro-hybrid stop-start systems, belt-mounted integrated starter generators, and alternative fuel/hybrid combinations. See Section 6.2.3, *Electricity*, and Section 6.3.3, *Electric 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 VIII.D.3 of the preamble to the final rule. The analysis in this section is intended to provide additional information in order to disclose impacts under NEPA.

[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 (SO_2) 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_2 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 (under all alternatives in 2025) (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 all action alternatives. 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 roadway noise exposure has dramatically decreased since the 1980s. Traffic noise levels are greatly

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

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 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 (DOT 2019b). In 2021, DOT reviewed and updated its environmental justice strategy to ensure that it continues to reflect its commitment to environmental justice principles. 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 (DOT 2021). The 2021 update 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.

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 areas, and urban areas that are subject to the heat island effect.[9] As part of the literature review

[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).

[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.

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. Minority and low-income populations are also more likely to experience refinery emissions exceeding EPA standards. In 2020, of nearly 700,000 people living within 3 miles of 17 refineries reporting benzene concentrations that exceed EPA's 9 microgram action level, 62 percent are African American, Hispanic, Asian American/Pacific Islander, or American Indian residents, and nearly 45 percent have incomes below the poverty level (Environmental Integrity Project 2021).

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 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 non-White 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 American 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). PM2.5 and nitrogen dioxide concentrations are also highest for Black and Hispanic communities in Massachusetts, in part because of their proximity to industrial facilities and highways (Rosofsky et al. 2018). 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 non-White 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.

[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 2022, the United States had 6,586,610 km of roadways, 293,564 km of railways, and 13,513 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

Ambient air pollution exposure has an increased impact on the health of minorities, individuals with lower income, and individuals with lower educational attainment (Kiomourtzoglou et al. 2016). In particular, race plays a significant deciding factor in determining one's risk of exposure to air pollution after controlling for other socioeconomic and demographic factors (Di et al. 2017; Tessum et al. 2021). 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. 2018). EPA's 2019 Integrated Science Assessment for Particulate Matter found that race and ethnicity are major factors influencing PM2.5-related health risk, and that Black individuals, in particular, are at increased risk for health effects, given higher levels of exposure (EPA 2019a).

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 final 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, such as California's Enhanced Fleet Modernization Program (EFMP) and EFMP Plus-up Pilot Program, which help low-income individuals and families retire gasoline-powered vehicles and purchase more fuel-efficient cars (University of California, Los Angeles 2017). There are also 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. The California Energy Commission (CEC) found that by 2030, the state will need nearly 1.2 million chargers to meet the demands of a projected 7.5 million plug-in electric vehicles (CEC 2021). 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 (Holland et al. 2020). Holland et al. (2020) define environmental benefits as the difference in air pollution damages between driving an EV and driving the foregone gasoline vehicle. Holland et al. found that in the past decade, changes in emission rates and shifts in power generation led to EVs being cleaner on average than gasoline-powered vehicles. Those benefits of EV adoption are not distributed homogeneously across geographies or populations. 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 (Holland et al. 2019). In comparison to gasoline-powered vehicles, benefits from EVs are significantly more equitably distributed across a wider range of individuals.

Based on 2010 through 2017 data on local damages, Holland et al. found that environmental benefits tend to decrease as individual income decreases (Holland et al. 2019). While individuals earning an annual household income of more than $65,000 received positive environmental benefits from EV adoption, individuals with an income below this threshold did not receive the value of environmental benefits. Benefits from changing from a gasoline vehicle to an EV were realized above the $65,000 threshold because the pollution damages associated with driving gasoline vehicles were higher among higher-income populations, resulting in a positive net benefit when comparing against the relatively equitable EV pollution damages. Benefits from EV adoption were 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 were 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. showed that economic pollution damages—i.e., benefits—from EV adoption were realized for Asian American and Hispanic populations, but not for White and Black populations because Hispanic and Asian American populations are more dense in the West and EVs are generally more environmentally beneficial in the West where penetration of EVs has been higher. Updating data on EV penetration and power sources would likely affect future findings on the distribution of benefits. Given that low-income and non-White populations are disproportionately exposed to traffic density (Rowangould 2013), and thus, some types of air pollution, health benefits from driving EVs 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; in New York, electric transportation jobs in the state are projected to grow 32 percent by 2024 (AEE 2021). 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, such as those facing cumulative exposure to multiple pollutants, 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). Urban areas are 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 2018e). 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).

Climate change can also exacerbate poor air quality, further compounding the risk to overburdened communities (EPA 2021i). Changes in temperature, humidity, precipitation, and other meteorological factors can increase distribution of PM2.5 and ozone, and longer and more intense warm seasons are expected to increase the number of days with poor air quality. Climate change–driven increases in wildfires may also result in higher PM2.5 concentrations. Under 2°C of increased warming nationwide, climate-driven effects on PM2.5 may result in 2,100 more annual premature deaths among people age 65 and older and 2,500 more annual childhood asthma diagnoses. Health-related sensitivities in low-income and minority populations increase the risk of damaging impacts from poor air quality under climate change, underscoring the potential benefits of improving air quality for communities overburdened by poor environmental quality.

Some subgroups face more health risks due to climate change. Black individuals are 41 to 60 percent more likely than non-Black individuals to live in areas with high projected increases in premature mortality caused by climate-driven changes in PM2.5, as well as 40 percent more likely than non-Black individuals to live in areas with the highest projected increases in extreme temperature (EPA 2021i). Indigenous people in the United States also face increased health disparities, such as high rates of diabetes, that cause increased sensitivity to extreme heat and air pollution (GCRP 2018a). See Section 8.6.4.2, *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.

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, PM2.5, and VOCs in 2035 are projected to decrease under all action alternatives compared to the No Action Alternative. Upstream emissions of SO_2 in 2035 are projected to increase under all action alternatives, compared to the No Action Alternative. Upstream emissions of toxic air pollutants in 2035 are projected to stay the same or 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, PM2.5 and SO_2 in 2035 are projected to decrease under all action alternatives compared to the No Action Alternative. Tailpipe emissions of NO_X and VOCs in 2035 are projected to increase under all action alternatives compared to the No Action Alternative. Tailpipe emissions of acetaldehyde, acrolein, and formaldehyde in 2035 are projected to increase under Alternative 1 but decrease under Alternatives 2, 2.5, and 3 compared to the No Action Alternative. Tailpipe emissions of 1,3-butadiene in 2035 are projected to stay the same or decrease under all action alternatives compared to the No Action Alternative. Tailpipe emissions of benzene and diesel particulate matter are projected to increase under all action alternatives 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 final rule preamble, Technical Support Document, and FRIA issued concurrently with this Final 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 4 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 further exacerbated by 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 0.7 to 1.6 percent in 2100. Compared to annual global CO_2 emissions, the Proposed Action and alternatives 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 5.4.2-3 and Table 5.4.2-4) by 2100. 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 GCAMReference scenario.

Adverse health impacts are projected to decrease nationwide under each of the action alternatives (except that some impact metrics show no change in 2025) compared to the No Action Alternative

(Table 4.2.3-1). 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 final rule sets nationwide standards, 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 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

[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 Final Regulatory Impact Analysis (FRIA) issued with the final 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; currently they are more efficient compared to internal combustion engine (ICE) vehicles (DOE 2022). 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, *EV Charging Infrastructure*, describes how increased infrastructure spending will increase the number of U.S. EV charging stations. Section 8.3.3.5, *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 8.3.3.6, *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). In particular, on November 15, 2021, the Infrastructure Investment and Jobs Act was signed into law and directed the Secretary of Transportation to establish a VMT pilot program.[4] 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). The analysis also shows light-duty vehicle VMT quickly recovering to its pre-pandemic level before increasing slowly to about 3.4 trillion miles in 2040 and remaining near that level through 2050 (while also varying slightly among 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

[4] Pub. L. No. 117-58, tit. III, § 13002.

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.

Recent policies in EOs are expected to result in greater electricity generation from renewable sources with cumulative benefits for fuel refining and the electrification of the vehicle fleet. On January 20, 2021, President Biden issued EO 13990, *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*,[5] which revoked the Keystone XL Pipeline permit. This 179-mile pipeline from Alberta, Canada, to Steele City, Nebraska was to transport 830,000 barrels of oil each day. EO 13990 also directed EPA to consider proposing new regulations to establish comprehensive standards of performance and emissions 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. In addition, EO 13990 placed a temporary moratorium on all activities relating to the implementation of the Coastal Plain Oil and Gas Leasing Program in the Arctic National Wildlife Refuge. On January 27, 2021, President Biden issued EO 14008, *Tackling the Climate Crisis at Home and Abroad*,[6] which placed the climate crisis at the forefront of national security and foreign policy. This EO called for the identification of steps for the United States to promote ending international financing of carbon-intensive fossil fuel–based energy, while simultaneously advancing sustainable development and a green recovery, including driving international collaboration on innovation and deployment of clean energy technologies. On May 7, 2021, President Biden issued EO 14027, *Establishment of the Climate Change Support Office*,[7] which established the Climate Change Support Office within the Department of State and, among other duties, directed it to support efforts that address clean energy, including increasing international climate ambition and ensuring that climate change is integrated into all elements of U.S. foreign policy-making decision processes.

There are increasingly negative environmental and climate impacts associated with the fossil fuel industry, such as those resulting from the use of fracking to extract oil and gas. Section 6.2.2.2, *Shale Gas and Hydraulic Fracturing*, discusses the increased use of hydraulic fracturing of shale gas deposits over the last decade. In 2019, hydraulically fractured wells accounted for 86 percent of natural gas production and is projected to increase to 92 percent of natural gas production by 2050 (EIA 2021a). Section 6.2.2.2 shows that EVs powered by natural-gas-fueled electricity results in lower life-cycle GHG emissions, but also creates concerns for increased air pollution emissions from drilling and fracturing operations; water pollution from wastewater handling and local groundwater vulnerabilities; and small, unintentional seismic events that result from extraction methods.

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

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

[6] Executive Order 14008, Tackling the Climate Crisis at Home and Abroad, FR 7619 (Jan. 27, 2021).

[7] Executive Order 14027, Establishment of the Climate Change Support Office, FR 25947 (May 7, 2021).

regulations (e.g., carbon dioxide [CO_2] standards),[8] 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). While the timing of cost competitiveness will depend on how battery costs evolve, it will also depend on other factors that very clearly vary significantly from one country to the next—in particular, the prices of petroleum-based fuels and the prices of electricity. Regarding battery costs, NHTSA's analysis applies battery cost learning curves discussed in Chapter 3.3.5 of NHTSA's Technical Support Document (TSD).

8.3.3.4 EV Charging Infrastructure

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 in the United States could have additional impacts on EV market share. The DOE Alternative Fuel Data Center reports that there are 50,122 EV charging stations in the United States, including 46,532 public stations.[9] The Infrastructure Investment and Jobs Act includes $5 billion in funding for states to build a national charging network. The Act also provides $2.5 billion to support innovative approaches and charger deployment.[10] NHTSA's analysis does not attempt to account explicitly for the future availability of EV charging facilities, much less to apply an explicit assumption regarding how the availability of charging facilitates the EV market's development. NHTSA's analysis does, however, apply "phase-in caps" that limit the estimated pace of the market's adoption of BEVs (i.e., vehicles that, unlike PHEVs, cannot use gasoline), reflecting expectations that the market will be more broadly accepting of longer-range (e.g., 300- to 400-mile) BEVs than shorter-range (e.g., 200- to 300-mile) BEVs. NHTSA's TSD discusses these and other electrification-related inputs to the analysis in Chapter 3.3.

8.3.3.5 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 (FHWA 2017). 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

[8] 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.

[9] https://afdc.energy.gov/stations/#/analyze?country=US&fuel=ELEC&ev_levels=all.

[10] FACT SHEET: The Biden-Harris Electric Vehicle Charging Action Plan, December 13, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/13/fact-sheet-the-biden-harris-electric-vehicle-charging-action-plan/.

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[11] may overstate mpg for ICE vehicles used by drivers with daily commutes in congested stop-and-go traffic (Davis and Boundy 2021).

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).

The MPGe of EVs has grown by almost 20 percent between MYs 2011 and 2020, and the battery range of equivalent EVs is growing even more rapidly (EPA 2021j; DOE 2021c). Additionally, the time required to charge the batteries to reach full range potential is shrinking, even though EVs with greater ranges require more electricity to reach full charge. These changes are due both to improvements in battery design and advancements in EV charger technology that enable a faster charge (DOE 2020a, 2020b). Accordingly, the relatively steady EV fuel economy is not projected to have a controlling negative impact on EV sales because a greater range of travel and the shortening of time to reach full charge have been shown to have a greater impact on consumer preferences. In a recent survey, 52 percent of consumers polled included the driving range of the battery as a top reason not to consider purchasing an EV (NREL 2020). EV fuel economy is expected to advance significantly in the future; an Argonne National Laboratory study predicts improvement in fuel economy of 43 to 81 percent for HEVs and 73 to 96 percent for PHEVs by 2045 (ANL 2018).

The recently enacted Infrastructure Investment and Jobs Act recommends increased electrification of public fleets such as public transportation and school buses, improvements to energy transmission potential and grid stability, and investment in EV charging infrastructure across the country. Additionally, EO 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*, instructs the U.S. government to develop a plan for all new light-vehicle purchases to be zero-emission vehicles (ZEV) by 2027.[12] The U.S. government fleet includes about 657,000 cars, SUVs, and trucks, so the renewed focus on the procurement of EVs would also increase sales for domestic EV and component manufacturers.[13]

[11] The EPA city drive cycle test is one component of the EPA fuel economy ratings.

[12] Executive Order 14057, Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, 86 FR 70935 (Dec. 13, 2021).

[13] https://www.gsa.gov/policy-regulations/policy/vehicle-management-policy/federal-fleet-report.

8.3.3.6 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.[14] From 2010 to 2020, the average operating heat rate for coal power plants increased from 10,415 to 10,655 Btu/kWh, as the average heat rate for natural gas power plants fell from 8,185 to 7,731 Btu/kWh.[15] 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.[16] 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.[17] 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.[18]

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 criteria air pollutant) emissions associated with electricity consumption, including emissions associated with future BEV and PHEV 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.[19] From 2010 through 2018, the power capacity of U.S.

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[14] https://www.eia.gov/tools/faqs/faq.php?id=107&t=3.

[15] https://www.eia.gov/electricity/annual/html/epa_08_01.html.

[16] https://www.eia.gov/todayinenergy/detail.php?id=32572.

[17] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a.

[18] https://www.eia.gov/todayinenergy/detail.php?id=44976.

[19] https://www.eia.gov/todayinenergy/detail.php?id=44696#.

utility-scale battery storage systems increased from 59 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.[20] 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.[21] 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.

Additionally, investments in U.S. grid infrastructure and renewable energy generation will increase the efficiency of electricity transmission. The enactment of future policies that contribute to an expansion of the supply of renewable energy into the U.S. grid[22] would lower vehicle use emissions even further for EVs relative to ICE vehicles. Various stakeholders, including utilities and charging station operators, are also increasingly recognizing the benefits on decreased emissions, improved reliability, and lower costs of spreading out the charging load profiles by actively managing when EVs are charging.[23] EVs are most commonly charged overnight, leading to large spikes of electricity usage across the grid when many owners plug in their vehicles at about the same time. Actively managing the charging load flattens these spikes and spreads out energy usage overnight.[24,25] Actively managed charging depends on two-way communication between the utility and the consumer, usually through Wi-Fi or a cellular signal that is connected to the car to instruct it to charge once the utility sends a start signal. This signal is based on the current amount of power being used in that grid region, and instructs the vehicle to begin charging when electricity demand is the lowest.[26] Reducing spikes also generally reduces emissions because power facilities brought on to supply energy to meet peak demand, called “Peaker Plants”, tend to be older, less-efficient facilities (Gillingham et al. 2021). Avoiding peaks avoids the need to dispatch these plants and use the higher-emission energy they produce.

[20] https://www.eia.gov/todayinenergy/detail.php?id=43775.

[21] https://www.eia.gov/todayinenergy/detail.php?id=47276#.

[22] See Executive Order 14057, Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, 86 FR 70935 (Dec. 13, 2021).

[23] https://www.nrel.gov/news/program/2022/aligning-utilities-electric-vehicles-for-greater-grid.html.

[24] https://afdc.energy.gov/laws/utility-examples.

[25] https://www.nrel.gov/news/program/2020/how-might-electric-vehicles-affect-electric-loads.html.

[26] Smart Electric Power Alliance. 2021. A Comprehensive Guide to Electric Vehicle Managed Charging. Accessible at: https://sepapower.org/resource/a-comprehensive-guide-to-electric-vehicle-managed-charging/.

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 overall 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 (see Section 8.3.3.6, *Changes in Electric Grid Mix*).

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 2021c). 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 2021c) 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 (CAA), 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 final standards affect energy supply and use by decreasing domestic petroleum 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, 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,[27] 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 emissions rates from the power plant fleet (i.e., electric grid mix) are different during hours of peak electrical demand, when peak-load power plants are operating, and off-peak hours, when predominantly base-load 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 emissions 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.

[27] 43 CFR parts 3160 and 3170.

AEO 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 final 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 4.5.1 of the FRIA and Chapter 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 Assessment 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 has 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 more 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, *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. See Section 8.6.5, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*, for a discussion of the cumulative impacts of the Proposed Action and alternatives.

8.6 Greenhouse Gas Emissions and Climate Change

Climate modeling conducted for this SEIS 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.[28] 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*. Two global emissions scenarios were used in the climate modeling. The first is a medium-high global emissions scenario that takes into account a moderate reduction in global GHG emissions. The second is a modern shared socioeconomic pathway that assumes middle-of-the-road future development and emissions scenarios. These scenarios are consistent with global actions to reduce GHG emissions; specific actions that support the use of this scenario were included as examples in Section 8.6.3, *Other Past, Present, and Reasonably Foreseeable Future Actions*.

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 scenarios used for the main cumulative analysis are the Global Climate Change Assessment Model (GCAM) 6.0 scenario and the Shared Socioeconomic Pathway (SSP) 2-4.5, 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 by using the GCAM6.0 scenario and the SSP2-4.5 scenario as reference case global emissions scenarios that assume a moderate level of global actions to address climate change.

NHTSA chose the GCAM6.0 and SSP2-4.5 scenarios as plausible global emissions baselines because of the potential impacts of these reasonably foreseeable actions, yielding a moderate level of global GHG reductions from the GCAMReference and SSP3-7.0 baseline scenarios, respectively, used in the direct and indirect analysis. For the cumulative analysis, the GCAM6.0 and SSP2-4.5 scenarios serve as reference scenarios 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. The SSP2-4.5 scenario yields a lower radiative forcing of approximately 4.5 watts per square meter in the year 2100 but produces an emissions trajectory similar to GCAM6.0 given differences in underlying scenario assumptions. IPCC's

[28] Prior NHTSA EISs use the same global approach and practices. *See e.g.,* SAFE Vehicles Rule Final EIS at 8-18 (also noting in its section on cumulative GHG and climate change impacts that "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.").

Sixth Assessment Report does not include a scenario with a radiative forcing of 6.0 watts per square meter in 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, the GCAMReference emissions scenario, SSP1-2.6, and SSP3-7.0. 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.[29] The SSP1-2.6 scenario is considered similarly aggressive and illustrates a “green growth strategy” in which there is a low challenge to adaptation and mitigation. The GCAMReference scenario and SSP3-7.0 are representations 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.

The SSP2-4.5 scenario represents middle-of-the-road global development with mitigation action that is approximately in line with the upper end of combined pledges to reduce GHG emissions under the Paris Agreement. This scenario predicts CO_2 emissions will remain around current levels before starting to fall mid-century. Like GCAM6.0, SSP2-4.5 is based on a set of assumptions regarding economies, institutions, technological developments, resource and energy use intensities, and population. SSP2 assumes generally politically stable economies, continued technological developments, a decline in resource and energy use intensities, and the leveling off of population growth in the second half of the century. Under SSP2-4.5, atmospheric CO_2 concentrations are projected to be 568 ppm in 2100.

Consequently, NHSTA believes that GCAM6.0 and SSP2-4.5 represent reasonable proxies for the past, present, and reasonably foreseeable GHG emissions through 2100, and are used for that purpose in this cumulative impact analysis on GHG emissions and climate change.

For the cumulative impact analysis, NHTSA calculated the difference in annual GHG emissions under the Proposed Action and alternatives compared to the No Action Alternative. NHTSA applied this change to the GCAM6.0 and SSP2-4.5 scenarios to generate modified global-scale emissions scenarios, which show the impact of the Proposed Action and alternatives on the global emissions paths. For example, emissions from passenger cars and light trucks in the United States in 2040 under the No Action

[29] 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 2021b).

Alternative are estimated to be 1,211 million metric tons of carbon dioxide ($MMTCO_2$); emissions in 2040 under Alternative 3 are estimated to be 1,082 $MMTCO_2$. The difference of 130[30] $MMTCO_2$ represents the decrease in cumulative emissions projected to result from Alternative 3.[31] 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 130 $MMTCO_2$ less than this reference level or 48,904 $MMTCO_2$ in 2040 under the cumulative impacts analysis. Using the SSP2-4.5 scenario, cumulative global CO_2 emissions are estimated to be 44,254 $MMTCO_2$ in the United States under the No Action Alternative. Therefore, under Alternative 3, emissions would be 44,124 $MMTCO_2$ in 2040.

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, except for 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), SSP2-4.5 (568 ppm in 2100), RCP4.5 (544 ppm in 2100), SSP1-2.6 (438 ppm in 2100), GCAMReference scenario (789 ppm in 2100), and SSP3-7.0 (800 ppm in 2100).

8.6.3 Other Past, Present, and Reasonably Foreseeable Future Actions

NHTSA chose the GCAM6.0 and SSP2-4.5 scenarios as the primary global emissions scenarios 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 future 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 these scenarios 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 and SSP2-4.5 scenarios, can be considered reasonable 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

[30] This value is slightly different than subtracting the values in the text, due to independent rounding.

[31] The reduction in U.S. CO_2 emissions in 2040 under the Proposed Action and alternatives compared to the No Action Alternative ranges from 45 $MMTCO_2$ (Alternative 1) to 130 $MMTCO_2$ (Alternative 3). Differences may not calculate exactly due to rounding.

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, and Virginia.[32] 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).[33] Each of these measures is either a known commitment, 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

[32] 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 January 2022, the state has not yet officially joined, but has begun the rulemaking process.

[33] 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. 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).

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 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 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[34]), 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).

- **California Actions on Emissions.** In August 2020, California formalized bilateral agreements with six automakers to continue its emissions reduction framework developed in 2019 (CARB 2019). 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 by EPA in 2012 (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. In March 2022, EPA confirmed the Clean Air Act (CAA) waiver of preemption for California's ZEV sales mandate and GHG emissions standards.[35]

8.6.3.2 United States: Federal Actions

The following federal actions are already underway or reasonably foreseeable:

- **Repeal of 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*,[36] 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.[37] In December 2021, NHTSA announced a final rule to repeal the SAFE Vehicles Part One Final Rule.[38] Relatedly, on March 14, 2022, EPA published a notice that rescinded its 2019 withdrawal of the waiver of preemption for California's ZEV mandate and GHG

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[34] "*Section 177 states"* refers to the U.S. 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).

[35] *California State Motor Vehicles Pollution Control Standards; Advanced Clean Car Program; Reconsideration of a Previous Withdrawal of a Waiver of Preemption; Notice of Decision*, 87 FR 14332 (Mar. 14, 2022).

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

[37] *The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Part One: One National Program; Withdrawal of Waiver; Final Rule*, 84 FR 51310 (Sept. 27, 2019).

[38] *Corporate Average Fuel Economy (CAFE) Preemption; Final Rule,* 86 FR 74236 (Dec. 29, 2021).

emissions standards.[39] Given NHTSA's repeal of the SAFE Vehicles Part One Final Rule and EPA's reinstatement of California's CAA waiver, California and the Section 177 states are permitted to move forward with their vehicle GHG regulations, which means that new passenger cars and light trucks sold in those states would have to meet these standards. The CAFE Model accounts 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 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).
- **EO 14037, Strengthening American Leadership in Clean Cars and Trucks.** In EO 14037,[40] President Biden directed NHTSA and EPA to consider multiple actions to regulate the fuel efficiency of and CO_2 emissions from post-MY 2026 light-, medium-, and heavy-duty vehicles.
- **Renewable Fuel Standard 2 (RFS2).** Section 211(o) of the CAA requires that a renewable fuel standard be determined annually that is applicable to refiners, importers, and certain blenders of gasoline 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

[39] *California State Motor Vehicle Pollution Control Standards; Advanced Clean Car Program; Reconsideration of a Previous Withdrawal of a Waiver of Preemption; Notice of Decision*, 87 FR 14332 (Mar. 14, 2022).

[40] Executive Order 14037, Strengthening American Leadership in Clean Cars and Trucks, 86 FR 43583 (Aug. 10, 2021).

July 1, 2010, increases the volume of renewable fuel required to be consumed in the transportation sector from the baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022, as written in 2010. Since 2014, the volumetric requirements have been modified to account for lower-than-expected growth in advanced and cellulosic biofuels (EPA 2015d).[41] The increased use of renewable fuels over 30 years, given a zero percent discount rate, is projected to reduce GHG emissions by 4,500 $MMTCO_2e$.

- **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, 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 and volatile organic compound leaks from oil and gas operations was finalized. In 2020, EPA issued two final rules that amended the 2016 NSPS. The first, published on September 14, 2020, finalized changes to the prior standards that remove oil and gas transmission and storage operations and associated CH_4 emission limits (“policy amendments final rule”).[42] The second, published on September 15, 2020, finalized technical changes to the prior standards 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”).[43] In June 2021, President Biden signed a Congressional Review Act resolution to disapprove (repeal) the policy amendments final rule.[44] EPA has announced its intentions to reconsider the technical amendments

[41] https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based.

[42] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources Review; Final Rule*, 85 FR 57018 (Sept. 14, 2020).

[43] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Source Reconsideration; Final Rule*, 85 FR 57398 (Sept. 15, 2020).

[44] Pub. L. No. 117-23, S.J.Res.14 (June 30, 2021).

final rule.[45] If the technical amendments final rule remains in place, CH_4 emissions can be expected to increase by 10 $MMTCO_2e$ by 2030.[46] In November 2021, EPA proposed a new rule that would significantly reduce emissions from the crude oil and natural gas industries.[47] The rule would revise new source performance standards for new sources and propose guidelines under the CAA for states to follow in developing new performance standards for existing sources. In total, this action could reduce methane emissions by 41 million tons through 2035.

- **Infrastructure Investment and Jobs Act.[48]** On November 15, 2021, the Infrastructure Investment and Jobs Act was signed into law. This bipartisan infrastructure bill authorizes funds for federal-aid highways, highway safety programs, and public transit programs. Among other provisions, this legislation will invest $7.5 billion to build a network of EV chargers in the United States and $39 billion to improve public transit infrastructure. This investment will include replacing existing public vehicles with ZEVs, as well as expanding public transit options across the country. The transportation sector is the largest single source of GHG emissions in the United States. Improving access to and quality of public transit systems will reduce GHG emissions via reduced dependency on single-occupancy vehicles. The bill also aims to build more climate-resilient transmission lines to facilitate the expansion of renewables at lower costs.
- **Regulations on Hydrofluorocarbons (HFCs).** On December 27, 2020, the American Innovation and Manufacturing (AIM) Act was enacted by Congress. The AIM 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. Specifically, the AIM Act directs EPA to phase down production and consumption of HFCs to 15 percent of their baseline levels in a stepwise manner by 2036 through an allowance allocation and trading program. This action is expected to reduce GHG emissions by 4,700 $MMTCO_2$ from 2022 to 2050 (EPA 2021k). On October 14, 2021, EPA issued a decision to grant or partially grant petitions requesting EPA restrict the use of HFCs in the refrigeration and air conditioning, aerosols, and foams sectors. EPA will complete a rulemaking within 2 years of the date the petitions were granted.
- **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).
- **The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050.** In November 2021, the United States submitted its long-term strategy to the UNFCCC, communicating a goal of net-zero emissions by 2050. This document lays how the United States

[45] 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).

[46] *Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Source Reconsideration; Final Rule*, 85 FR 57398, 57434 (Sept. 15, 2020).

[47] *Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review; Proposed Rule*, 86 FR 63110 (November 15, 2021).

[48] *Infrastructure Investment and Jobs Act, Notice of Implementation*, 87 FR 1122 (Nov. 15, 2021).

plans to achieve both the near-term 2030 GHG target and the longer-term 2050 target. To achieve these goals, the long-term strategy lays out multiple pathways the United States could take, all of which include “five key transformations” including decarbonizing electricity, electrifying end uses and switching to clean fuels, cutting energy waste, reducing non-CO_2 emissions, and scaling up CO_2 removal (U.S. State Department and U.S. Executive Office of the President 2021).

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 January 2022, 192 countries, including the United States, comprising over 97 percent of global GHG emissions had ratified, accepted, or approved the Paris Agreement (WRI 2022; 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. COP-26 emphasized the need to attain net-zero emissions by 2050 by phasing out coal, accelerating the shift to EVs, and by ending and reversing deforestation. Over 130 countries have pledged to reach net-zero emissions by mid-century.

- **Global Methane Pledge.** On November 2, 2021, more than 100 countries representing 70 percent of the global economy and nearly half of anthropogenic methane emissions signed a pledge to reduce global methane emissions to help limit warming to 1.5°C (European Union 2021). The Global Methane Pledge spans both developing and developed nations and commits to a reduction in global methane levels reaching at least 30 percent reduction from 2020 levels by 2030. If the plans of the Pledge are met, warming could be reduced by at least 0.2°C by 2050, providing a significant basis for global emissions reduction and climate mitigation efforts (U.S. White House 2021). The Global Methane Pledge also provides co-benefits for improved air quality, mitigation of health issues, and reduction of agricultural losses.
- **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 Health, Societal, and Environmental Impacts of Climate Change

8.6.4.1 Introduction

As described in Section 5.4, *Environmental Consequences*, and Section 8.6.5, *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 8.6.5, 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.[49] 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 8.6.4.2, *Sectoral Impacts of Climate Change*, discusses the sector-specific impacts of climate change, while Section 8.6.4.3, *Regional Impacts of Climate Change*, discusses the region-specific impacts of climate change.

8.6.4.2 Sectoral Impacts of Climate Change

This section discusses how climate change resulting from global GHG emissions (including the U.S. light-duty transportation sector under the Proposed Action and alternatives) could affect certain key natural and human resources: freshwater resources; terrestrial and freshwater ecosystems; ocean systems, coasts, and low-lying areas; food, fiber, and forest products; urban areas; rural areas; human health; human security; and stratospheric ozone. In addition, this section discusses compound events, tipping points, and abrupt climate change.

NHTSA's analysis draws largely from recent studies and reports, including the IPCC *Fifth Assessment Report* (IPCC 2013a, 2013b, 2014a, 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), the Working Group I contribution to the IPCC *Sixth Assessment Report* on the physical science basis of climate change (IPCC 2021a, 2021b), 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

[49] 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.

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 2021a).

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. While there is limited evidence that anthropogenic climate change has affected the frequency and magnitude of floods at a global scale (Kundzewicz et al. 2013), projections reveal regional intensification of heavy precipitation and flooding for Africa and Asia (*high confidence*), North America (*medium to high confidence*), and Europe (*medium confidence*) for 1.5°C of warming (IPCC 2021b).

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 deteriorating water infrastructure compounds the risk climate change poses to society (*high confidence*).

In the United States, there is mixed information on the historical connection between climate change and drought. GCRP 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 2015e). 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). The impact of climate change on groundwater recharge varies globally (IPCC 2014b citing Allen et al. 2010b, Crosbie et al. 2013b, Ng et al. 2010, and Portmann et al. 2013). There is *medium confidence* that increased precipitation intensities have enhanced groundwater recharge, particularly in the tropics, while there is *high confidence* that groundwater depletion has occurred over at least the 21st century due to water extraction for irrigation within many agricultural areas (IPCC 2021a). 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 2015f; Abt Associates 2016). Water conservation and demand management are also being promoted as important nonstructural, low-regrets[50] 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).

[50] A low-regrets approach is commonly used to signify a method of action with relatively low cost and relatively large benefits under predicted future climates.

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[51] 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, Primack et al. 2009, Cook et al. 2012a, and Peñuelas et al. 2013; EPA 2021l). 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[52] or genotypic[53] modifications, migrations, or extinction (IPCC 2014b citing Dawson et al. 2011, Bellard et al. 2012, Peñuelas et al. 2013). Changes in morphology[54] 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

[51] Phenology refers to the relative timing of species' life-cycle events.

[52] Referring to an organism's observable traits, such as color or size.

[53] Referring to an organism's genetic makeup.

[54] Referring to an organism's structural or anatomical features (e.g., egg size, wing shape, or even of the organism as a whole).

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). 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[55] 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 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

[55] 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.

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 (*high confidence*), with impacts on climate, ocean circulation, chemistry, and ecosystems (IPCC 2021b). 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).[56] 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 (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

[56] 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.

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 preindustrial 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). Updated numerical predictions show that 70 to 90 percent of coral reefs are projected to decline at a warming level of 1.5°C, with larger losses at 2°C (IPCC 2021a). 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 (0.3 to 0.6 foot) by 2030, 0.15 to 0.38 meter (0.5 to 1.3 feet) by 2050, and 0.3 to 1.2 meter (1 to 3.9 feet) 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 (0.52 to 2.07 feet) by 2050 and a rise of 0.3 to 2.5 meters (0.98 to 8.2 feet) 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 one quarter of all human-caused CO_2 since the preindustrial era, decreasing ocean surface pH by about 0.11 unit[57] (approximately 0.017 to 0.027 pH unit per decade since the 1980s), resulting in the lowest surface pH levels (i.e., highest ocean acidity) in the last 26,000 years (IPCC 2021a). The most recent projections show surface pH may decline by approximately -0.16 ± 0.002 under the SSP1-2.6 and -0.44 ± 0.005 under SSP5-8.5 by 2080 to 2099 relative to 1870 to 1899; these new estimates of ocean acidity are slightly more acidic than previous estimates as the SSPs generally have higher atmospheric CO_2 concentrations (IPCC 2021a). 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 including monsoons, agricultural river runoff, and internal variability (IPCC 2014b, 2021a). IPCC concluded there is *high confidence* that coastal acidification will continue into the 21st century but with large spatiotemporal variability as drivers of local acidity changes are influenced by biological processes, natural and anthropogenic eutrophication, sea ice melt, coastal upwelling, and seasonal dynamics (IPCC 2021a). There is high agreement that coastal acidification, regardless of cause, negatively affects marine organisms such as reef-building corals, crabs, pteropods, and sessile fauna (IPCC 2021a). 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 would challenge coral growth (GCRP 2018a citing Ricke et al. 2013). 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 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.

[57] The pH scale is logarithmic; therefore, each whole unit decrease in pH is equivalent to a 10-fold increase in acidity.

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.[58] 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).

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).

[58] Net primary production is estimated as the amount of carbon synthesized via photosynthesis minus the amount of carbon lost via cellular respiration.

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[59]) 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 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 2016g; 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

[59] 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.

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 2015e; 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 there is currently *high confidence* that forests are serving as a net carbon sink globally (IPCC 2014b). However, forests are projected to become less effective at capturing accumulated CO_2 as GHG emissions increase (IPCC 2021b). GCRP also 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 1990–1992 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). More recent estimates project approximately 60 percent of the global population will reside in urban areas by 2030 (IPCC 2021a). In the United States, approximately 85 percent of the population lives in metropolitan areas[60] (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 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

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[60] 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).

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 2021m).

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 2021m; 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, Asian Americans/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 2021m; 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 2015e, 2021m; 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 2015e; 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 2021m; GCRP 2016; Reid et al. 2016, 2019). 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 2021m; 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 2021m; 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 2021m; 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 2021m; 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 2021m; 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 2021m; 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 2021a; 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 2021m). 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 2021m; 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 2021m; 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 2021m; 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 et 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).

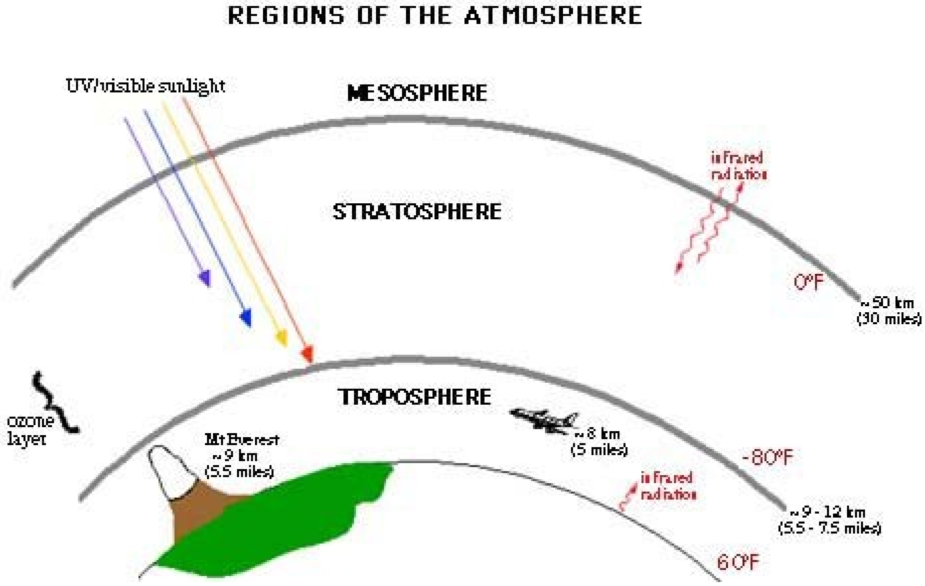
Local and traditional knowledge is a valuable source of information for adapting to climate change (IPCC 2014b; GCRP 2014). There is high agreement in the literature that the integration of local and traditional and scientific knowledge increases adaptive capacity (IPCC 2014b citing Kofinas et al. 2002, 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).[61] 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 8.6.4-1).

[61] 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 8.6.4-1. 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* and *extremely 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 1979, respectively (IPCC 2021b). 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.[62] Subsequent agreements have followed that incorporate more stringent reductions of ozone-depleting substances and expand the scope to include additional chemical species that attack ozone. Some ozone-depleting substances such as 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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[62] The polar regions experience the greatest reduction in total ozone, with about a 5 percent reduction in the Arctic and 18 percent reduction in the Antarctic (Fahey and Hegglin 2011). Significant thinning in the ozone layer has been observed above the Antarctic since the spring of 1985, to such a degree it is termed the *ozone hole* (Ravishankara et al. 2008). This location is particularly susceptible to ozone loss due to a combination of atmospheric circulation patterns, and the buildup of ozone-depletion precursors during the dark winter months from June to September.

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).[63] Observations have shown that these winds can extend through the troposphere to the surface, leading to cooling over most of Antarctica. These studies suggest changes in stratospheric ozone can affect surface climate parameters.

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, thus 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 (CFCs), CH_4, and N_2O by reducing their lifetime and increasing their removal from the atmosphere. In addition, this could increase the vertical transport of ozone concentrations from the stratosphere to the troposphere over mid-latitude and polar regions (Fahey et al. 2008 citing Butchart and Scaife 2001).

[63] During the polar winter, a giant vortex with wind speeds exceeding 300 kilometers (186 miles) per hour can establish above the South Pole, acting like a barrier that accumulates ozone-depleting substances. In Antarctic springtime, temperatures begin to warm and the vortex dissipates. The ozone-depleting substances, now exposed to sunlight, release large amounts of reactive molecules that significantly reduce ozone concentrations (Fahey and Hegglin 2011).

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, (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).

Climatic 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 through2002 and 2009 through 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 and complex events 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. 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 Atlantic Meridional Overturning Circulation (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 regardless of the future GHG emissions trajectory, but the AMOC could also undergo fluctuations because of large natural internal variability (IPCC 2021a). IPCC also reports that it is *very unlikely* that the AMOC will experience an abrupt collapse before 2100 (*medium confidence*) (IPCC 2021a). Should an AMOC collapse occur, it is *very likely* to drive abrupt shifts in weather patterns and the water cycle, including a weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons (IPCC 2021a). There is *low confidence* in changes to the AMOC beyond the 21st century, but a large-scale collapse from large, sustained warming cannot be excluded (IPCC 2021a).

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 2021b). 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 marine-based glaciers grounded on bedrock below sea level. Marine-based glaciers are prone to unground, destabilize, and rapidly contribute to sea-level rise due to a combination of mechanisms including basal melting, retreat, and acceleration. Climate change may drive abrupt and irreversible ice loss through an instability of marine-based sectors of the West Antarctic Ice Sheet in the absence of ice shelf buttressing. Several studies suggest that recent observations of sustained mass loss from large glaciers in Antarctica are consistent with the onset of this instability (Joughin et al. 2014; Rignot et al. 2014; IPCC 2021a). Some studies demonstrate the potential irreversibility of marine-based ice sheet loss and the presence of thresholds beyond which ice loss becomes self-sustaining, whereas other studies note glacier stability can be regained if ice shelves provide buttressing (IPCC 2021a; Mengel and Levermann 2014). Overall, there remains medium agreement for anthropogenic forcing of observed Antarctic mass balance changes and deep uncertainty regarding processes that may contribute to large increases in Antarctic mass loss under high GHG emissions (IPCC 2021a). The likelihood of rapid destabilization of the Greenland Ice Sheet this century is low, because the ice sheet periphery is not predominantly marine-based and most areas of deep water contact between ice sheets and the ocean are limited to narrow troughs and fjord systems that constrict ice discharge into ocean basins (NRC 2013b).

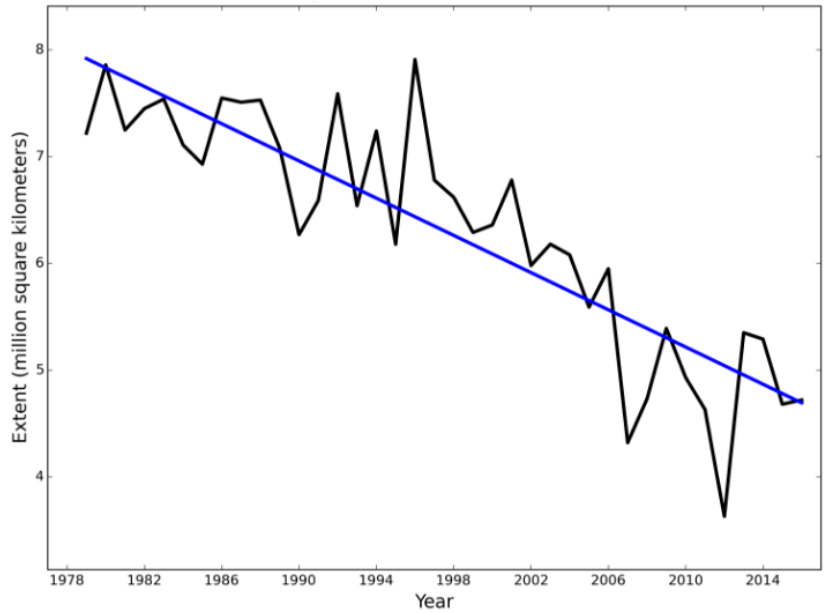
Arctic Sea Ice

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 8.6.4-2) (GCRP 2017). IPCC (2021b) 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.

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 (i.e., where the ice extent is < 1 million km^2) in September by the end of the 21st century under SSP2-4.5, SSP3-7.0, and SSP5-8.5 (IPCC 2021a). In the near term, it is *very likely* that September sea ice area minimums would continue to decrease (IPCC 2021a). The same projections also reveal decreasing March sea ice area maximums but to a lesser extent.

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 opportunities for shipping and economic activities, but also creating new political and legal challenges among circumpolar nations (NRC 2013b).

Figure 8.6.4-2. Average Monthly Arctic Sea-Ice Extent (September 1979–2016)[a]



Notes:
[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.
Source: NSIDC 2016

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 2021b). 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 2021b). 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). The studies speak to the delayed timing of reductions, which increases the overall cumulative amount of GHGs in the atmosphere. Consequently, regardless of future emission rates, the greater amount of GHGs present in the atmosphere increases the likelihood of climatic changes and thus crossing certain tipping points.

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.

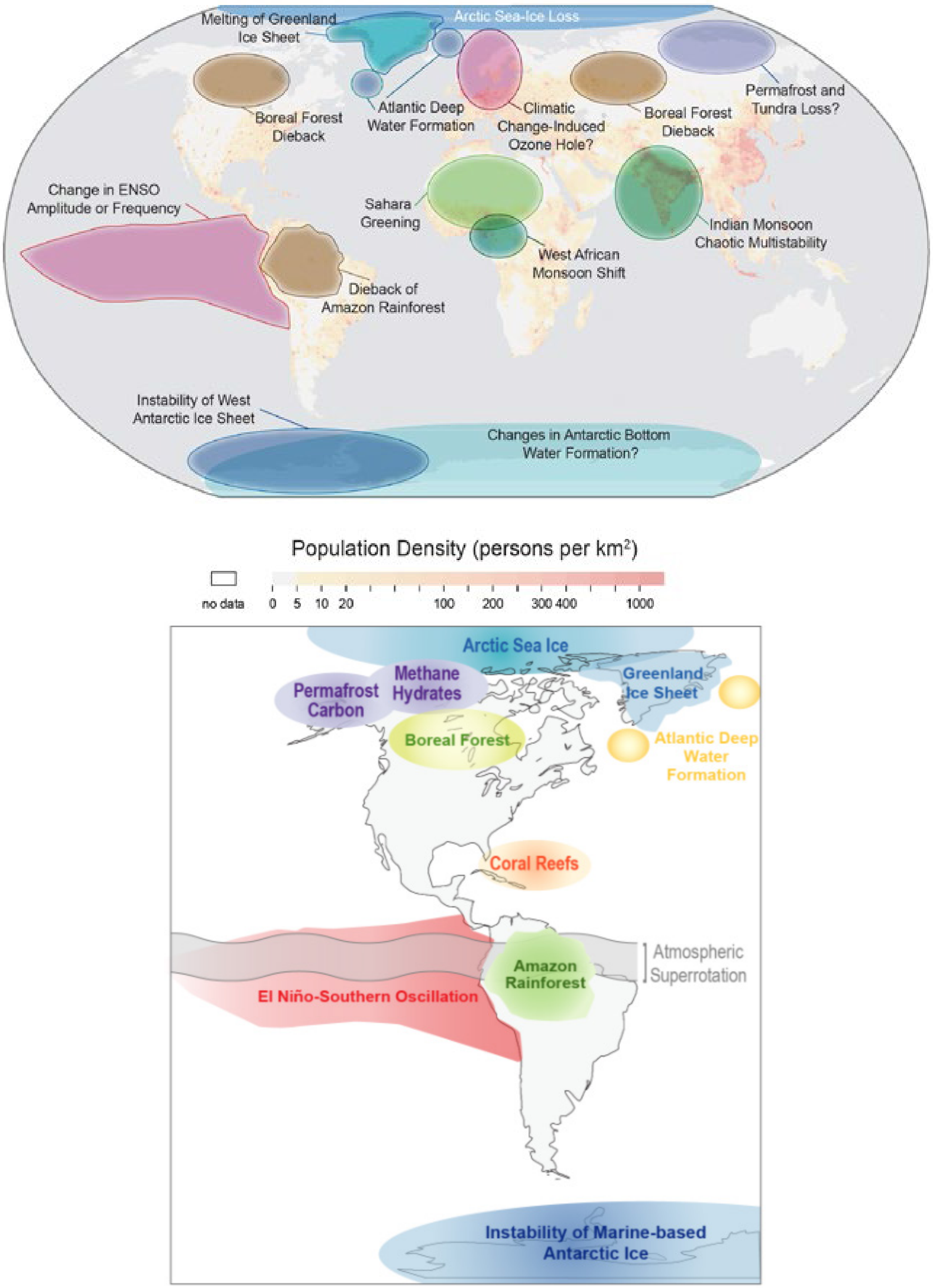
It is expected that some species will become extinct or fall below viable numbers in the next few decades (NRC 2013b). IPCC states that there is *high confidence* that a large fraction of species faces increased extinction risk due to climate change during the 21st century and beyond (IPCC 2014b).

Additional Tipping Points

GCRP (2017) and NRC (2013b) indicate a number of other potential tipping points (Figure 8.6.4-3), which are described in this section.

- **El-Niño-Southern Oscillation (ENSO).** It is *very likely* that regional rainfall variability due to ENSO will increase over this century, particularly in late 21st century (IPCC 2021b). In the United States, the rainfall variability associated with ENSO events will *likely* move eastward in the future, however some model disagreement exists (IPCC 2021a). 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). Ultimately, it is *likely* that extreme El Niño events, including rainfall exceeding the 5 mm/day threshold in the eastern equatorial Pacific, will increase in intensity (IPCC 2021a).
- **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). Overall, this region is projected to experience enhanced aridity (*high confidence*) and although the occurrence of a tipping point driving this ecosystem to an arid state in the 21st century is *unlikely*, continued deforestation and warming increase the probability of the tipping point (IPCC 2021a).
- **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).

Figure 8.6.4-3. Potential Tipping Points



Source: GCRP 2017 adapted from Lenton et al. 2008
km^2 = square kilometer

- **Release of methane hydrates and permafrost and tundra loss.** A catastrophic release of CH_4 to the atmosphere from clathrate hydrates[64] 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.

8.6.4.3 Regional Impacts of Climate Change

In response to the MY 2017–2025 CAFE Standards Draft EIS, NHTSA received a public comment on Section 9.3.2.1 noting that, “with regard to climate change, regional impacts are likely to be particularly relevant to the public.” The comment further encouraged NHTSA to include regional models and information contained in state or regional assessments for each region of the 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 8.6.4.2, *Sectoral Impacts of Climate Change*) for

[64] 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).

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 8.6.4.2, *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.

8.6.5 Cumulative Impacts on Greenhouse Gas Emissions and Climate Change

8.6.5.1 Greenhouse Gas Emissions

NHTSA estimated the emissions resulting from the Proposed Action and alternatives using the methods described in Section 5.3, *Analysis Methods*.

8.6.5.2 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 and

SSP 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 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 RCP emissions scenarios (i.e., RCP2.6 [low], RCP4.5 [medium], RCP6.0 [medium-high], and RCP8.5 [high]) from the IPCC RCP series, and five of the most widely used SSP scenarios (i.e., SSP1-1.9 [low], RCP1-2.6 [medium-low], SSP2-4.5 [medium], SSP3-7.0 [medium-high], SSP5-8.5 [high]).

The GCAM6.0 and SSP2-4.5 scenarios (Section 8.6.2.1, *Global Emissions Scenarios Used for the Cumulative Impact Analysis*) were used to represent the No Action Alternative in the MAGICC runs for the cumulative impacts analysis. Table 8.6.5-1, Table 8.6.5-2 and Figure 8.6.5-1 through Figure 8.6.5-8 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 8.6.5-1 and Figure 8.6.5-3 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 8.6.5-1, Table 8.6.5-2 (and the accompanying figures), the band of estimated CO_2 concentrations as of 2100 is narrow. For GCAM6.0, the values range from 687.29 ppm under the No Action Alternative to 686.49 ppm under Alternative 3. Under SSP2-4.5 the values range from 568.07 ppm under the No Action Alternative to 567.34 ppm under Alternative 3. The values for Alternative 2 and Alternative 2.5 fall within this range. 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 0.22 (Alternative 3) percent by 2100. Using the SSP2-4.5 emissions scenario, global CO_2 emissions from 2021 to 2100 are projected to be 1,873,002 $MMTCO_2$. Global emissions through 2021 are considerably less than in the GCAM6.0 scenario due to the projections that emissions will begin to decline around mid-century. The incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.20 (Alternative 1) and 0.50 (Alternative 3) percent by 2100. The values for Alternative 2 and Alternative 2.5 fall within this range.

Table 8.6.5-1. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise, and Ocean pH by Alternative [a]—GCAM6.0

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	545.87	686.99	1.215	1.810	2.837	22.16	35.15	70.19	8.4150	8.3609	8.2724
Alt. 2	472.48	545.76	686.74	1.215	1.809	2.835	22.16	35.14	70.17	8.4150	8.3610	8.2726
Alt. 2.5	472.47	545.73	686.68	1.215	1.809	2.835	22.16	35.14	70.16	8.4150	8.3610	8.2726
Alt. 3	472.44	545.66	686.49	1.215	1.808	2.832	22.16	35.13	70.11	8.4150	8.3611	8.2727
Reductions Under Alternatives												
Alt. 1	0.04	0.13	0.30	0.000	0.001	0.001	0.00	0.01	0.03	0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.55	0.000	0.001	0.003	0.00	0.01	0.05	-0.0001	-0.0002	-0.0003
Alt. 2.5	0.09	0.27	0.61	0.000	0.001	0.003	0.00	0.01	0.06	-0.0001	-0.0002	-0.0003
Alt. 3	0.12	0.35	0.80	0.001	0.003	0.005	0.00	0.02	0.11	-0.0001	-0.0002	-0.0005

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

Table 8.6.5-2. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise, and Ocean pH by Alternative [a]—SSP2-4.5

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)	470.25	522.24	568.07	1.158	1.605	2.212	22.36	33.76	60.73	8.4168	8.3776	8.3458
Alt. 1	470.21	522.11	567.79	1.158	1.604	2.210	22.36	33.76	60.71	8.4168	8.3777	8.3460
Alt. 2	470.17	521.99	567.54	1.157	1.603	2.208	22.36	33.75	60.67	8.4168	8.3778	8.3462
Alt. 2.5	470.16	521.96	567.47	1.157	1.603	2.208	22.35	33.75	60.65	8.4168	8.3778	8.3462
Alt. 3	470.13	521.89	567.34	1.157	1.602	2.207	22.35	33.74	60.63	8.4169	8.3779	8.3463
Reductions Under Alternatives												
Alt. 1	0.04	0.12	0.27	0.000	0.001	0.001	0.00	0.00	0.02	-0.0000	-0.0001	-0.0002
Alt. 2	0.08	0.25	0.53	0.001	0.002	0.003	0.00	0.01	0.06	-0.0001	-0.0002	-0.0004
Alt. 2.5	0.09	0.28	0.59	0.001	0.002	0.004	0.00	0.02	0.08	-0.0001	-0.0002	-0.0004
Alt. 3	0.12	0.35	0.73	0.001	0.003	0.005	0.00	0.03	0.10	-0.0001	-0.0003	-0.0005

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 8.6.5-1 through Figure 8.6.5-4 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 8.6.5-4, 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. Reductions from Alternative 2 and Alternative 2.5 fall within this range.

Figure 8.6.5-1. Atmospheric Carbon Dioxide Concentrations by Alternative—GCAM6.0

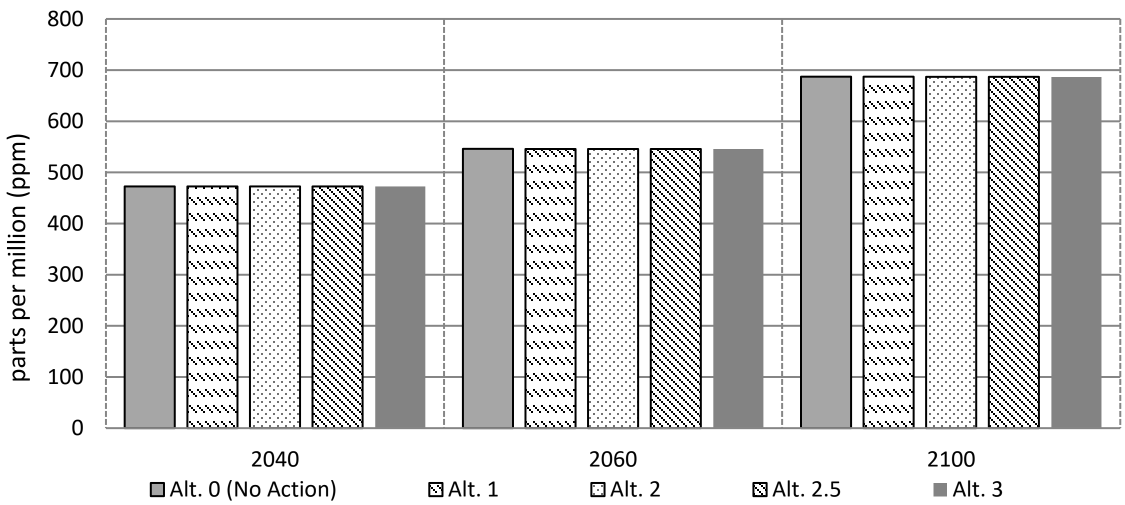


Figure 8.6.5-2. Atmospheric Carbon Dioxide Concentrations by Alternative—SSP2-4.5

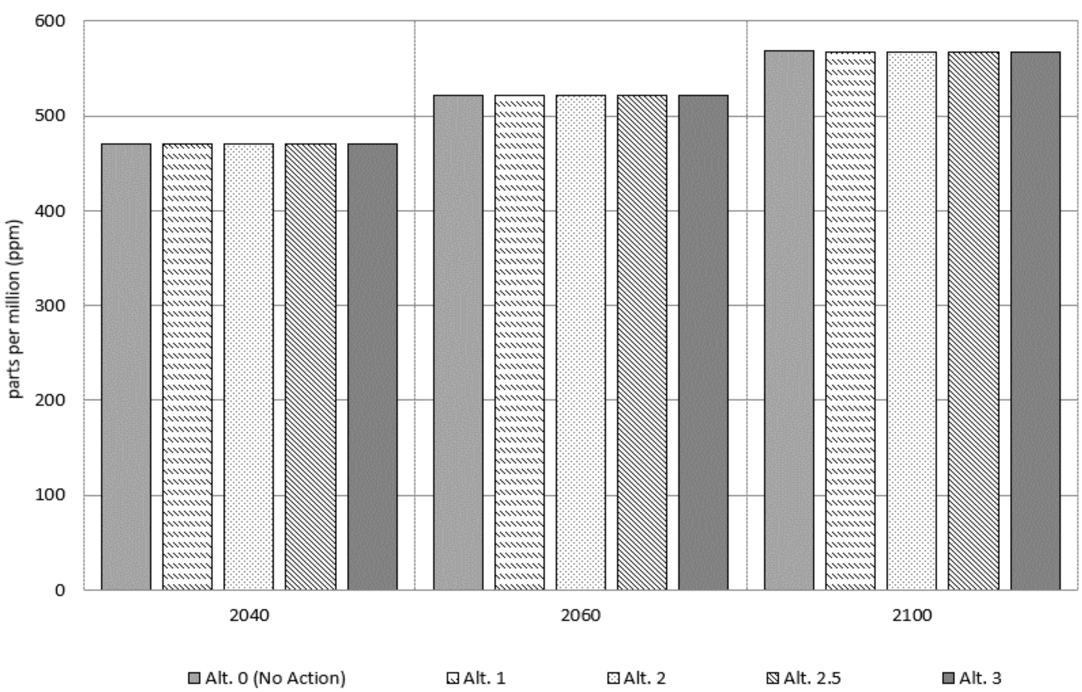


Figure 8.6.5-3. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative—GCAM6.0

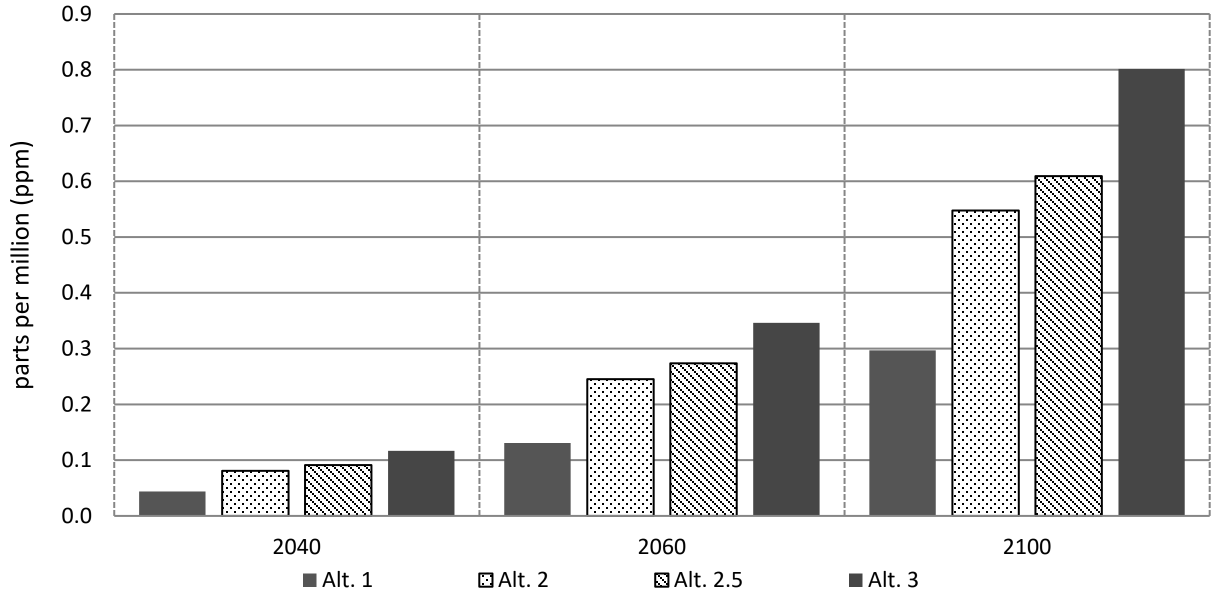
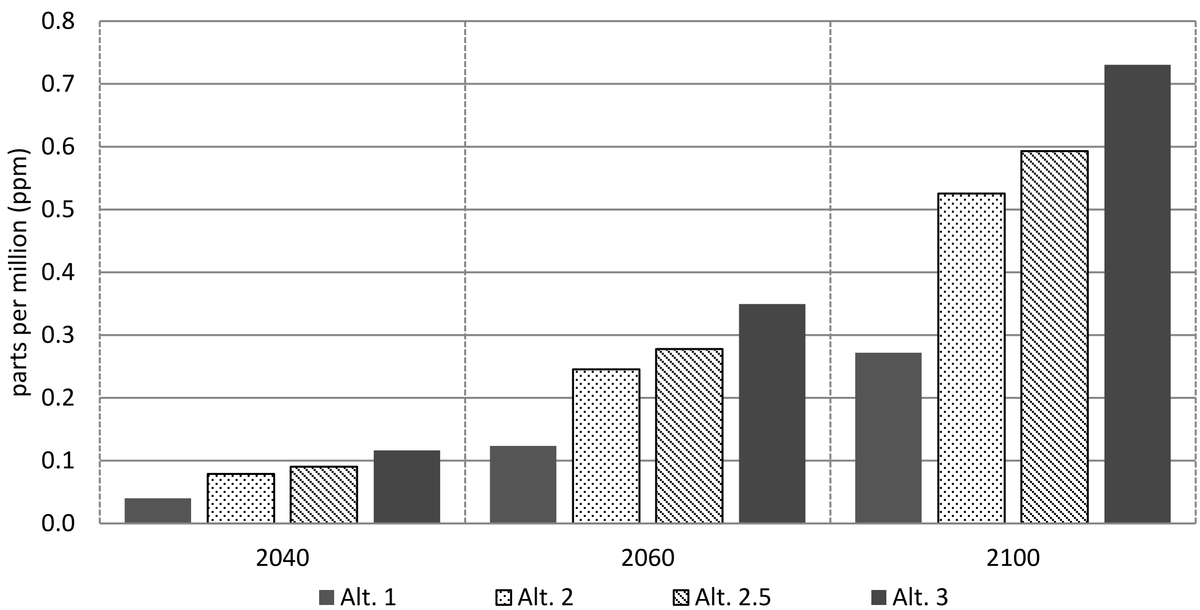


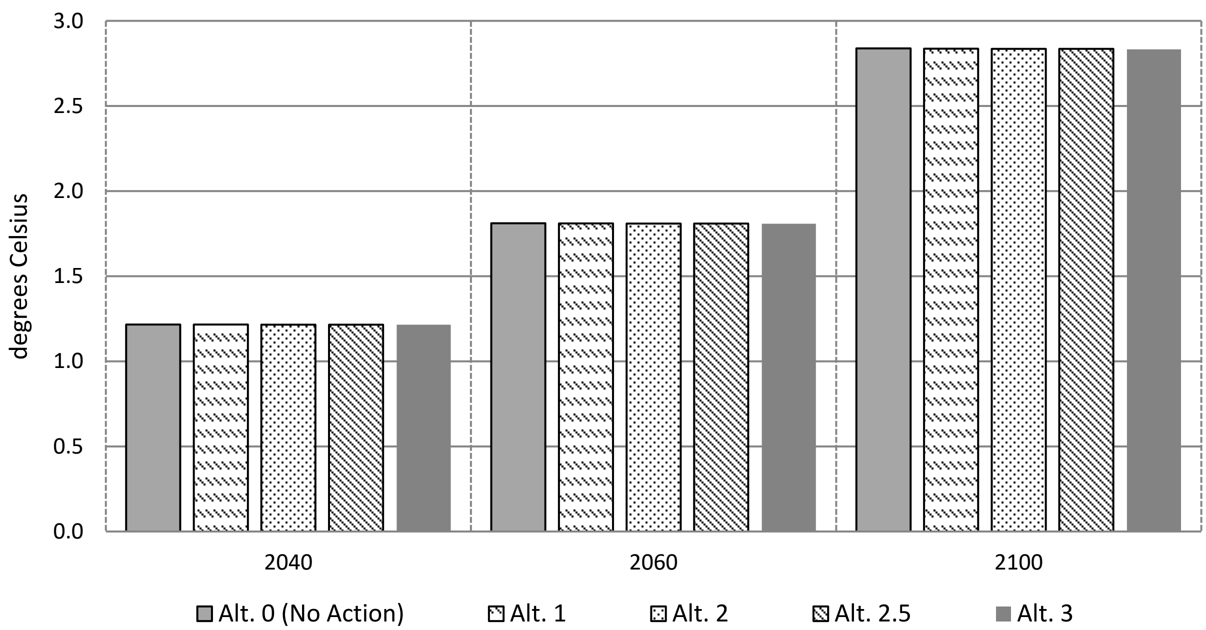
Figure 8.6.5-4. Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative—SSP2-4.5



Temperature

MAGICC simulations of mean global surface air temperature increases are shown in Figure 8.6.5-5 through Figure 8.6.5-8. For the GCAM6.0 scenario, under the No Action Alternative, 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. Using the SSP2-4.5 emissions scenario, the cumulative global mean surface temperature is projected to increase by 1.158°C (2.084°F) by 2040, 1.605°C (2.889°F) by 2060, and 2.212°C (3.982°F) by 2100.[65] The differences among alternatives are small (Figure 8.6.5-7 and Figure 8.6.5-8). For example, in 2100, the decrease in temperature under the action alternatives would range from approximately 0.001°C (0.002°F) under Alternative 1 to 0.005°C (0.009°F) under Alternative 3 for GCAM6.0 and 0.001°C (0.002°F) under Alternative 1 to 0.005°C (0.009°F) under Alternative 3 for SSP2-4.5. For both emissions scenarios, reductions under Alternative 2 and Alternative 2.5 fall within this range. 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 Sixth Assessment Report are summarized in Table 5.4.2-5.

Figure 8.6.5-5. Global Mean Surface Temperature Increase by Alternative—GCAM6.0



[65] 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 8.6.5-6. Global Mean Surface Temperature Increase by Alternative—SSP2-4.5

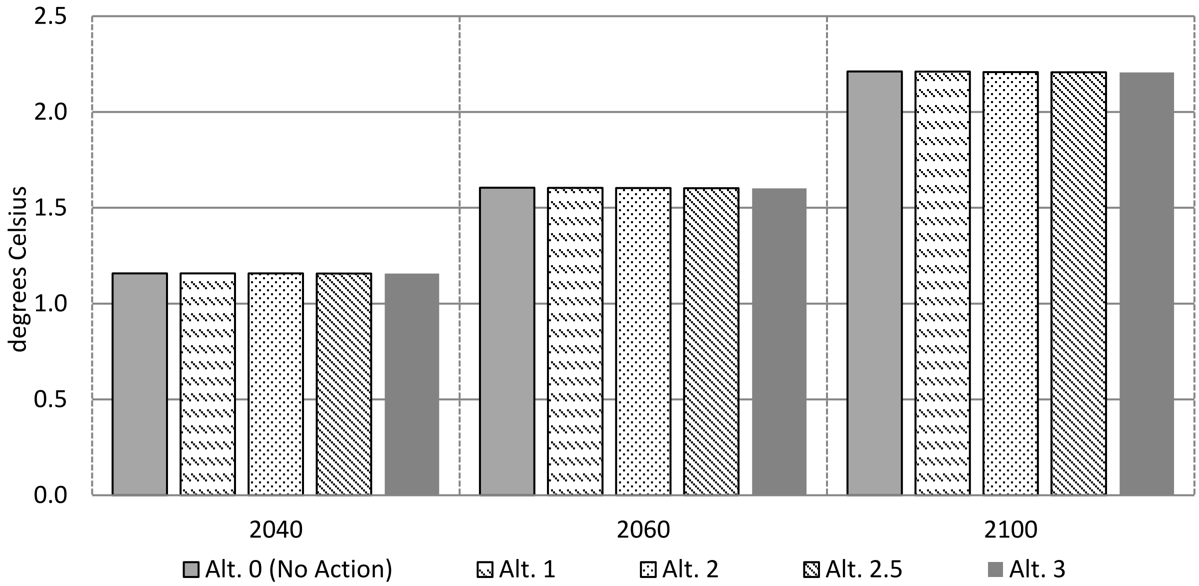


Figure 8.6.5-7. Reductions in Global Mean Surface Temperature Compared to the No Action Alternative—GCAM6.0

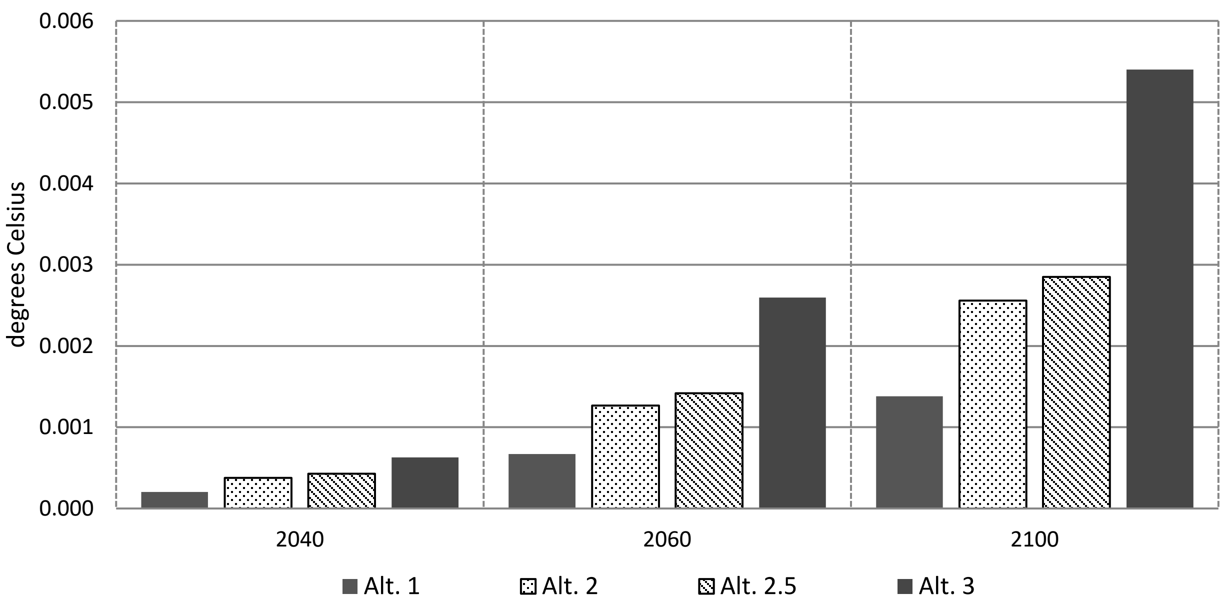
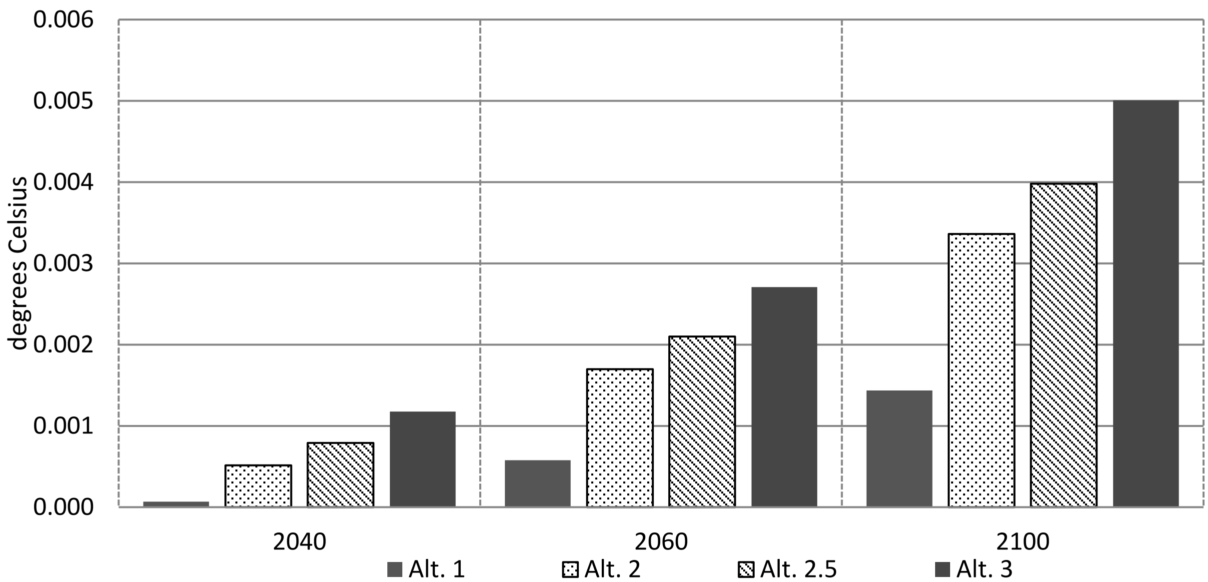


Figure 8.6.5-8. Reductions in Global Mean Surface Temperature Compared to the No Action Alternative—SSP2-4.5



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 8.6.5-3 and Table 8.6.5-4, the reduction would be less than 0.02 percent in all instances for both GCAM6.0 and SSP2-4.5 emissions scenarios.

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 8.6.5-3. 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)	1.86%		
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	2.837
Alternative 2	1.215	1.809	2.835
Alternative 2.5	1.215	1.809	2.835
Alternative 3	1.215	1.808	2.832
Reductions in Global Temperature (°C) Compared to the No Action Alternative[b]			
Alternative 1	0.000	0.001	0.001
Alternative 2	0.000	0.001	0.003
Alternative 2.5	0.000	0.001	0.003
Alternative 3	0.001	0.003	0.005
Global Mean Precipitation Increase (%)			
Alternative 0 (No Action)	2.04%	3.04%	4.77%
Alternative 1	2.04%	3.04%	4.77%
Alternative 2	2.04%	3.04%	4.76%
Alternative 2.5	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 2.5	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

Table 8.6.5-4. Global Mean Precipitation (Percent Increase) Based on SSP2-4.5 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)	2.16%		
Global Temperature Above Average 1986–2005 Levels (°C) for the SSP2-4.5 Scenario			
Alternative 0 (No Action)	1.158	1.605	2.212
Alternative 1	1.158	1.604	2.210
Alternative 2	1.157	1.603	2.208
Alternative 2.5	1.157	1.603	2.208
Alternative 3	1.157	1.602	2.207
Reductions in Global Temperature (°C) Compared to the No Action Alternative[b]			
Alternative 1	0.000	0.001	0.001
Alternative 2	0.001	0.002	0.003
Alternative 2.5	0.001	0.002	0.004
Alternative 3	0.001	0.003	0.005
Global Mean Precipitation Increase (%)			
Alternative 0 (No Action)	2.50%	3.47%	4.78%
Alternative 1	2.50%	3.46%	4.77%
Alternative 2	2.50%	3.46%	4.77%
Alternative 2.5	2.50%	3.46%	4.77%
Alternative 3	2.50%	3.46%	4.77%
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%	0.01%
Alternative 2.5	0.00%	0.00%	0.01%
Alternative 3	0.00%	0.01%	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 increase in precipitation is less than 0.005% and thus is rounded to 0.00%.
SSP = Shared Socioeconomic Pathway; 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 Sixth Assessment Report are summarized in Table 5.4.2-10.

Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.2.2.1, *Climate Change Attributes*, under *Sea-Level Rise*. Table 8.6.5-1 presents the cumulative impact on sea-level rise from each alternative and show sea-level rise in 2100 under the GCAM6.0 scenario, ranging from 70.22 centimeters (27.65 inches) under the No Action Alternative to 70.11 centimeters (27.60 inches) under Alternative 3, for a maximum increase of 0.11 centimeter (0.04 inch) by 2100. Table 8.6.5-2 presents the cumulative impact on sea-level rise from each alternative under the SSP2-4.5 scenario and shows sea-level rise in 2100 ranging from 60.73 centimeters (23.91 inches) under the No Action Alternative to 60.63 centimeters (23.87 inches) under Alternative 3, for a maximum decrease of 0.10 centimeter (0.04 inch) by 2100. The values for Alternative 2 and Alternative 2.5 fall within these ranges.

Ocean pH

Table 8.6.5-1 shows the projected increase of ocean pH under each action alternative compared to the No Action Alternative. Using the GCAM6.0 scenario, 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 0.0005 by 2100. Alternatively, the SSP2-4.5 scenario identifies ocean pH values ranging from 8.3458 (No Action Alternative) to 8.3463 (Alternative 3) in Table 8.6.5-2, for a maximum increase in pH of 0.0005 by 2100. The values for Alternative 2 and Alternative 2.5 fall within these ranges.

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 assesses climate sensitivities against the full range of results by utilizing baseline results, the least stringent, and most stringent action alternative. Sensitivity analysis results for Alternative 2 and Alternative 2.5 would fall within the ranges presented below. Table 8.6.5-5 through Table 8.6.5-10 present the results of the sensitivity analyses for cumulative impacts.

Table 8.6.5-5. 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	8.3927
	2.0	457.30	500.90	521.85	0.793	1.114	1.389	40.80	8.3842
	2.5	460.23	506.45	533.11	0.952	1.352	1.729	50.33	8.3761
	3.0	462.88	511.57	543.93	1.097	1.573	2.059	60.04	8.3685
	4.5	469.44	524.72	573.71	1.464	2.152	2.978	89.27	8.3481
	6.0	474.49	535.31	599.95	1.752	2.627	3.797	117.62	8.3309
Alt. 1	1.5	454.00	494.76	509.91	0.618	0.858	1.039	31.57	8.3929
	2.0	457.26	500.78	521.59	0.793	1.113	1.387	40.78	8.3844
	2.5	460.19	506.32	532.85	0.952	1.351	1.728	50.31	8.3763
	3.0	462.84	511.44	543.66	1.097	1.572	2.057	60.01	8.3686
	4.5	469.40	524.59	573.42	1.463	2.151	2.975	89.22	8.3483
	6.0	474.44	535.17	599.65	1.751	2.626	3.794	117.56	8.3311
Alt. 3	1.5	453.93	494.56	509.50	0.618	0.857	1.036	31.53	8.3932
	2.0	457.18	500.57	521.16	0.792	1.112	1.384	40.72	8.3847
	2.5	460.12	506.11	532.40	0.951	1.349	1.724	50.24	8.3766
	3.0	462.77	511.23	543.20	1.096	1.570	2.053	59.93	8.3690
	4.5	469.33	524.37	572.91	1.463	2.148	2.970	89.09	8.3486
	6.0	474.37	534.95	599.10	1.751	2.623	3.787	117.38	8.3314
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.12	0.25	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.26	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.04	0.13	0.27	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.27	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.04	0.13	0.29	0.000	0.001	0.002	0.05	-0.0002
	6.0	0.04	0.13	0.31	0.000	0.001	0.002	0.06	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.66	0.000	0.002	0.003	0.05	-0.0005
	2.0	0.12	0.33	0.68	0.001	0.002	0.004	0.07	-0.0005
	2.5	0.12	0.34	0.71	0.001	0.002	0.005	0.09	-0.0005
	3.0	0.12	0.34	0.74	0.001	0.003	0.006	0.12	-0.0005
	4.5	0.12	0.35	0.80	0.001	0.003	0.008	0.18	-0.0005
	6.0	0.12	0.35	0.86	0.001	0.004	0.009	0.24	-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

Table 8.6.5-6. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for SSP1-2.6 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	444.09	448.90	410.27	0.686	0.774	0.664	28.16	8.4668
	2.0	447.56	455.08	419.62	0.879	1.020	0.926	36.26	8.4586
	2.5	450.66	460.79	428.77	1.054	1.253	1.192	44.73	8.4508
	3.0	453.47	466.08	437.66	1.214	1.473	1.457	53.43	8.4432
	4.5	460.38	479.67	462.49	1.616	2.054	2.221	79.91	8.4229
	6.0	465.66	490.63	484.64	1.931	2.537	2.919	105.82	8.4056
Alt. 1	1.5	444.05	448.78	410.05	0.686	0.773	0.663	28.15	8.4670
	2.0	447.51	454.96	419.39	0.879	1.019	0.925	36.24	8.4588
	2.5	450.62	460.68	428.53	1.054	1.253	1.191	44.71	8.4510
	3.0	453.43	465.96	437.41	1.214	1.472	1.455	53.40	8.4434
	4.5	460.34	479.55	462.23	1.616	2.053	2.219	79.87	8.4231
	6.0	465.62	490.51	484.37	1.931	2.536	2.916	105.76	8.4058
Alt. 3	1.5	443.97	448.57	409.69	0.685	0.772	0.661	28.10	8.4673
	2.0	447.44	454.75	419.01	0.878	1.018	0.922	36.18	8.4592
	2.5	450.55	460.46	428.13	1.053	1.250	1.187	44.63	8.4513
	3.0	453.35	465.73	437.00	1.213	1.470	1.451	53.31	8.4438
	4.5	460.26	479.32	461.76	1.615	2.050	2.213	79.71	8.4235
	6.0	465.54	490.26	483.86	1.929	2.532	2.909	105.55	8.4062
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.12	0.22	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.12	0.23	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.04	0.12	0.24	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.12	0.24	0.000	0.001	0.002	0.03	-0.0002
	4.5	0.04	0.12	0.26	0.000	0.001	0.002	0.04	-0.0002
	6.0	0.04	0.12	0.28	0.000	0.001	0.003	0.05	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.58	0.001	0.002	0.003	0.06	-0.0005
	2.0	0.12	0.33	0.61	0.001	0.002	0.004	0.08	-0.0005
	2.5	0.12	0.34	0.64	0.001	0.003	0.005	0.10	-0.0005
	3.0	0.12	0.34	0.66	0.001	0.003	0.006	0.12	-0.0006
	4.5	0.12	0.36	0.73	0.002	0.004	0.008	0.19	-0.0006
	6.0	0.12	0.37	0.79	0.002	0.005	0.010	0.26	-0.0006

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; SSP = Shared Socioeconomic Pathway

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 8.6.5-7 through Table 8.6.5-10, 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 scenarios with the highest CO_2 emissions (GCAMReference and SSP3-7.0 scenarios), and the least impact in the scenarios with the lowest CO_2 emissions (RCP4.5 and SSP1-2.6). The total range of the impact of Alternative 3 on CO_2 concentrations in 2100 is roughly 0.58 to 0.98 ppm across all six global emissions scenarios. Alternative 3, using the GCAM6.0 scenario and a 3.0°C (5.4°F) climate sensitivity, would have a 0.80 ppm decrease compared to Alternative 1, which would have a 0.30 ppm decrease in 2100. Similarly, Alternative 3, using the SSP2-4.5 scenario and a 3.0°C (5.4°F) climate sensitivity, would have a 0.73 ppm decrease compared to Alternative 1, which would have a 0.27 ppm decrease in 2100. The values for Alternative 2 and Alternative 2.5 fall within the aforementioned ranges.

Table 8.6.5-7. 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	463.29	527.60	643.17	0.694	1.004	1.505	36.93	8.2981
	2.0	466.69	534.20	658.44	0.885	1.294	1.970	47.81	8.2890
	2.5	469.75	540.28	673.04	1.058	1.562	2.414	58.95	8.2805
	3.0	472.51	545.87	686.99	1.215	1.810	2.837	70.19	8.2724
	4.5	479.34	560.24	725.23	1.611	2.455	3.996	103.75	8.2511
	6.0	484.58	571.82	759.04	1.920	2.983	5.035	136.30	8.2331
Alt. 3	1.5	463.21	527.39	642.73	0.694	1.003	1.503	36.89	8.2984
	2.0	466.62	533.99	657.97	0.884	1.292	1.967	47.76	8.2893
	2.5	469.68	540.06	672.55	1.058	1.560	2.410	58.88	8.2808
	3.0	472.44	545.66	686.49	1.215	1.808	2.832	70.11	8.2727
	4.5	479.27	560.02	724.67	1.610	2.452	3.991	103.62	8.2515
	6.0	484.51	571.59	758.42	1.920	2.980	5.028	136.12	8.2334
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.13	0.27	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.28	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.04	0.13	0.29	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.30	0.000	0.001	0.001	0.03	-0.0002
	4.5	0.04	0.13	0.32	0.000	0.001	0.002	0.04	-0.0002
	6.0	0.04	0.14	0.33	0.000	0.001	0.002	0.06	-0.0002
Reductions Under Alternative 3 compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.72	0.000	0.002	0.003	0.05	-0.0004
	2.0	0.12	0.34	0.75	0.001	0.002	0.004	0.07	-0.0004
	2.5	0.12	0.34	0.78	0.001	0.002	0.005	0.09	-0.0004
	3.0	0.12	0.35	0.80	0.001	0.003	0.005	0.11	-0.0005
	4.5	0.12	0.35	0.87	0.001	0.003	0.007	0.17	-0.0005
	6.0	0.12	0.36	0.95	0.001	0.004	0.009	0.24	-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*, 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 8.6.5-8. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for SSP2-4.5 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	460.79	504.72	531.64	0.651	0.874	1.122	32.45	8.3709
	2.0	464.28	511.04	544.28	0.836	1.135	1.496	41.68	8.3621
	2.5	467.42	516.87	556.43	1.004	1.378	1.860	51.15	8.3537
	3.0	470.25	522.24	568.07	1.158	1.605	2.212	60.73	8.3458
	4.5	477.22	536.01	600.00	1.546	2.197	3.187	89.29	8.3249
	6.0	482.55	547.07	628.01	1.851	2.683	4.053	116.75	8.3074
Alt. 1	1.5	460.75	504.60	531.38	0.651	0.874	1.121	32.44	8.3711
	2.0	464.24	510.92	544.02	0.836	1.134	1.495	41.66	8.3622
	2.5	467.38	516.74	556.16	1.004	1.378	1.859	51.13	8.3539
	3.0	470.21	522.11	567.79	1.158	1.604	2.210	60.71	8.3460
	4.5	477.18	535.89	599.71	1.546	2.196	3.185	89.26	8.3251
	6.0	482.51	546.95	627.71	1.851	2.682	4.051	116.71	8.3075
Alt. 3	1.5	460.67	504.39	530.98	0.651	0.873	1.119	32.40	8.3714
	2.0	464.17	510.70	543.60	0.835	1.133	1.493	41.61	8.3625
	2.5	467.30	516.52	555.72	1.003	1.376	1.856	51.07	8.3542
	3.0	470.13	521.89	567.34	1.157	1.602	2.207	60.63	8.3463
	4.5	477.10	535.65	599.20	1.545	2.193	3.180	89.13	8.3254
	6.0	482.43	546.70	627.16	1.849	2.679	4.045	116.53	8.3079
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.12	0.25	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.12	0.26	0.000	0.000	0.001	0.01	-0.0002
	2.5	0.04	0.12	0.27	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.12	0.27	0.000	0.001	0.001	0.02	-0.0002
	4.5	0.04	0.12	0.29	0.000	0.001	0.002	0.03	-0.0002
	6.0	0.04	0.12	0.30	0.000	0.001	0.002	0.04	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.65	0.001	0.002	0.003	0.05	-0.0005
	2.0	0.12	0.34	0.68	0.001	0.002	0.004	0.07	-0.0005
	2.5	0.12	0.34	0.71	0.001	0.002	0.004	0.08	-0.0005
	3.0	0.12	0.35	0.73	0.001	0.003	0.005	0.10	-0.0005
	4.5	0.12	0.36	0.80	0.001	0.003	0.007	0.16	-0.0005
	6.0	0.12	0.37	0.85	0.002	0.004	0.008	0.22	-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; SSP = Shared Socioeconomic Pathway

Table 8.6.5-9. 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	8.3714
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74	8.3625
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52	8.3542
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28	8.3463
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93	8.3254
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70	8.3079
Alt. 1	1.5	469.57	545.97	737.20	0.741	1.128	1.889	41.03	8.2447
	2.0	473.05	552.96	755.19	0.941	1.445	2.450	52.73	8.2351
	2.5	476.17	559.39	772.39	1.122	1.738	2.980	64.50	8.2261
	3.0	478.99	565.31	788.80	1.287	2.008	3.483	76.26	8.2177
	4.5	485.95	580.49	833.94	1.699	2.706	4.866	110.89	8.1954
	6.0	491.30	592.74	874.51	2.019	3.278	6.169	144.64	8.1761
Alt. 3	1.5	469.49	545.76	736.76	0.740	1.127	1.888	41.01	8.2449
	2.0	472.98	552.75	754.75	0.941	1.444	2.449	52.70	8.2353
	2.5	476.10	559.18	771.93	1.122	1.737	2.978	64.47	8.2264
	3.0	478.92	565.10	788.33	1.287	2.006	3.481	76.22	8.2180
	4.5	485.88	580.27	833.45	1.698	2.705	4.864	110.83	8.1956
	6.0	491.22	592.51	874.00	2.019	3.277	6.165	144.55	8.1763
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.13	0.29	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.29	0.000	0.001	0.001	0.02	-0.0002
	2.5	0.04	0.13	0.30	0.000	0.001	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.31	0.000	0.001	0.001	0.03	-0.0002
	4.5	0.04	0.13	0.34	0.000	0.001	0.002	0.04	-0.0002
	6.0	0.04	0.14	0.37	0.000	0.001	0.003	0.06	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.33	0.72	0.000	0.001	0.002	0.03	-0.0004
	2.0	0.12	0.34	0.74	0.000	0.001	0.002	0.04	-0.0004
	2.5	0.12	0.34	0.76	0.000	0.002	0.003	0.05	-0.0004
	3.0	0.12	0.34	0.78	0.001	0.002	0.003	0.07	-0.0004
	4.5	0.12	0.35	0.82	0.001	0.002	0.005	0.10	-0.0004
	6.0	0.12	0.36	0.88	0.001	0.003	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 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

Table 8.6.5-10. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for SSP3-7.0 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	478.50	557.44	746.90	0.764	1.164	1.934	42.07	8.2395
	2.0	482.04	564.64	765.59	0.970	1.491	2.508	54.17	8.2297
	2.5	485.22	571.24	783.41	1.155	1.791	3.050	66.36	8.2205
	3.0	488.08	577.31	800.39	1.324	2.068	3.564	78.53	8.2119
	4.5	495.12	592.82	847.00	1.743	2.784	4.976	114.38	8.1891
	6.0	500.49	605.26	888.66	2.070	3.369	6.297	149.24	8.1696
Alt. 1	1.5	478.46	557.32	746.61	0.764	1.163	1.933	42.06	8.2396
	2.0	482.00	564.52	765.29	0.970	1.490	2.507	54.15	8.2298
	2.5	485.18	571.12	783.11	1.155	1.791	3.049	66.34	8.2206
	3.0	488.04	577.18	800.09	1.324	2.068	3.562	78.51	8.2120
	4.5	495.08	592.69	846.70	1.744	2.784	4.974	114.35	8.1892
	6.0	500.45	605.13	888.28	2.070	3.369	6.294	149.20	8.1697
Alt. 3	1.5	478.39	557.10	746.16	0.763	1.162	1.932	42.02	8.2399
	2.0	481.93	564.29	764.82	0.969	1.489	2.505	54.11	8.2301
	2.5	485.10	570.89	782.61	1.154	1.789	3.046	66.28	8.2209
	3.0	487.96	576.95	799.57	1.322	2.066	3.559	78.43	8.2123
	4.5	495.00	592.44	846.10	1.742	2.781	4.970	114.22	8.1895
	6.0	500.38	604.87	887.67	2.068	3.365	6.288	149.03	8.1700
Reductions Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.04	0.13	0.28	0.000	0.000	0.001	0.01	-0.0002
	2.0	0.04	0.13	0.29	0.000	0.000	0.001	0.01	-0.0002
	2.5	0.04	0.13	0.30	0.000	0.000	0.001	0.02	-0.0002
	3.0	0.04	0.13	0.30	0.000	0.001	0.001	0.02	-0.0002
	4.5	0.04	0.13	0.30	0.000	0.001	0.002	0.03	-0.0001
	6.0	0.04	0.13	0.37	0.000	0.001	0.002	0.04	-0.0002
Reductions Under Alternative 3 Compared to the No Action Alternative									
Alt. 3	1.5	0.12	0.34	0.74	0.001	0.002	0.002	0.04	-0.0004
	2.0	0.12	0.35	0.77	0.001	0.002	0.003	0.06	-0.0004
	2.5	0.12	0.36	0.79	0.001	0.002	0.004	0.08	-0.0004
	3.0	0.12	0.36	0.82	0.001	0.003	0.004	0.10	-0.0004
	4.5	0.12	0.37	0.90	0.001	0.003	0.006	0.15	-0.0004
	6.0	0.12	0.38	0.98	0.002	0.004	0.009	0.22	-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; SSP = Shared Socioeconomic Pathway

The sensitivity of the simulated global mean surface temperatures for 2040, 2060, and 2100 varies over the simulation period, as shown in Table 8.6.5-5 through Table 8.6.5-10. 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 modeling using the GCAMReference and SSP3-7.0 scenario (the scenarios with the highest global emissions of GHGs), the action alternatives result in a greater reduction in global mean surface temperature than when modeled under RCP4.5 and SSP1-2.6 (the scenarios 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 8.6.5-5 through Table 8.6.5-10. 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.

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 for carbon monoxide (CO), nitrogen oxide (NO_X), and sulfur dioxide (SO_2) and decrease for particulate matter (PM2.5) and volatile organic compounds (VOCs) under the Proposed Action and alternatives, compared to the No Action Alternative, before declining in 2035 and 2050 under all action alternatives for all criteria pollutants except for SO_2. The same is true for nationwide emissions of hazardous air pollutants (expected increases in 2025 and decreases in 2035 and 2050 under the action alternatives for most pollutants), except for diesel particulate matter (DPM) emissions, which are expected to decrease

[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).

in all analysis years under all action alternatives, compared to the No Action Alternative. In 2035 and 2050, aggregate emissions of 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. 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 and NO_X, the majority of nonattainment areas would experience increases in emissions across all action alternatives in 2025, but decreases in 2035 and 2050, compared to the No Action Alternative. For PM2.5, SO_2, and VOCs, across all alternatives, the majority of nonattainment areas would experience decreases in emissions in 2025, 2035, and 2050 compared to the No Action Alternative.

In 2025, compared to the No Action Alternative, in the majority of nonattainment areas all action alternatives would have increased emissions of most toxic air pollutants but would have decreased emissions of DPM. In 2035, compared to the No Action Alternative, the results are mixed: for acetaldehyde and acrolein, emissions would increase in the majority of nonattainment areas under Alternative 1 and decrease under Alternatives 2, 2.5, and 3, while for benzene, 1,3-butadiene, DPM, and formaldehyde, emissions in 2035 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.

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*), except there would be no changes to some impacts in 2025 for some alternatives. In 2025, the decreases in health impacts would be largest for Alternative 1, smaller for Alternative 3, still smaller for Alternative 2, and smallest for Alternative 2.5. The decreases in health impacts would get larger from Alternative 1 to Alternative 3 in 2035 and 2050, except that for some health impacts in 2035 and 2050 the decreases are smaller for Alternative 2.5 than for Alternative 2. These decreases reflect the generally increasing stringency of the action alternatives as they become implemented. Under each action alternative, the decreases in health impacts would get larger from 2025 to 2050 (except that decreases in “Non-fatal heart attacks [all other studies]” would be unchanged between 2035 and 2050 under Alternatives 1 and 2).

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 final rule preamble, Technical Support Document, and Final Regulatory Impact Analysis issued concurrently with this Final 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 2021n). 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]

[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, there nevertheless would be decreases in most pollutant emissions compared to the No Action Alternative. 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 2025, 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 final rule, consult Chapter 6 of NHTSA's Final 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 RESPONSES TO PUBLIC COMMENTS

On August 10, 2021, the United States Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA) released a proposed rule that would revise Model Year (MY) 2024–2026 Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks. With the notice of proposed rulemaking (NPRM), NHTSA issued a Draft Supplemental Environmental Impact Statement (Draft SEIS) analyzing the environmental impacts of MY 2024–2026 CAFE standards and reasonable alternative standards. The U.S. Environmental Protection Agency (EPA) published a Notice of Availability for NHTSA's Draft SEIS in the *Federal Register* on August 20, 2021; publication of the Notice of Availability in the *Federal Register* initiated the Draft SEIS public comment period. The Notice of Availability requested public input on the agency's environmental analysis to Docket No. NHTSA-2021-0054 by October 4, 2021. On September 3, 2021, NHTSA's NPRM was published in the *Federal Register* and it invited the public to submit comments on the NPRM on or before October 26, 2021 (via Docket No. NHTSA-2021-0053). On September 24, 2021, NHTSA extended the comment period for the Draft SEIS to October 26, 2021.

NHTSA also held a virtual public hearing on the Draft SEIS and the proposed rule on October 13, 2021. NHTSA received statements from 77 individuals at the hearing. The agency received 14 comments in the docket for the Draft SEIS.

In preparing this Final SEIS, NHTSA reviewed comments received in SEIS Docket No. NHTSA-2021-0054 and comments relevant to the SEIS submitted to the NHTSA rulemaking docket (Docket No. NHTSA-2021-0053). NHTSA considered and evaluated all written and oral comments received during the public comment period in the preparation of this Final SEIS. In this chapter of the Final SEIS, NHTSA has quoted substantive excerpts from these comments and responded to the comments, as required by NEPA (40 CFR § 1503.4). The agency updated the SEIS in response to comments on the rule and Draft SEIS and based on updated information that became available after the agency issued the Draft SEIS. The comments presented in this chapter (including all footnotes) are verbatim comment excerpts as written by the commenters.

NHTSA approached those comments submitted to the SEIS and rulemaking dockets that were not substantive to specific aspects of the SEIS as follows:

- NHTSA received comments directly addressing or otherwise related to the proposed rule, Technical Support Document (TSD), or Preliminary Regulatory Impact Analysis (PRIA) under the rulemaking docket (NHTSA-2021-0053) and the SEIS docket (NHTSA-2021-0054). Topics of these comments included technology cost and effectiveness, economic impacts of the rule, harmonization of the NHTSA and EPA rules, balancing the Energy Policy and Conservation Act of 1975 (EPCA) statutory criteria, and the underlying assumptions in them. NHTSA has reviewed all of the comments, and in this chapter, **NHTSA includes and addresses only those comments (or portions of those comments) considered substantive to the SEIS. NHTSA addresses substantive comments that concern the rule but that are not related to the SEIS in the preamble to the final rule and its associated documents in the public docket.**
- NHTSA received oral and written comments stating either general support for or general opposition to the proposed rule. NHTSA appreciates those comments, but because they do not raise specific issues or concerns pertaining to the SEIS, this chapter does not respond to those comments. This chapter responds to comments specific to the SEIS or to those that substantively address SEIS analytical methods or approaches.

Written comments submitted to NHTSA are part of the administrative record and are available on the Federal Docket at http://www.regulations.gov, Reference Docket No.: NHTSA-2021-0054 (SEIS) and NHTSA-2021-0053 (rulemaking). The closed captioning recorded at the virtual public meeting was sometimes indiscernible and where this occurred, it is noted in this chapter. As noted in a memorandum posted to the SEIS docket (NHTSA-2021-0054), the video of the virtual public meeting is available for viewing via a link on the NHTSA website.[1] A text file of the closed captioning from the virtual public hearing is available upon request.

Table 10-1 lists the topics addressed in this chapter. Sections 10.1 through 10.9 provide relevant comments on the Draft SEIS and the proposed rule and NHTSA's responses to those comments.

Table 10-1. Outline of Issues Raised in Public Comments on the Draft SEIS

10.1	**Purpose and Need**
10.1.1	Purpose and Need Statement
10.1.2	NEPA Process
10.2	**Proposed Action and Alternatives**
10.2.1	No Action Alternative/Baseline (Alternative 0)
10.2.2	Reasonable Range of Alternatives
10.2.3	Suggestions for More Stringent Alternatives
10.3	**Energy**
10.4	**Air Quality**
10.4.1	Local Air Quality Impacts
10.4.2	Health Effects
10.5	**Greenhouse Gas Emissions and Climate Change**
10.5.1	Social Cost of Carbon
10.6	**Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies**
10.6.1	Energy Sources
10.6.2	Vehicle Materials and Technologies
10.7	**Other Impacts**
10.7.1	Endangered Species Act
10.7.2	Environmental Justice
10.8	**Cumulative Impacts**
10.8.1	Health, Societal, and Environmental Impacts of Climate Change
10.9	**Mitigation**

[1] https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy.

10.1 Purpose and Need

10.1.1 Purpose and Need Statement

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

As NHTSA acknowledges in the present proposal, the agency has long considered environmental impacts as part of "the need of the United States to conserve energy," and this interpretation has been approved by both the D.C. Circuit and Ninth Circuit. 86 Fed. Reg. at 49,794 (citing Ctr. for Auto Safety v. NHTSA, 793 F.2d 1322, 1325 n.12 (D.C. Cir. 1986); Public Citizen v. NHTSA, 848 F.2d 256, 262-63 n.27 (D.C. Cir. 1988); Ctr. for Biological Diversity v. NHTSA, 538 F.3d 1172 (9th Cir. 2007)). In SAFE 2, however, NHTSA failed to consider environmental impacts under this factor. Instead, it adopted standards that substantially increase emissions of multiple pollutants that harm public health and that would increase GHG emissions by 923 million metric tons, and it did so without mentioning these environmental impacts as part of its consideration of the need to conserve. See 85 Fed. Reg. at 25,049, 25,054, 25,057, 24,176, 25,144.

The present proposal returns to NHTSA's long-standing approach, and properly examines the environmental impact of the proposal as part of the agency's overall assessment of the need to conserve energy.[2] It concludes that "[a]ll of the action alternatives considered in this proposal reduce carbon dioxide emissions and, thus, the effects of climate change, as compared to the baseline." 86 Fed. Reg. at 49,795. And NHTSA finds that "over the lifetimes of the vehicles that would be subject to this proposal," emissions of criteria pollutants and air toxics "are currently forecast to fall significantly." Id. The examination of these environmental impacts—along with the impacts on "minority and low-income communities who would be most likely to be exposed to the environmental and health effects of oil production, distribution, and consumption, or the impacts of climate change," id.—is a necessary part of the agency's analysis regarding the need to conserve energy. Moreover, consideration of these impacts supports most stringent standards.

Response

NHTSA agrees that this rulemaking would lead to a broad range of potential environmental benefits, including those benefits highlighted by the commenters. The analyses performed for the final rule and this Final SEIS, in addition to the supplementing qualitative discussion of environmental benefits that could not be quantified, continue to support this conclusion. NHTSA discusses how the agency

[2] The adoption of more stringent standards, as proposed here, would also be consistent with Section 176 of the Clean Air Act, which requires NHTSA to analyze whether the proposed standards "conform" to EPA-approved State Implementation Plans demonstrating how States will reduce (or maintain) criteria-pollutant levels. 42 U.S.C. [section] 7506(c)(1); see also 40 C.F.R. [section] 93.150(a). In SAFE 2, NHTSA blatantly disregarded this requirement, asserting a conformity determination was not required, 85 Fed. Reg. at 25,250, while at the same time admitting that the SAFE 2 standards would cause increased criteria-pollutant emissions. In contrast, the proposed standards correct course, reducing harmful air pollution and therefore advancing the Clean Air Act's foundational objective. Although NHTSA unfortunately persists, in this proposal, in claiming a conformity analysis is not required because emissions will be caused by the decisions of automakers and consumers beyond its control, 86 Fed. Reg. at 49,841, that improper interpretation has no prejudicial effect here because the proposal would reduce criteria pollution.

considered "the need of the U.S. to conserve energy," and more specifically environmental implications, in its decision to set maximum feasible standards further in the final rule preamble Section VI.A.5.d)(3).

10.1.2 NEPA Process

Comment

Docket Number: NHTSA-2021-0053-0059
Organization: Wisconsin Department of Natural Resources

The WDNR has identified several areas of NHTSA's proposal that can be improved or should be addressed in its final rule, which are described below. WDNR notes that the U.S. Environmental Protection Agency (EPA) issued a companion rule to NHTSA's proposal which also contains analyses of anticipated GHG and criteria pollutant emissions impacts.[3] Where appropriate, WDNR has referenced EPA's information in these comments. WDNR strongly urges NHTSA to continue to collaborate closely with EPA as the agencies finalize their respective rules, particularly when it comes to addressing any collateral impacts on criteria pollutant emissions.

Response

The NHTSA and EPA rulemakings 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.

Other differences between the agencies' rulemakings are due to each agencies' authority. NHTSA issues CAFE standards pursuant to its statutory authority under EPCA, as amended by the Energy Independence and Security Act (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 (42 U.S.C. § 7521(a)). Chapter 1, *Purpose and Need for the Action*, and more specifically Section 1.3.2, *Greenhouse Gas Standards for Light-Duty Vehicles (U.S. Environmental Protection Agency)*, discusses additional authorities and program provisions respective to each agency.

Section 1.4, *Cooperating Agencies*, also discusses additional EPA involvement in this rulemaking. EPA is a Cooperating Agency on this Final SEIS, and as such, EPA was asked to review and comment on the Draft and Final SEISs prior to publication.

[3] "Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards," Docket ID No. EPA– HQ–OAR–2021–0208, published August 20, 2021 (86 FR 43726).

10.2 Proposed Action and Alternatives

10.2.1 No Action Alternative/Baseline (Alternative 0)

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

In its proposal, NHTSA seeks comment on whether to include California's Zero Emission Vehicle (ZEV) and GHG standards in NHTSA's No Action baseline, assuming EPA reinstates the waiver for these standards before NHTSA takes final action on this proposal. 86 Fed. Reg. at 49,793. We agree that the inclusion of both the ZEV and GHG standards in the baseline case would be reasonable. It is plainly reasonable for an agency to include the preexisting legal obligations of regulated parties in No Action baselines, since these baselines aim to capture, as accurately as possible, how regulated parties would behave but for the proposals under consideration.[4] Indeed, California's ZEV and GHG standards have been adopted in thirteen other States and thus apply to a significant portion of the vehicle market that NHTSA's No Action case models. And, specifically, here this inclusion is a reasonable way to effectuate Congress's directive that NHTSA consider "other motor vehicle standards of the Government" in setting maximum feasible CAFE standards. As discussed below, EPCA's reference to "other motor vehicle standards of the Government" in 49 U.S.C. section 32902(f) unambiguously includes California vehicle emission standards for which EPA has granted a Clean Air Act preemption waiver. However, the particular factual context of this rulemaking and the other three factors in section 32902(f) indicate that, in this instance, NHTSA's incorporation of these California standards into its baseline does not materially affect its determination of maximum feasible CAFE standards.

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NHTSA's reflection of California 209(b) standards in the No-Action baseline incorporates the eminently reasonable assumption, consistent with reasoned decision-making, that regulated parties will comply with preexisting legal obligations outside the proposed regulatory action. See TSD at 43, 49 ("Rulemaking analysis attempts to isolate the impact of the action being considered, which means that [the baseline] need[s] to capture accurately what else is happening *besides* the action."). Incorporating California 209(b) standards into the baseline also serves as one reasonable way to consider these standards' possible effects on fuel economy, as EPCA requires. Before NHTSA's CAFE Model simulates manufacturers' response to different proposed standards, it first constructs a baseline vehicle fleet that manufacturers will likely produce (here, through MY 2026), based on, among other things, currently applicable regulatory standards. The model then simulates how manufacturers would iteratively apply a menu of fuel- economy-improving technologies to that baseline fleet until each manufacturer's fleet is brought into compliance with the new CAFE standard under consideration (or until manufacturers would choose to pay penalties instead of complying). 86 Fed. Reg. at 49,623-27. The CAFE Model can

[4] Courts have upheld the inclusion of such obligations in regulatory baselines in a variety of contexts. E.g., NRDC v. Thomas, 838 F.2d 1224, 1238 (D.C. Cir. 1988) (holding, in part, that using "[State-Implementation-Plan]-required emissions rates as the baseline" was "a quite reasonable interpretation" of relevant provision of Clean Air Act); Cooling Water Intake Structure Coal. v. EPA, 905 F.3d 49, 81 (2d Cir. 2018) (quoting "environmental baseline" requirements for Endangered Species Act consultations as including "the past and present impacts of all Federal, State, or private actions" and distinguishing those from impacts resulting from agencies exercising discretion); Am. Rivers v. F.E.R.C., 201 F.3d 1186, 1192 (9th Cir. 1999) (upholding agency use of facility's operations pursuant to terms and conditions of existing license as no action baseline).

then estimate several economic, environmental, and public health effects of manufacturers' simulated compliance strategies to inform NHTSA's evaluation of what standards are maximum feasible. Id. NHTSA has used increasingly detailed versions of this CAFE Model since 2001. Id. at 49,623.

NHTSA's incorporation of California 209(b) standards—along with other applicable standards with which automakers must comply—into the CAFE Model baseline is a reasonable way to "consider … [their] effect … on fuel economy." 49 U.S.C. [section] 32902(f). This language directs NHTSA to ask whether manufacturers can comply with other motor vehicle standards and the new CAFE standard at the same time; essentially, a fuel economy level is not the "maximum feasible" if it is achievable only through noncompliance with "other motor vehicle standards of the Government." By reflecting California's 209(b) standards in the baseline case, NHTSA ensures, consistent with Congress's direction that any compliance pathway modeled for proposed fuel economy standards continues to comply with California 209(b) standards as well. Thus, any fuel economy improvements the new CAFE standard may require will neither interfere with California's 209(b) standards nor be infeasible for regulated automakers. As discussed below, we believe that California's ZEV and GHG standards here do not actually have any "effect … on fuel economy" that would change NHTSA's analysis. But generally, where a California 209(b) standard has any such effect, reflecting these standards in the CAFE Model baseline fleet is a reasonable way to account for, and accommodate, such effect and satisfy section 32902(f).

At the same time, by excluding full-vehicle electrification technologies from the menu of available technology pathways that automakers may use to improve fuel economy above the No- Action baseline and thereby comply with new CAFE standards, NHTSA satisfies the prohibition in section 32902(h)(1) against considering the fuel economy of ZEVs or other alternative fuel vehicles when it determines what fuel economy level is "maximum feasible." 86 Fed. Reg. at 49,626, 49,655. The function of section 32902(h) is to preserve the compliance flexibilities that Congress built into the CAFE program—i.e., the special statutory measures of fuel economy for alternative- and dual-fueled vehicles, and the credit trading program—as optional, while still requiring maximum feasible fuel economy levels. See 86 Fed. Reg. at 49,797-98. By excluding increased adoption of ZEV technology (and credit trading) from its modeling of fuel economy improvements, NHTSA ensures that these potential compliance strategies are not essential to achieving such improvements in the fleet average. Id. Thus, NHTSA's regulatory analysis of the proposed action alternatives remains focused exclusively on the fuel economy improvements automakers could make to their internal combustion engine (ICE) vehicles and without trading in the relevant compliance period.

Baseline fleets will, of course, include some ZEVs because automakers are selling increasing numbers of them. Accordingly, there are ZEVs in the real-world 2020 fleet, which is NHTSA's starting point in constructing the baseline fleet for this proposal. Likewise, automakers must, and may otherwise choose to, sell ZEVs to meet consumer demand and to comply with legal obligations (including California's ZEV standards, in the event the waiver for those standards is restored). The presence of ZEVs in the baseline is, thus, separate and apart from any changes to the CAFE standards that NHTSA is considering. And in determining whether improvements to average fuel economy are "technologically feasible" or "economically practicable," NHTSA has only considered what fuel economy improvements are possible for the ICE vehicles in the fleet. Thus, NHTSA's determination of "maximum feasible" improvements only considers the vehicles it is permitted to consider, and any resulting change to the fuel economy standards would not require automakers to sell ZEVs.

Finally, we do not believe that NHTSA's mandatory consideration of California's 209(b) standards will materially affect NHTSA's determination of maximum feasible CAFE standards here, whether or not

NHTSA includes them in the baseline. As the NPRM shows, and as discussed above, the technologies necessary to achieve the proposed standards in the ICE fleet already exist and have been widely commercialized. The costs to incorporate these technologies are reasonable—in many instances, they have declined significantly over time—and more than pay for themselves in consumer fuel savings. See supra Parts I.B-I.C. The benefits of reduced fuel consumption to consumers, national security, air quality, and the climate are likewise compelling. Supra Part I.A. The technological feasibility, economic practicability, and energy conservation factors thus strongly favor NHTSA's proposed standards, and consideration of California's 209(b) standards does not change that. Notably, by including California's ZEV standards in the NPRM "No Action" baseline, NHTSA has already demonstrated that the proposed changes to the CAFE standards and the California ZEV standards will not interfere with each other and that it is entirely feasible for automakers to comply with both.

Indeed, reflecting California's 209(b) standards in the baseline fleet does not materially affect that fleet's average fuel economy and thus the average fuel economy automakers would achieve if NHTSA simply left the MY 2026 SAFE 2 standards in place. Generally, it is reasonable to assume in a No-Action case that manufacturers will achieve the fuel economy standards already in place (the SAFE 2 standards) as economically efficiently as possible. And, although NHTSA's baseline fleet for this proposal shows overcompliance with the SAFE 2 standards, NHTSA's detailed assessment of that overcompliance does not attribute it to California 209(b) standards. TSD at 50-57 (documenting three different causes of modeled overcompliance in the baseline fleet). Thus, whether California ZEV and GHG standards are included in or excluded from the baseline modeling, the baseline fleet's average fuel economy will likely be equivalent in either case, and the overall costs and benefits of improvements to that baseline fuel economy would likewise be very similar. In other words, whether or not NHTSA assumes manufacturers will comply with their legal obligations under California's 209(b) standards likely has little impact on NHTSA's consideration of whether changes to the SAFE 2 standards are warranted to produce "maximum feasible" average fuel economy standards. There is no reason to think NHTSA would favor a different CAFE standard without California's ZEV and GHG standards in the baseline or without considering those standards as "other motor vehicle standards of the Government."

Response

NHTSA has considered and accounted for California's ZEV standards in developing the baseline for this final rule and agrees that it is reasonable to include these standards in the baseline. For additional discussion of NHTSA's decision to include ZEV in the baseline, see the final rule preamble Section II.G.

10.2.2 Reasonable Range of Alternatives

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

NHTSA's Proposal contains three "action" alternatives. *See, e.g.*, 86 Fed. Reg. at 49,745. The different "action" alternatives are defined in terms of percent-increases in CAFE stringency from year to year: whereas the current SAFE 2 standards raise stringency by 1.5% per year for both passenger cars and light trucks through model year 2025, Alternative 1 increases stringency by 9.14% for passenger cars in model year 2024, and 3.26% thereafter; Alternative 2 (the proposal or "preferred alternative") increases stringency by 8% per year; and Alternative 3 increases stringency by 10% per year. 86 Fed. Reg. at 49,744-56. Thus, all of the action alternatives, including the preferred alternative, are more stringent than the SAFE 2 standards. Adopting any of these alternatives would provide numerous crucial benefits to our States and Cities. In fact, from consumer savings on fuel to reductions in multiple forms of harmful pollution, standards considerably more stringent than SAFE 2 will have even greater net benefits than reflected in NHTSA's Proposal.

Response

NHTSA agrees that the range of alternatives presented in the proposal and accompanying Draft SEIS, and now the final rule and this Final SEIS, represent a reasonable range of final agency actions. All of the action alternatives NHTSA has evaluated for this SEIS would result in substantial fuel savings and associated GHG emissions reductions, as well as many of the other benefits highlighted by the commenters.

10.2.3 Suggestion for More Stringent Alternatives

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

As demonstrated above, NHTSA's analysis firmly supports the statutory basis for standards more stringent than SAFE 2. Based on the agency's calculations in the NPRM, NHTSA has reasonably determined that the preferred alternative could be "maximum feasible." But the full record may well support finalization of standards more stringent than the preferred alternative. The NPRM finds that the preferred alternative delivers significant societal benefits when benefits and costs are measured using a calendar year-based approach, and that the preferred alternative is substantially in equipoise with the no action alternative under a model year-based approach. NPRM at 49,608 Table I-8 ($37.1 billion to $100 billion in net benefits), Table I-5 (-$15.1 billion to $0.3 billion in net benefits). This analysis, however, is overly conservative, as it relies on several inputs that, if adjusted to reflect the best available evidence, would unambiguously demonstrate the fact that increasing stringency strongly benefits society. The most significant of these inputs are outlined below. We urge NHTSA to adopt improved inputs that follow the best available science.

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Despite room for improvement in NHTSA's input assumptions, NHTSA's analysis still shows that the proposed rule would further NHTSA's statutory mandate to conserve fuel. The proposed alternative would save 50 billion to 205 billion gallons of gasoline and $44.9 billion to $73.0 billion in discounted fuel costs. 86 Fed. Reg. at 49,607 tbl. I-3 (gasoline), 49,770-71 tbl. V-28, V-29 (fuel costs). NHTSA should revise the input assumptions described above to further strengthen the record and better elucidate the proposed alternative's true net benefits, but NHTSA's analysis—and the record as a whole—strongly supports the adoption of fuel economy standards more stringent than those in place now.

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The preferred alternative standards—Alternative 2—are technologically feasible, economically practicable, and effectuate the purpose of EPCA to conserve energy. Based on that and the analysis presented in the Notice of Proposed Rulemaking, "maximum feasible" standards must be at least as stringent as Alternative 2. However, NHTSA should consider, based on the full record before it, whether even more stringent standards—up to and including Alternative 3—are "maximum feasible." As laid out in the detailed comments, NHTSA's analysis should be updated in a number of key respects, which would aid in that consideration, including: (1) adjusting the measure of rebound driving from fifteen to ten percent; (2) revising in the value of new vehicle demand elasticity from -1.0 to -0.34; (3) correcting to the per-mile marginal cost of congestion; (4) adopting the fatality rate per mile as the best measure of the safety of driving; (5) removing unsupported restrictions on the availability of high compression ratio technology in compliance modeling; and (6) changing the calculation of the social cost of greenhouse gases. We urge NHTSA to make those further improvements to its analysis and to finalize the most stringent standards it reasonably can—in other words, the "maximum feasible" standards.

Response

NHTSA has reviewed all of the comments, and in this chapter, NHTSA includes and addresses only those comments (or portions of those comments) considered substantive to the SEIS. NHTSA addresses comments that concern the rule but that are not substantive to the SEIS in the preamble to the final rule and its associated documents in the public docket.

NHTSA has carefully balanced the statutory factors described above to derive a range of alternatives analyzed in this SEIS. The agency believes that considering more aggressive standards beyond what the agency has modeled for the action alternatives would exceed maximum feasibility. To the extent that commenters are concerned about CAFE Model input assumptions that inform the analyses presented in the Draft and Final SEIS, as discussed further in the final rule preamble Section II.C, *Changes in Light of Public Comments and New Information*, NHTSA did update the analysis for the final rule. Some of these updates include updates to assumptions mentioned by the commenter, e.g., adjusting the measure of rebound driving from fifteen to ten percent. A full list of changes for the final rule analysis and the basis for those changes is discussed in the final rule preamble, TSD, and Final Regulatory Impact Analysis (FRIA).

Based on these updates and other factors, NHTSA determined a more stringent alternative was maximum feasible. For this Final SEIS, NHTSA has chosen Alternative 2.5 as the Preferred Alternative, which is a slightly more stringent alternative than the Preferred Alternative (Alternative 2) identified in the Draft SEIS.

Comment

Docket Number: NHTSA-2021-0054-0015
Organization: Institute for Policy Integrity at NYU School of Law
Commenter: Meredith Hankins

After comparing Alternatives 2 and 3 based on an updated cost-benefit analysis and factoring in unquantified effects and distributional effects, NHTSA should also consider whether a different alternative may be more appropriate. For example, NHTSA raises the possibility of combining an Alternative 2-based standard for MY2024 with Alternative 3-based standards for MY2025 and MY2026.[5] NHTSA should consider whether some level of increased stringency above Alternative 2 will better

[5] 86 Fed. Reg. at 49,756.

advance its statutory purposes of maximizing fuel economy considering the environmental, health, and security needs of the United States to conserve energy.

Response

NHTSA agrees with this comment and for the Final SEIS NHTSA has included a new alternative, Alternative 2.5, which is the Preferred Alternative.

Comment

Docket Number: NHTSA-2021-0054[6]
Organization: Consumer Reports
Commenter: Christopher Harto

This proposal does not go far enough and restores less than two-thirds of the consumer savings compared to the original [Indiscernible – low audio] standards. This can and must do better to protect consumers while ensuring equity in the [Indiscernible – low audio]. Automakers have proven time and again they will not deliver the savings consumers want and need without strong standards in place. According to the latest Drudge Report article, after accounting for shifts in fleet, automakers improved overall fuel economy by near 0.2 miles per gallon from 2026 to 2029. While they lobbied the previous administration to roll back the standards [Indiscernible – low audio]. Consumers and the climate don't have another four years to wait. Consumer Reports has two key recommendations to improve this rule. Making the following changes will allow consumers to recover most of the savings they would have achieved under the original Obama Biden rule. Number one, NHTSA should return to the Obama Biden rule level in 2024. Automakers agreed to the level of stringency in 2012 and had plans in place to meet the standards as recently as last year. With extra credits earned under the [Indiscernible] rule they should be able to catch-up. Number two, transition to the set stringency and 2026 at least as strong as [Indiscernible – low audio]. U.S. is behind the curve on climate commitment and only setting aggressive CAFE targets will allow us to catch-up. At this moment you have a historic opportunity to make a difference in the lives of all Americans and we urge you to seize on this by setting maximum, viable standards that restore the benefits of the 2012 Obama standards.

Docket Number: NHTSA-2021-0054
Commenter: Douglas Gruenau

Hello got my name is Douglas Gruenau and I am a private citizen. I live in Santa Fe, New Mexico. We are living through a mega drought. The great majority of people that I know are choosing options of vehicles that are electric or hybrid. We have done the same in order to mitigate the production of greenhouse gases but we know we alone cannot significantly create a change in the production of greenhouse gases. Therefore, I am requesting that the [Indiscernible] requirements are set significantly higher in order to spur innovation in the auto industry to create more efficient vehicles and lead automakers to make better batteries for electric cars and more efficient hybrids. This has to be done in order to ensure a better future for our children, our grandchildren and their descendants. Thank you.

[6] This comment was received during NHTSA's public hearing on October 13, 2021.

Response

As described in Chapter 1, *Purpose and Need for the Action*, NHTSA must consider the requirements of EPCA, which sets forth the four factors the agency must balance when determining “maximum feasible” standards. NHTSA’s explanation for how it arrived at the range of alternatives under consideration is in Section IV and VI of the preamble to the final rule and incorporated by reference in this SEIS. NHTSA must consider *all* the statutory factors when considering which standards are maximum feasible. Based on those factors, as described in the preamble to the final rule, and this analysis, NHTSA believes the range of alternatives under consideration is reasonable, in light of the factors it must balance.

NHTSA has determined that Alternative 2.5 is technologically feasible, economically practicable, supports the need of the U.S. to conserve energy, and is complementary to other motor vehicle standards of the Government that are simultaneously applicable. As discussed further in Section VI.D of the final rule preamble, NHTSA has determined that Alternative 3 is beyond maximum feasible. NHTSA concludes that Alternative 2.5 is maximum feasible for MYs 2024–2026.

10.3 Energy

The Environmental Defense Fund and the California Office of the Attorney General submitted several comments on the assumptions regarding the impact of reduced gasoline consumption on refinery emissions and the United States’ position as an energy exporter. Those comments are addressed in Section III.F.2. and Section III.G.2. of the final rule preamble.

Comment

Docket Number: NHTSA-2021-0054-0011
Organization: EPA

EPA is providing the following technical comments for your consideration on the energy analysis within Chapter 3.

The Draft SEIS states: “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.” The draft SEIS does not, however, quantify the impact of the proposal on imports. EPA recommends that NHTSA attempt to quantify this impact rather than assume it. For example, see the proposed rulemaking U.S. EPA (2021) Revised 2023 and Later Model Year Light- Duty Vehicle GHG Emissions Standards Regulatory Impact Analysis, subsection 3.2.4. https://www.epa.gov/system/files/documents/2021-08/420r21018.pdf_.

In section 3.1.1, the draft SEIS states: “The AEO 2021 forecasts that the United States will be a net energy exporter in every year from 2020 through 2050.” If the U.S. is already a net energy petroleum exporter, the reader might wonder why reducing net imports is an issue. Therefore, EPA recommends clarifying in this section that while the U.S. is a net exporter of petroleum, to supply the types of crude oil utilized by U.S refineries, we must import some heavier, sour crude oils and export our overproduction of lighter, sweet crude oils. Thus, the U.S. is still dependent on imported crude oil despite the overall balance of petroleum trade.

Two references that EPA believes will help inform these discussions are listed in sub-bullets below. The first states that even if the U.S. is “independent” in petroleum use, we still can experience economic shocks due to spikes in crude oil prices – crude oil is priced on the world market. The second is the American Petroleum Institute's description of why the U.S. needs to continue to import petroleum.

- https://foreignpolicy.com/2019/09/18/the-myth-of-u-s-energy-independence-has- gone-up-in-smoke/

- https://www.api.org/news-policy-and-issues/blog/2018/06/14/why-the-us-must- import-and-export-oil

Response

Chapter 3, *Energy*, of this Final SEIS describes the fuel use and environmental impacts of each alternative. For a more extensive description of economic and energy security impacts, consult the Chapter 6 of the FRIA and Chapter 6 of the TSD.

The Final SEIS states that Annual Energy Outlook (AEO) 2021 forecasts that the United States will be a net energy exporter from 2020 through 2050, reflecting net imports for petroleum that are more than offset by net exports of coal, natural gas, and natural gas liquids. AEO 2021 also forecasts that the United States will be a net importer of crude oil and refined petroleum products through 2050. https://www.epa.gov/system/files/documents/2021-08/420r21018.pdf. Additional text has been added to Chapter 3 of the Final SEIS to further clarify this forecast. This forecast is consistent with the forecast in U.S. EPA (2021) Revised 2023 and Later Model Year Light- Duty Vehicle GHG Emissions Standards Regulatory Impact Analysis, subsection 3.2.4.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

All three of the alternatives proposed by NHTSA—but especially Alternatives 2 and 3—would have a long-term positive effect on consumers. NHTSA projects that under any of the alternatives in the proposal, fuel savings will exceed the technology costs necessary to comply with the standards. 86 Fed. Reg. at 49,710. Specifically, NHTSA estimates that its preferred alternative could reduce a vehicle's fuel costs by about $1,280, while increasing the average cost of a new vehicle by only about $960. *Id.* at 49,605; *see also* Table II-8. And drivers will not only experience lower costs as a result of new vehicles' decreased fuel consumption, but also will benefit from "fewer refueling stops required because of [the vehicles'] increased driving range," and "mobility benefits" from lowering overall operating costs. Id. at 49,721.[7] These are noted improvements from the SAFE 2 standards, which will cost consumers money overall, because increases in fuel expenditures under those standards would exceed estimated decreases in vehicle prices. 85 Fed. Reg. at 24,180-81.

Moreover, these proposed improvements in fuel economy benefit consumer welfare beyond reduced fuel expenditures for those buying new vehicles. Oil consumption in the United States is expected to fall as vehicle manufacturers produce more fuel efficient vehicles in response to the more stringent standards. 86 Fed. Reg. at 49,735. Indeed, lower total fuel consumption is expected even if total miles driven increase slightly. 2021 CAFE PRIA, *supra* note 8, at section 4.6.1. NHTSA estimates that "over the lives of vehicles produced prior to MY 2030, the proposal would save about 50 billion gallons of

[7] See also NHTSA, Preliminary Regulatory Impact Analysis: Proposed Rulemaking for Model Years 2024-2026 Light Duty Vehicle Corporate Average Fuel Economy Standards (2021 CAFE PRIA) at Appendix I, Table A-23-1 (Aug. 2021).

gasoline" compared to the SAFE 2 standards. 86 Fed. Reg. at 49,615. Decreasing the domestic consumption in the United States will in turn produce "a corresponding[] decrease in the Nation's demand for crude petroleum, a commodity that is traded actively in a worldwide market." Id.at 49,735. Because the United States accounts for a significant share of global oil consumption, its decreasing demand will "exert some downward pressure on worldwide prices," thus tending to lower gas prices for all consumers. Id.[8]

This decrease in domestic demand for oil will have some important externalities that positively affect consumers directly and our States and Cities more generally.

First, decreasing domestic demand for petroleum would decrease domestic income inequality by reducing oil prices. *See id.* at 49,735-36. Changes in oil prices have important distributional effects between consumers of refined petroleum products and producers of oil. Higher gasoline prices result in significant costs for families in the United States.[9] And while corporate profits in the U.S. petroleum industry would rise with higher prices, potentially resulting in net zero GDP impacts, this transfer of wealth would have detrimental effects on U.S. consumer well- being, the distribution of fossil fuel share holdings across income groups, and differences in the proportion of saving to spending as well as energy burdens across income groups.[10] Importantly to our States and Cities,[11] "the transfer of revenue from U.S. oil producers to U.S. oil consumers could have substantial benefits for the most economically disadvantaged, reducing income inequality…."[12]

Second, decreasing domestic demand for petroleum could reduce consumers' exposure to oil price shocks. Id. at 49,736. Since the 1970s, Americans have experienced six significant gas price shocks following spikes in the world oil market.[13] Oil price shocks have been a contributing factor to economic recessions.[14] And with climate change, an increased frequency of extreme weather events that disrupt foreign and domestic energy supplies can be expected, causing supply shortages and price spikes.[15] For example, Hurricane Ida caused a temporary disruption of nine-tenths of crude oil production in the Gulf of Mexico, resulting in Gulf Coast gasoline prices rising by 49% over the same time the previous year.[16]

Decreasing United States dependency on global oil markets helps insulate consumers from such global price shocks and supply disruptions. Even when, as in 2020, the United States has positive net oil

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[8] See also United States Energy Information Administration, Oil and petroleum products explained: Use of oil (last updated May 10, 2021), https://www.eia.gov/energyexplained/oil-and-petroleum-products/use-of-oil.php.

[9] White Paper of Applied Economics Clinic, "An Analysis of NHTSA's Preliminary Regulatory Impact Analysis of 2021 Proposed Rulemaking for Model Years 2024-2026 Light-Duty Vehicle CAFE Standards" (October 2021) (AEC Comment) (submitted with CARB's Comments) at 11.

[10] Id. at 10-11.

[11] For example, the Governor of New Jersey recently signed Executive Order 262, establishing the Wealth Disparity Task Force, the purpose of which is to combat long-standing wealth gaps based on race and ethnicity. Governor Philip D. Murphy, New Jersey, Executive Order No. 262 (Sept. 14, 2021).

[12] AEC Comment, supra note 10, at 11.

[13] James D. Hamilton, Historical Oil Shocks (Dec. 22, 2010), in Parker, R. E.and R. Whaples, Handbook of Major Events in Economic History (2013), available at http://econweb.ucsd.edu/~jhamilton/oil_history.pdf.

[14] See id. at 26.

[15] AEC Comment, supra note 10, at 8.

[16] Id.

exports, consumers still feel the effects of price shocks as the price of oil is determined by the global markets. And in any event, the United States is not self-sufficient in petroleum production.[17] Rather, the U.S. Energy Information Administration's 2021 Annual Energy Outlook forecast expects domestic gross crude oil imports to remain between 6.9 and 7.8 million metric barrels per day through 2050 without the proposed CAFE standard revision.[18] Thus, "regardless of whether exports equal or even exceed imports, global supply shocks will still impose costs" on United States consumers, among others.[19] Stricter fuel economy standards and lower fuel consumption can help insulate the United States from these effects. Moreover, more stringent fuel economy standards could further help stabilize oil costs through their effect in preventing more climate warming (discussed in more depth below), which will reduce the frequency and intensity of extreme weather events that disrupt oil production.

Auto manufacturers have not significantly improved fuel economy without increasingly stringent standards in the past, and thus our States and Cities conclude that implementing standards more stringent than the SAFE 2 standards is important in order to promote the consumer benefits described above.

2. Reduced Fuel Use Improves Our National Security

Our States and Cities also recognize that reduction in fuel use can benefit our national security. Experts have noted numerous foreign policy costs that arise from the domestic consumption of foreign oil, including: (1) disruptions in oil supply, (2) political realignment from dependence on imported oil that limits United States alliances and partnerships, (3) increasing the power of oil- exporting countries to enact policies that are contrary to United States interests, and (4) the maintenance of United States military presence in the Middle East arising from interest in protecting oil interests.[20] Reducing dependence on imported oil could "lower U.S. military and foreign policy costs of safeguarding the U.S. oil supply and reduce revenue to regimes that are considered inimical to U.S. interests."[21] These costs could indeed be significant. Since September 11, the United States has budgeted $5.4 trillion to wars—an average of $284 billion per year between 2001 and 2020.[22]

Moreover, our States and Cities agree with NHTSA "that the environmental costs of oil use are intertwined with the security costs of oil use . . . as climate change destabilizes traditional geopolitical power structures over times." 86 Fed. Reg. at 49,796. Thus, "[o]il conservation is more effective than increased domestic oil production at improving U.S. oil security." Id. (citing Stephen Brown, New Estimates of the security costs of U.S. oil consumption 113 Energy Policy 172 (Feb. 2018), available at https://www.sciencedirect.com/science/article/abs/pii/S0301421517307413).

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[17] Id. at 7.

[18] Id. (citing U.S. Energy Information Administration, Annual Energy Outlook 2021, Appendix D, Table D.4, available at https://www.eia.gov/outlooks/aeo/pdf/appd.pdf).

[19] Id. (citing U.S. Energy Information Administration, Annual Energy Outlook 2021, Appendix D, Table D.4, available at https://www.eia.gov/outlooks/aeo/pdf/appd.pdf).

[20] 86 Fed. Reg. at 49,796 (citing Council on Foreign Relations, National Security Consequences of U.S. Oil Dependency, Independent Task Force Report No. 58, October 2006, available at https://cdn.cfr.org/sites/default/files/report_pdf/0876093659.pdf).

[21] AEC Comment, supra note 10, at 11.

[22] Id. at 12.

Response

This Final SEIS describes the fuel use and environmental impacts of each alternative. Readers may consult Chapter 6 of the FRIA and Chapter 6 of the TSD, which are incorporated in this final SEIS by reference, for a more extensive description of economic and energy security impacts of this action.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

Historically, NHTSA has considered the national balance of payments in evaluating the need to conserve energy because importing large amounts of oil can create a significant wealth transfer to oil-exporting countries and leave the United States economically vulnerable. See 86 Fed. Reg. at 49,794. In SAFE 2, NHTSA claimed that this factor was "fallow," and no longer supported the need to conserve. 85 Fed. Reg. at 24,215. Specifically, it asserted that exports equal or slightly exceed imports, and that any increase in demand resulting from the SAFE 2 standards would be fulfilled by domestic production rather than imports (a claim later contradicted in other aspects of the rule's underlying analysis). *See id.*

NHTSA has partially corrected its analysis in the present proposal. While the agency notes that petroleum imports currently do not drive the United States' trade deficit with other nations, as they did as recently as 2009, it nevertheless acknowledges that the United States continues to rely on oil imports and that there is considerable "uncertainty in the Nation's long-term import- export balance." 86 Fed. Reg. at 49,795. As NHTSA acknowledges, its proposal "aims to improve fleet-wide fuel efficiency and helps reduce the amount of petroleum consumed in the U.S., and therefore aims to improve this part of the U.S. balance of payments." Id. at 49,794.

Moreover, NHTSA could improve its analysis by noting that even as a net exporter last year, the United States is still not self-sufficient in petroleum production. Rather, the United States' domestic gross crude oil imports are expected to remain between 6.9 and 7.8 million metric barrels per day through 2050 without the proposed CAFE standard revision.[23] Incremental reduction in expenditures on foreign oil would thus serve to improve the national balance of payments and fulfill the statutory purpose.

Response

The SEIS states that AEO 2021 forecasts the United States will be a net energy exporter every year from 2020 through 2050, reflecting net imports for petroleum that are more than offset by net exports of coal, natural gas, and natural gas liquids. The SEIS also reflects the AEO 2021 forecast that the United States will be a net importer of crude oil and refined petroleum products through 2050. NHTSA has added additional text to Chapter 3 of the Final SEIS to further clarify this forecast.

The Final SEIS describes the fuel use and environmental impacts of each alternative. The FRIA and Chapter 6 of the TSD include a more extensive description of economic and energy security impacts.

[23] U.S. Energy Information Administration, Annual Energy Outlook 2021, tbl. D.1, https://www.eia.gov/outlooks/aeo/pdf/appd.pdf.

10.4 Air Quality

Comment

Docket Number: NHTSA-2021-0054-0011
Organization: EPA

EPA is providing the following technical comments for your consideration on the air quality analysis within Chapter 4.

On page 4-3, EPA recommends a clarification to the following sentence: "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)."

- EPA recommends removing acrolein from that list, because it is no longer included as a risk driver or contributor in the most recent National Air Toxics Assessment (2014 NATA).

- EPA recommends citing the 2014 NATA, see sub-bullet below, instead of the 2007 MSAT rule.

- U.S. EPA (2018) Technical Support Document EPA's 2014 National Air Toxics Assessment. https://www.epa.gov/national-air-toxics-assessment/2014-nata- assessment-results

On page 4-6, there is a citation related to effects from ambient ozone on plants and ecosystems. The citation currently points to a 2016 USDA website; it should instead point to the 2020 ozone Integrated Science Assessment, see sub-bullet below.

- U.S. EPA. Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-20/012, 2020.

On page 4-7, there is a citation in the PM health effects section (EPA 2019a) that currently goes to the inventory of GHG emissions and sinks. EPA believes this citation is meant to go to the PM ISA.

- U.S. EPA. Integrated Science Assessment (ISA) for Particulate Matter (Final Report, 2019). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-19/188, 2019.

On page 4-8, the introductory paragraph to the air toxics section also includes acrolein as a NATA risk driver or contributor and mentions that the toxics text is adapted from the Tier 3 preamble.

- EPA recommends removing acrolein as it is no longer a risk driver or contributor in the 2014 NATA.

- EPA recommends citing the EPA's August 10 light-duty vehicle GHG proposal RIA Chapter 7.1.1.6, link in sub-bullet, which is updated to reflect the 2014 NATA.

- U.S. EPA (2021) Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards Regulatory Impact Analysis. https://www.epa.gov/system/files/documents/2021-08/420r21018.pdf

On page 4-8, EPA believes the citation to EPA 2018b is supposed to go to the 2014 NATA TSD, also published in 2018 by EPA, instead of to the Benefit per Ton TSD, see sub-bullet below.

- U.S. EPA (2018) Technical Support Document EPA's 2014 National Air Toxics Assessment. https://www.epa.gov/national-air-toxics-assessment/2014-nata-assessment- results

On page 4-12, EPA is providing a clarification to the following sentence that references a TSCA risk evaluation for formaldehyde. "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)."

- EPA recommends deleting this sentence and instead using this sentence from our health effects text which refers to the IRIS reassessment and states, "EPA's draft assessment, which addresses NRC recommendations, was suspended in 2018. The draft assessment was unsuspended in March 2021".

- U.S. EPA (2018). See https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=419.

Response

NHTSA has made the following changes in response to this comment:

- With respect to the comments on pages 4-3 and 4-8 related to acrolein, a footnote has been added in Chapter 4, *Air Quality*, of this Final SEIS explaining that EPA no longer considers acrolein to be a key driver of health risk from mobile sources and citing the 2014 National Air Toxics Assessment. However, the analysis in Chapter 4 retains acrolein for consistency with the Draft SEIS. The citation to the Tier 3 Motor Vehicle Emission and Fuel Standards Rule has been updated as requested.
- With respect to the comment on page 4-6 related to citations, the citation to USDA 2016 has been updated as requested.
- With respect to the comment on page 4-7 related to citations, the citation to EPA 2019a has been corrected as requested.
- With respect to the comment on page 4-8 related to citations, the citation to EPA 2018b has been corrected as requested.
- With respect to the comment on page 4-12 related to formaldehyde, the sentence regarding formaldehyde has been updated as requested.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

As NHTSA acknowledges in the present proposal, the agency has long considered environmental impacts as part of "the need of the United States to conserve energy," and this interpretation has been approved by both the D.C. Circuit and Ninth Circuit. 86 Fed. Reg. at 49,794 (citing Ctr. For Auto Safety v. NHTSA, 793 F.2d 1322, 1325 n.12 (D.C. Cir. 1986); Public Citizen v. NHTSA, 848 F.2d 256, 262-63 n.27 (D.C. Cir. 1988); Ctr. For Biological Diversity v. NHTSA, 538 F.3d 1172 (9th Cir. 2007)). In SAFE 2, however, NHTSA failed to consider environmental impacts under this factor. Instead, it adopted standards that substantially increase emissions of multiple pollutants that harm public health and that would increase GHG emissions by 923 million metric tons, and it did so without mentioning these environmental impacts as part of its consideration of the need to conserve. See 85 Fed. Reg. at 25,049, 25,054, 25,057, 24,176, 25,144.

The present proposal returns to NHTSA's long-standing approach, and properly examines the environmental impact of the proposal as part of the agency's overall assessment of the need to conserve energy.[24] It concludes that "[a]ll of the action alternatives considered in this proposal reduce carbon dioxide emissions and, thus, the effects of climate change, as compared to the baseline." 86 Fed. Reg. at 49,795. And NHTSA finds that "over the lifetimes of the vehicles that would be subject to this proposal," emissions of criteria pollutants and air toxics "are currently forecast to fall significantly." Id. The examination of these environmental impacts— along with the impacts on "minority and low-income communities who would be most likely to be exposed to the environmental and health effects of oil production, distribution, and consumption, or the impacts of climate change," id.—is a necessary part of the agency's analysis regarding the need to conserve energy. Moreover, consideration of these impacts supports most stringent standards.

Response

NHTSA agrees that increasing the fuel economy of the passenger car and light-truck fleet would result in public health and climate benefits, which are analyzed in this Final SEIS, Chapter 5 of the TSD, and Chapter 6 of the FRIA.

10.4.1 Local Air Quality Impacts

Comment

Docket Number: NHTSA-2021-0053-0059
Organization: Wisconsin Department of Natural Resources

As noted in comment #2, NHTSA's analysis helpfully assesses the criteria pollutant impacts of its proposal on nonattainment and maintenance areas for various NAAQS, using the data available about these areas at the time of drafting. On June 14, 2021, EPA revised its initial area designations for the 2015 ozone NAAQS for several states, including Wisconsin and the Chicago area. In the case of many affected states, including Wisconsin, EPA's revisions resulted in larger geographic nonattainment areas for this NAAQS. To help policymakers understand how criteria pollutant emissions are expected to change in these nonattainment areas due to this rule, NHTSA should update its analysis to reflect the newly revised areas.

Response

In response to this comment, NHTSA updated the Final SEIS analysis to reflect EPA's revised area designations for the 2015 ozone National Ambient Air Quality Standards (NAAQS), including

[24] The adoption of more stringent standards, as proposed here, would also be consistent with Section 176 of the Clean Air Act, which requires NHTSA to analyze whether the proposed standards "conform" to EPA-approved State Implementation Plans demonstrating how States will reduce (or maintain) criteria-pollutant levels. 42 U.S.C. [section] 7506(c)(1); see also 40 C.F.R. [section] 93.150(a). In SAFE 2, NHTSA blatantly disregarded this requirement, asserting a conformity determination was not required, 85 Fed. Reg. at 25,250, while at the same time admitting that the SAFE 2 standards would cause increased criteria-pollutant emissions. In contrast, the proposed standards correct course, reducing harmful air pollution and therefore advancing the Clean Air Act's foundational objective. Although NHTSA unfortunately persists, in this proposal, in claiming a conformity analysis is not required because emissions will be caused by the decisions of automakers and consumers beyond its control, 86 Fed. Reg. at 49,841, that improper interpretation has no prejudicial effect here because the proposal would reduce criteria pollution.

nonattainment area designations in Wisconsin and the Chicago area. Chapter 4, Table 4.1.2-1 in this Final SEIS provides the nonattainment area designations.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

In addition, other forms of air pollution pose a widespread and persistent problem in our States and Cities. Criteria pollutants (including fine particulate matter (PM2.5) and ozone precursors) and air toxics negatively affect the health and welfare of people living in our States and Cities, and some contribute to climate change.[25] In 2020, more than 30.7 million Americans breathed air with elevated[26] levels of PM2.5 pollution for more than 100 days, and an additional 175.4 million Americans breathed air with elevated levels of PM2.5 for at least 31 days.[27] Millions also breathed air with elevated levels of ozone for more than 100 days.[28] Even air containing levels of PM2.5 and ozone below current federal air quality standards is harmful to public health.[29]

NHTSA projects that standards more stringent than SAFE 2 will achieve long-term emissions reductions of criteria pollutants (specifically carbon monoxide, PM2.5, and ozone precursors) and air toxics that adversely affect public health and welfare.[30] Our States and Cities support more stringent standards for this additional reason: reducing these emissions is crucial to improve public health and to assist States in attaining and maintaining the National Ambient Air Quality Standards (NAAQS).[31] Reductions in criteria pollutant emissions will also help mitigate some of the impacts of climate change, including poor air quality and other impacts described above.[32] Moreover, reducing these emissions is critical to meeting our States and Cities' environmental justice goals. 86 Fed. Reg. 49,461, 49,717, 49,722 (Sept. 3, 2021). But we need federal help to reduce emissions that are outside our control and to meet those goals.[33]

[25] Bryan Huxley-Reicher, et al., Trouble In The Air 6–14 (Fall 2021), accessible at https://environmentamerica.org/sites/environment/files/Trouble-in-the-Air-2021-Revised.pdf.

[26] Elevated levels means levels above which EPA considers "good." Id. at 9.

[27] Id. at 3.

[28] Id.

[29] Id. at 4, 6–10.

[30] NHTSA, Draft Supplemental Environmental Impact Statement for Model Year 2024-2026 Corporate Average Fuel Economy Standards (Draft SEIS) 4-39, 4-40 (2021); 2021 CAFE PRIA, supra note 8, at Section 4.1 ("Reducing the volume of fuel refined (or imported), distributed, and consumed throughout the U.S. will lower emissions of GHGs and criteria air pollutants, thus reducing the costs that potential climate-related impacts and adverse health effects from air pollution impose on the general public.").

[31] As one example, Washington's recently passed Climate Commitment Act requires actions be taken to reduce criteria pollutants and GHG emissions and seeks "to identify overburdened communities where the highest concentrations of criteria pollutants occur, determine the sources of those emissions and pollutants, and pursue significant reductions of emissions and pollutants in those communities." Wash. Rev. Code Ann. [section] 70A.002.001(7) (West 2021).

[32] Nat'l Research Council, Advancing the Science of Climate Change 326 (2010), accessible at http://nap.edu/12782 ("In a warmer future world, stagnant air, coupled with higher temperatures and absolute humidity, will lead to worse air quality even if air pollution emissions remain the same."); Bryan Huxley-Reicher, et al., supra note 98, at 4, 11– 12, 14–17.

[33] California's South Coast Air Basin's ability to attain the ozone standard in 2023 will require reductions from federal measures. CARB, Revised Draft 2020 Mobile Source Strategy 14, 68 (Apr. 23, 2021), available at

Response

NHTSA agrees that increasing the fuel economy of the passenger car and light-truck fleet would result in public health and climate benefits, which are analyzed in this Final SEIS, Chapter 5 of the TSD, and the Chapter 6 of the FRIA.

In this Final SEIS, NHTSA projects that the technologies that vehicle manufacturers would use to comply with the CAFE standards could reduce some emissions. However, NHTSA does not have authority to regulate emissions. EPA regulates emissions, which it exercises through setting emissions standards and other activities.

10.4.2 Health Effects

Comment

Docket Number: NHTSA-2021-0054-0010
Organization: Sheboygan Ozone Reduction Alliance
Commenter: Rebecca Duquesnoy

My name is Rebecca Duquesnoy and I am part of the Sheboygan Ozone Reduction Alliance, or SORA. I am a concerned citizen and also a parent of two young children. I want to Thank President Biden and the administration for acknowledging and addressing pollution from transportation.

Sheboygan, WI is an amazing place to raise a family we have great schools, parks, natural resources, community and activities. What you might not know is that Sheboygan county, with a population of over 115,000, is one of the top 25 most ozone polluted cities in the United States according to the American Lung Association. One of my children has special needs. She has Prader-Willi Syndrome and will need to exercise throughout her life in order to stay at a healthy weight. A healthy set of lungs is essential to her well-being. My other child is 4 and I would like him to develop healthy lungs as well. In order to keep my children healthy, we often go indoors in the afternoon and evening to avoid the highest ozone levels. My children should not have to miss out on their childhood because of high ozone levels. This summer was incredibly hot, and with climate change, our summers may continue to be hotter. This will mean more and more days where my children have to stay inside, rather than play and experience their childhood as it should be. In addition, I am a farmer and I HAVE to go outside daily, often in the evening. This year when the wildfires were so bad in Canada & Minnesota, I had to work 8 hours in high particulate matter. I cough quite frequently on days with poor air quality and I don't have any health issues. Every day I am exposed to poor air quality and I am concerned at the long term damage.

Response

NHTSA agrees that poor air quality adversely affects human health, especially the health of sensitive populations such as children with chronic health conditions, and that poor air quality can adversely affect healthy adults who are exposed for a sufficiently long period of time. This Final SEIS shows that increasing the fuel economy of the passenger car and light-truck fleet, such as implementing the

https://ww2.arb.ca.gov/sites/default/files/2021-04/Revised_Draft_2020_Mobile_Source_Strategy.pdf. See Tianyang Wang, et al., Mortality burdens in California due to air pollution attributable to local and nonlocal emissions, 133 ENV'T INTERNATIONAL 105232 (2019).

Preferred Alternative, would result in public health and climate benefits, which are analyzed in this Final SEIS, Chapter 5 of the TSD, and Chapter 6 of the FRIA.

Comment

Docket Number: NHTSA-2021-0054-0012
Organization: Sierra Club
Commenter: Joshua Berman

The DSEIS's air quality and human health impacts analyses are distorted by NHTSA's unreasonably high assumption about the additional driving that will occur as fuel economy improvement lowers the cost of driving (the rebound effect). One notable result is that, based on the erroneous rebound effect, NHTSA projects adverse health impacts in 2025[34]. As discussed in the Appendix to Joint Summary Comments of Environmental, Advocacy, and Science Organizations on NHTSA's Notice of Proposed Rulemaking: Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks, 86 Fed. Reg. 49,602 (Sept. 3, 2021), which are being filed in Docket ID No. NHTSA-2021-0053 and are hereby incorporated by reference, NHTSA's use of a 15 percent rebound effect is unreasonably high and unsupported by the evidence. NHTSA has provided a thorough justification for a 10 percent (or lower) rebound effect in several prior rulemakings and lacks any basis to rely on a larger rebound effect in this rulemaking. Indeed, 10 percent is at the *maximum* end of appropriate rebound values, and the true fuel economy rebound effect is likely much lower and may even be zero.

The health impacts summary on page S-9 of the DSEIS also leaves a confusing and false impression about the certainty of adverse health impacts. NHTSA appropriately notes in its "key findings" summary of air quality impacts, "[i]t is important to stress that…if NHTSA has overestimated the rebound effect, then emissions would be lower[35]...," and helpfully frames its results in the criteria pollutants summary as "quite small" increases that "could be affected by the assumptions in the model"[36]. The health impacts summary, however, does not contain this important context. Commenters suggest NHTSA add additional clarification about the uncertainties and assumptions in the 2025 summary on page S-9.

Response

NHTSA discusses its choice of rebound effect in Section III.E.3. of the preamble to the final rule and in Chapter 3.3 of the FRIA. In addition, in Chapter 4.3 of the TSD, NHTSA reviews the most recent evidence on the rebound effect and discusses the rebound effect used in the analysis for the final rule and the Final SEIS. For the final rule, NHTSA's analysis uses a 10 percent rebound effect, which is a downward adjustment from the rebound effect used in the analysis for the NPRM and supporting the Draft SEIS.

As noted by the commenter, NHTSA notes in the introductory text of the *Key Findings* section in the *Summary* of this Final SEIS that changes in assumptions would alter the air pollution estimates and provides an example of what would happen if emissions of the rebound effect were under- or overestimated. This text was intended to apply to all key findings; however, for clarity NHTSA has noted this point in the health impacts portion of the *Summary*.

[34] DSEIS at S-9.

[35] *Id.* at S-8.

[36] *Id.*

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

NHTSA anticipates significant emissions reductions of carbon monoxide, PM2.5, volatile organic compounds (VOCs) and nitrogen oxide (NO_X) (ozone precursors) under all action alternatives.[37] The health benefits associated with a reduction in PM2.5 and ozone pollution are well-documented.[38] Short- and long-term PM2.5 exposures both result in mortality risk, cardiovascular effects, and respiratory effects.[39] In California alone, over 5,000 premature deaths and hundreds of illnesses and emergency room visits for respiratory and cardiovascular disease are linked to PM2.5 pollution annually.[40] Recent studies also show that persons exposed to air pollution may be more vulnerable to contracting COVID-19 and more likely to experience the severe and fatal outcomes from infection.[41] Ozone pollution leads to similar negative health effects, especially for respiratory health.[42]

The mobile source sector is a major contributor to these health impacts because it is one of the largest emitters of PM2.5 and ozone precursors in the United States.[43] NHTSA has long acknowledged that

[37] 86 Fed. Reg. at 49,780; Draft SEIS, supra note 103, at 4-39, 4-40.

[38] Ozone Transport Commission, OTC Modeling Committee, Analysis of the Potential Health Impacts of Reducing Ozone Levels in the OTR Using BenMAP – 2019 Edition (Sept. 16, 2019); Office of Massachusetts Attorney General Maura Healey, COVID-19's Unequal Effects in Massachusetts 6 (2020) (explaining that eliminating human- generated emissions from the City of Boston would reduce PM2.5 and ozone concentrations throughout the region, leading to a decrease in morbidity and mortality and saving the region billions of dollars); Leah Burrows, Deaths from fossil fuel emissions higher than previously thought, Harvard John A. Paulson School of Engineering and Applied Sciences (Feb. 9, 2021), https://www.seas.harvard.edu/news/2021/02/deaths-fossil-fuel-emissions-higher- previously-thought (reporting on recent study finding that more than 8 million people died in 2018 from fossil fuel pollution); Erika Garcia, et al., Association of Changes in Air Quality with Incident Asthma in Children in California, 1993-2014, 312 JAMA 19:1906-1915 (2019) (decreases in PM2.5 emissions are significantly associated with lower asthma incidence); Yaron Ogen, Assessing Nitrogen Dioxide (NO_2) Levels As A Contributing Factor To Coronavirus (COVID-19) Fatality 726 Sci. Total Environ. (Jul. 2020), accessed at https://pubmed.ncbi.nlm.nih.gov/32302812/ (finding that long-term exposure to NO_2 may be an important contributor to the high COVID-19 fatality rates observed in five European regions).

[39] EPA, Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter 3- 18 – 3-19, 3-101, 3-104 (discussing studies finding statistically significant associations between harm to health and annual exposures below 12 µg/m3, 3-113).

[40] CARB, Revised Mobile Source Strategy, supra note 106, at 18.

[41] Michael Petroni, et al., Hazardous air pollutant exposure as a contributing factor to COVID-19 mortality in the United States ENVIRON. RES. LETT. 15 0940a9 (2020) (analysis indicating that chronic, cumulative exposure to hazardous air pollutants at below reference concentration levels may increase vulnerability to COVID-19 mortality); Donghai Liang, et al., Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States (2020) (finding significant associations between NO_2 and COVID-19 case-fatality and mortality rates); X. Wu, et al., Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis 6 SCI. ADV. eabd4049 (2020) (investigating the impact of long-term PM2.5 exposure on COVID-19 mortality rates).

[42] EPA, Integrated Science Assessment for Ozone and Related Photochemical Oxidants, Executive Summary ES-6– ES-8, ES-17 (Apr. 2020).

[43] Calvin A. Arter, et al., Mortality-based damages per ton due to the on-road mobile sector in the Northeastern and Mid-Atlantic U.S. by region, vehicle class and precursor, 16 ENVIRON. RES. LETT. 2–3 (2021), available at https://doi.org/10.1088/1748-9326/abf60b. Mobile sources emit primary particulate matter and particulate matter precursors that contribute to secondary formation of particulate matter in the atmosphere. EPA, Policy Assessment, supra note 109, at 2-3; EPA, Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards at 2-5 (May 2020), https://www.epa.gov/sites/default/files/2020-05/documents/o3-final_pa-05-29- 20compressed.pdf.

people living, working, and attending school near major roadways face greater air pollution exposure.[44] 77 Fed. Reg. 62,624, 62,907 (Oct. 15, 2012); 75 Fed. Reg. 25,324, 25,504 (May 7, 2010). In some urban areas, mobile sources, which include gasoline- powered highway vehicles, diesel-powered highway vehicles, and other engine-driven sources (e.g., ships, aircraft, construction, and agricultural equipment), account for 13% to 30% of the total primary PM2.5 emissions.[45] In California, more than half of the PM2.5 pollution is produced by mobile sources.[46] These emissions contribute to and exacerbate asthma, impair lung function, and increase cardiovascular mortality.[47] Traffic-related air pollution is especially harmful because it not only exacerbates asthma but may also cause more people to become asthmatic.[48] In Philadelphia, for example, some of the most polluted areas are along major highways or zones with heavy traffic, and the most polluted zip codes also have the largest number of lung cancer patients.[49] Mobile sources are also the number one contributor to high ozone levels in the Ozone Transport Region.[50]

More stringent standards will also help support NAAQS attainment and maintenance, which in turn will advance local, state, and federal public health goals.[51] Various locations throughout our States and Cities have been unable to attain, or face difficulty maintaining, the NAAQS for ozone and PM2.5.[52] For example, multiple counties in California are registering severe, serious, or extreme nonattainment with the 8-Hour Ozone NAAQS. Nonattainment areas outside of California will also benefit from more stringent standards that may result in a reduction of ozone precursors, for example, Colorado's Denver Metro/North Front Range, which includes a major transportation corridor and a refinery and, based on 2018–2020 ozone monitoring data, is expected to shift from serious to severe nonattainment for the 2008 8-Hour Ozone NAAQS.

Likewise, counties in Connecticut and New York are in serious nonattainment with the 2008 8- Hour Ozone NAAQS and are in moderate nonattainment with the 2015 8-Hour Ozone NAAQS. Their challenges in attaining the NAAQS are due in part to ozone-forming pollution from out-of- state upwind

[44] Draft SEIS, supra note 103, at 4-34.

[45] EPA, Policy Assessment, supra note 109, at 2-5.

[46] CARB, Revised Mobile Source Strategy, supra note 106, at 18.

[47] Id. at 24–26 (citing multiple studies); California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Update to the California Communities Environmental Health Screening Tool: CalEnviroScreen 4.0 Public Review Draft 93 (Feb. 2021) ("[C]hildren who live or attend schools near busy roads are more likely to suffer from asthma and bronchitis than children in areas with lower traffic density.").

[48] Bryan Huxley-Reicher, et al., supra note 98, at 6.

[49] Thomas P. McKeon, et al., Environmental exposomics and lung cancer risk assessment in the Philadelphia metropolitan area using ZIP code–level hazard indices Environ. Sci. Pollut. Res. 28:31758–31769, 31764 (2021); Stephanie Stahl, Earth Week: New Research Links Lung Cancer to Air Pollution in Philadelphia, CBS Philly (Apr. 20, 2021), https://philadelphia.cbslocal.com/2021/04/20/earth-new-research-links-lung-cancer-to-air-pollution-in- philadelphia/.

[50] Ozone Transport Commission, Mobile Sources Committee Annual Report 2020 2 (2020). The Ozone Transport Region includes Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

[51] Draft SEIS, supra note 103, at [section] 4.2.1.2.

[52] EPA, Current Nonattainment Counties for Criteria Pollutants (data current as of Aug. 31, 2021), https://www3.epa.gov/airquality/greenbook/ancl.html (providing NAAQS compliance status of all counties); CARB, Criteria Pollutant Emission Reductions from California's Zero-Emission Vehicle Standards for Model Years 2017- 2025 5 (Jul. 6, 2021), App. A to Comments of States and Cities in Support of EPA Reversing Its SAFE 1 Actions.

sources, which NHTSA's standards could help reduce.[53] New Jersey has taken action to reduce NO_X and VOC emissions from mobile sources and from stationary sources, including power plants and refineries, in an attempt to attain the NAAQS.[54] But New Jersey and other States cannot attain or maintain the NAAQS alone,[55] and NHTSA's standards may provide important emissions reductions in upwind states and across the country.[56] Even in areas presently attaining the NAAQS, long-term PM2.5 exposures are associated annually with up to 45,000 deaths, and 14,600 ischemic heart disease deaths, and thus, even a modest reduction of PM2.5 pollution has beneficial impact.[57] No safe level of PM2.5 has been identified, and so reductions in PM2.5 emissions will bring public health benefits to our States and Cities regardless of NAAQS attainment status.[58]

For these reasons, the undersigned support NHTSA's proposal, which will benefit public health as a consequence of reduced criteria pollutant emissions.[59]

The action alternatives considered in NHTSA's proposal would further reduce emissions of most air toxics in the long term from vehicles and from the extraction, transport, distribution, and refining of petroleum fuels.[60] Reductions in air toxics emissions will benefit public health and welfare, in part because these emissions are known to cause cancer and other serious health effects.[61]

New Jersey, for example, will benefit from the reduction of air toxics emissions anticipated by NHTSA because mobile sources are the largest contributors of air toxics emissions in the state.[62] In Allegheny County in Pennsylvania, mobile sources account for over 9% of the estimated cancer risk from air toxics emissions, mostly due to gasoline cars.[63] The City of Richmond in California, with five petroleum

[53] EPA, Current Nonattainment Counties for Criteria Pollutants, supra note 122.

[54] State of New Jersey Department of Environmental Protection, New Jersey SIP Revision for the Attainment and Maintenance of the Ozone NAAQS x, 4-14 (Dec. 2017).

[55] Id. at xii.

[56] EPA, Current Nonattainment Counties for Criteria Pollutants, supra note 122.

[57] Indeed, because PM2.5 exposure below the current NAAQS is clearly harmful, a multi-state coalition, which includes many of the signatories to this comment, petitioned EPA to reconsider its 2020 decision not to strengthen the current NAAQS for Particulate Matter. On June 10, 2021, EPA acknowledged that the current standards may not be adequate to protect public health and welfare, and announced its decision to reconsider its prior decision. EPA, EPA to Reexamine Health Standards for Harmful Soot that Previous Administration Left Unchanged (June 10, 2021), https://www.epa.gov/newsreleases/epa-reexamine-health-standards-harmful-soot-previousadministration- left-unchanged.

[58] EPA, Policy Assessment, supra note 109, at 3-103 ("Studies that examine the shapes of concentration-response functions over the full distribution of ambient PM2.5 concentrations have not identified a threshold concentration[ ] below which associations no longer exist").

[59] Draft SEIS, supra note 103, at [section] 4.2.3; 86 Fed. Reg. at 49,800–01.

[60] Id. at [section] 4.2.2.

[61] Id. at [section] 4.1.1.2; USEPA, Air Toxics Emissions, Report on the Environment (updated Sept. 12, 2019), accessible at https://cfpub.epa.gov/roe/indicator.cfm?i=2; Centers for Disease Control and Prevention, Indicators and Data, Indicator: Air Toxics, National Environmental Public Health Tracking (updated March 11, 2019), accessible at https://ephtracking.cdc.gov/showIndicatorPages.action?selectedContentAreaAbbreviation=11&selectedIndicatorId=81&selectedMeasureId=.

[62] New Jersey Department of Environmental Protection, 2019 New Jersey Air Quality Report 10-1 (Nov. 23, 2020).

[63] Cancer & Environment Network of Southwestern Pennsylvania, National Air Toxics Assessment and Cancer Risk in Allegheny County Pennsylvania (updated May 2021), https://www.catf.us/wp-content/uploads/2021/07/NATA- Factsheet-Final-May-2021.pdf.

refineries nearby and residents facing disproportionately high rates of cancer and other health impacts from air pollution, serves as another example of an area that will benefit from a reduction in air toxics emissions.[64]

Response

NHTSA recognizes that air pollutants contribute to human health effects and agrees that increasing the fuel economy of the passenger car and light-truck fleet will result in public health benefits, which are analyzed in this Final SEIS (Section 4.2.3, *Health Impacts*) and the rulemaking documents.

10.5 Greenhouse Gas Emissions and Climate Change

Comment

Docket Number: NHTSA-2021-0054-0011
Organization: EPA

EPA provides the following technical comments on the greenhouse gas (GHG) emissions analysis in the summary and Chapter 5.

In August 2021, the Intergovernmental Panel on Climate Change (IPCC) issued the Sixth Assessment Report (AR6), updating the state of the knowledge of anticipated changes to climate and greenhouse gas emissions levels. EPA recommends that NHTSA review and update the greenhouse gas emissions and climate change assessment to incorporate the latest updates from the IPCC, where appropriate. The following specific sections have been identified to be updated consistent with the latest scientific information consolidated in the IPCC AR6 report.

Page S-12: "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 humanmade climate forcers." To be consistent with the findings of the IPCC AR6, the wording of the second sentence should be changed. The emphasis as written is that the warming requires including natural GHGs and other climate forcers like solar activity, with humanmade forcers the afterthought. The IPCC articulates that the most accurate estimate is that the contribution of all-natural factors was very near neutral, and that the increase in human GHGs is responsible for all the warming. Moreover, the reference to natural GHGs is confusing – is this a reference to background natural GHG concentrations, or to changes in GHG concentrations due to natural factors? And if the latter, what factors is NHTSA referring to? This sentence is unnecessary, as NHTSA addresses this issue in more detail in the subsequent paragraphs.

Page S-14 states "They would also, to a small degree, reduce the impacts and risks of climate change." To provide a more accurate representation of the findings in the IPCC AR6, EPA recommends deleting "to a small degree" and replacing with language used later in the section that states "Although the projected reductions in CO_2 and climate effects are small compared with total projected future climate

[64] CARB, Analysis in Support of Comments of the California Air Resources Board on Corporate Average Fuel Economy Standards for Model Years 2024-2026 Passenger Cars and Light Trucks at 38 (Oct. 26, 2021), submitted separately in this docket.

change, they are quantifiable, directionally consistent, and would represent an important contribution to reducing the risks associated with climate change."

Page 5-16: Figure 5.2.2-4 is based on information from 2013. EPA recommends updating this figure with the data and information available in the IPCC AR6 and other national references. To more accurately discuss the implications of including dynamic ice sheet loss in sea level rise, EPA recommends comparing the AR6 Working Group 1 sea level rise estimate for SSP5-8.5 to the low- likelihood, high-impact storyline sea level rise projection for the same scenario.

Response

The Final SEIS includes updates to multiple chapters from Intergovernmental Panel on Climate Change (IPCC) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (WGI AR6), which was released in August 2021, after the development of the Draft SEIS. NHTSA revised the sentences on GHG impacts on warming and climate impacts to clarify the science presented in this updated report, which includes all changes recommended in this comment. NHTSA retained Figure 5.2.2-4 because it provides a range of likelihood for ice sheet melt without estimating implications of dynamic ice sheet loss. Dynamic ice sheet loss remains highly uncertain, which would not change with the issuance of WGI AR6 because it provides similar results from the Shared Socioeconomic Pathways (SSP) model results.

Comment

Docket Number: NHTSA-2021-0054-0015
Organization: Institute for Policy Integrity at NYU School of Law
Commenter: Meredith Hankins

NHTSA should fully value all significant upstream emissions reductions, including those occurring abroad. NHTSA is inappropriately excluding considering of emissions reductions associated with at least some upstream fuel extraction, refining, and other activities that occur outside U.S. borders. Such a practice is especially inappropriate for greenhouse gas emissions, which have the same effect on climate change regardless of their point of origin.

*****

To begin, many of the issues highlighted above—an unnecessarily high rebound estimate, an inappropriately high sales elasticity estimate—cause NHTSA's model to overestimate how rebound driving and assumed shifts to used vehicles may partly offset emissions reductions, and so leads NHTSA to underestimate the total upstream and downstream emissions reductions that can be achieved by various regulatory alternatives. Correcting those methodological issues will produce more accurate estimates of emissions reductions and will show greater climate, environmental, and public health benefits.

Moreover, NHTSA may be wrongly ignoring a significant portion of upstream emissions, by counting only domestic emissions.

Though neither the preamble nor the preliminary regulatory impact analysis ("PRIA") are clear on this point, the draft technical support document ("TSD") includes a section that "provides the calculation methodology of these updated upstream emission factors (in g/mmBTU) for the following regulated criteria pollutants as well as greenhouse gases."[65] That section of the TSD specifies that the CAFE model makes "two upstream adjustments": one for the "Share of Fuel Savings Leading to Reduced Domestic Fuel Refining," and another for the "Share of Reduced Domestic Refining from Domestic Crude."[66] The section concludes that "the final CAFE aggregation applies a fuel savings adjustment to the Petroleum Refining process and a combined fuel savings and *reduced domestic refining adjustment to the pair of Petroleum Extraction and Petroleum Transportation processes* for . . . *each pollutant* in the full set of pollutants."[67] This strongly suggests that NHTSA may not be counting any emissions related to upstream fuel activities that occur abroad, including for greenhouse gas emissions emitted abroad.

The draft supplemental environmental impact statement (DSEIS) confirms that "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."[68] Assuming this is an accurate description of how NHTSA calculated emissions not just for the DSEIS but for its main regulatory analysis as well, NHTSA is not counting carbon dioxide, methane, nitrous oxide, particulate matter, or any other pollutants emitted during the recovery, extraction, or transportation of crude petroleum overseas, or during the refining, storage, or distribution of transportation fuels that occurs overseas.

This omission could ignore a significant quantity of upstream emissions. According to the TSD, NHTSA is assuming that "50 percent of any reduction in U.S. gasoline consumption resulting from this proposal would lead to lower domestic refining activity,"[69] meaning that the other 50 percent would correspond with reduced imports of refined fuel.[70] And of the 50 percent affecting fuel refined domestically, NHTSA is assuming that 100% would relate to imported crude, with no effect on the U.S. production of crude oil.[71] In other words, for every reduction in domestic fuel consumption of 100 gallons resulting from the proposed regulation, U.S. imports of refined fuel would change by 50 gallons, and U.S. imports of crude oil for domestic refining would change by 50 gallons. If NHTSA is indeed counting only domestic upstream emissions, NHTSA may be ignoring 100% of upstream emissions from fuel extraction, 50% of upstream emissions from refining, and some significant portion of upstream emissions from the distribution, transportation, and storage of crude or finished gasoline before it reaches U.S. shores.

Ignoring these significant upstream emissions just because they originate outside U.S. borders would be wrong for several reasons. First, the National Environmental Policy Act requires agencies to adopt a global perspective not just in their environmental impact statements,[72] but more broadly declares a

[65] TSD, supra note 9, at 476.

[66] Id. at 482.

[67] Id. at 483 (emphasis added).

[68] NHTSA, Draft Supplemental Environmental Impact Statement: Corporate Average Fuel Economy Standards Model Years 2024-2026, at 2-17 (2021) (emphasis added); see also id. ("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."); id. at 3-5 (observing "changes in aggregate domestic upstream emissions varying over time and among pollutants and regulatory alternatives").

[69] TSD, supra note 9, at 567.

[70] See id. at 562.

[71] *Compare* id. at 562 (explaining the previous 90%/10% assumption), *with* id. at 568 (explaining the new 100% assumption).

[72] 42 U.S.C. [section] 4332(2)(F).

national environmental policy and requires of all agencies that "to the fullest extent possible[,] the policies, regulations, and public laws of the United States *shall be interpreted and administered* in accordance with the policies set forth in this chapter,"[73] including the need to "recognize the worldwide and long-range character of environmental problems" and to "lend appropriate support" to help "maximize international cooperation."[74] In other words, especially because adopting a global perspective on climate damages will advance U.S. foreign policy goals,[75] NEPA requires NHTSA to interpret all of the laws it administers, including EPCA, in ways that recognize the worldwide character of environmental problems. Ignoring significant upstream foreign emissions in both the EIS and in its main analysis under EPCA would undermine this national policy.

Second, emissions that originate abroad can still have direct impacts on the United States. This is especially true of greenhouse gases, which are global pollutants that readily mix in the atmosphere and affect global climate. All greenhouse gases, regardless of their point of origin anywhere on the planet, will cause the same climate damages for the United States. Though criteria and toxic pollutants are usually thought of as local pollution, even some criteria and toxic pollutants emitted abroad can directly affect the United States. For example, in 2017, Canada supplied 43% of all crude imported into the United States, 45% of imported finished motor gasoline, and 30% of imported gasoline blending components; Mexico further supplied another 8% of crude imported into the United States.[76] EPA has in the past recognized that U.S. emissions of criteria and toxic pollution can affect health and welfare in our neighboring countries;[77] similarly, depending on the location of Canada and Mexico's fuel

[73] Id. [section] 4332(1) (emphasis added).

[74] Id. [section] 4332(2)(F); *see also EDF v. Massey*, 986 F.2d 528, 536 (D.C. Cir. 1993) ("Section 102(2)(F) further supports the conclusion that Congress, when enacting NEPA, was concerned with worldwide as well as domestic problems facing the environment. . . . Compliance with one of the subsections can hardly be construed to relieve the agency from its duty to fulfill the obligations articulated in other subsections."); *NRDC v. NRC*, 647 F.2d 1345, 1387 (D.C. Cir. 1981) (J. Robinson, concurring; J. Wilkey wrote for the court, but there was no majority opinion) (concluding that, even if a conflict with another statute prevents the agency from conducting an environmental impact statement, that "does not imply that NRC may ignore its other NEPA obligations," including the "provision for multinational cooperation" and the "policy of the United States with respect to the ecological well-being of this planet"; rather, the agency "should remain cognizant of this responsibility"); *Greene Cnty. Planning Bd. v. Fed. Power Comm'n*, 455 F.2d 412, 424 (2d Cir. 1972) ("The Commission's 'hands-off' attitude is even more startling in view of the explicit requirement in NEPA that the Commission 'recognize the worldwide and long-range character of environmental problems' and interpret its mandate under the Federal Power Act in accordance with the policies set forth in NEPA.").

[75] See the Joint Comments on the Social Cost of Greenhouse Gases that Policy Integrity and other groups submitted separately to this docket.

[76] In 2017, the United States imported from all countries 2.9 billion barrels of crude, 11 million barrels of finished motor gasoline, and 220 million barrels of motor gasoline blending components. Of that, Canada supplied 1.25 billion barrels of crude (43%), 5 million barrels of finished motor gasoline (45%), and 66 million barrels of motor gasoline blending components (30%). Mexico supplied 222 million barrels of crude (8%) and 1.5 million barrels of blending components (<1%). EIA, Petroleum & Other Liquids, https://www.eia.gov/dnav/pet/pet_move_impcus_d_nus_Z00_mbbl_a.htm.

[77] In the analysis of the Cross-State Air Pollution Rule, EPA noted— though could not quantify—the "substantial health and environmental benefits that are likely to occur for Canadians" as U.S. states reduce their emissions of particulate matter and ozone—pollutants that can drift long distances across geographic borders. Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone, 75 Fed. Reg. 45,210, 45,351 (Aug. 2, 2010). Similarly, in the Mercury and Air Toxics Standards, EPA concluded that a reduction of mercury emissions from U.S. power plants would generate health benefits for foreign consumers of fish, both from U.S. exports and from fish sourced in foreign countries. EPA did not quantify these foreign health benefits, however, due to complexities in the scientific modeling. EPA, Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards 65 (2011) ("Reductions in domestic fish tissue concentrations can also impact the health of foreign consumers . . . [and] reductions in U.S. power plant emissions will result in a lowering of the global burden of elemental mercury.").

production and distribution facilities and on prevailing winds, their emissions can affect health and welfare in the United States. None of these upstream emissions—and especially the global greenhouse gas pollutants—should be completely ignored.

Third, as detailed further in comments submitted separately to this docket by Policy Integrity and other groups on the social cost of greenhouse gases, through international spillover effects, foreign reciprocity, the extraterritorial interest of the U.S. government and its citizens, and altruism, worldwide climate effects also affect U.S. welfare and matter to U.S. decisionmakers and the public.

To the extent the proposed rule, PRIA, and draft EIS undercount significant emissions, the final rule, final RIA, and final EIS should correct those underestimates.

Response

As documented in Section 5.3.1, *Methods for Modeling Greenhouse Gas Emissions*, and further detailed in Chapter 5 of the TSD, the Greenhouse Gases and Regulated Emissions in Transportation (GREET) model developed by the U.S. Department of Energy Argonne National Laboratory is used to estimate upstream emissions associated with production, transportation, and storage of gasoline and diesel from crude oil, as well as emissions associated with the generation of electricity. NHTSA's analysis only considers domestic upstream emissions, an approach that is consistent with analyses for previous rulemakings. NHTSA also addresses its assumptions regarding petroleum imports and emissions in Section III.F.2. of the preamble to the final rule.

10.5.1 Social Cost of Carbon

NHTSA received a number of comments pertaining to the substance of NHTSA's analysis and valuation of the social cost of carbon (SC-CO_2), including cost methodology, discount rates, domestic versus global social cost of GHG emissions, the Interagency Working Group's findings, integrated assessment models, and sensitivity analysis. Because one of the primary purposes of NHTSA's RIA is to monetize and compare the potential costs and benefits of the Proposed Action and alternatives for the benefit of the decision-maker and the public, NHTSA believes that is the appropriate place for this analysis. Therefore, consistent with NHTSA's approach in past CAFE EISs, comments regarding these issues are addressed in NHTSA's final rule and FRIA, where the analysis is conducted and the results are discussed, and NHTSA is not including these comments in this chapter. NHTSA reiterates that the comment fragments below are reproduced verbatim from comments submitted to NHTSA's Docket No. NHTSA-2021-0054, including footnote references.

Comment

Docket Number: NHTSA-2021-0054-0014
Organization: Institute for Policy Integrity at New York University School of Law et al.

[Section A.] Relevant Statutes and Executive Orders Permit, if Not Compel, a Global Perspective on Climate Damages

The Energy Policy and Conservation Act ("EPCA"), National Environmental Policy Act, Administrative Procedure Act, and other key sources of law permit, if not require, NHTSA to consider the effects of U.S. pollution on foreign nations. NHTSA should highlight these legal provisions as further explanation for its focus on global climate impacts.

Under EPCA, NHTSA is charged with mandating fuel-economy standards that take into consideration, among other enumerated factors, "the need of the United States to conserve energy"[78]. For decades, courts have affirmed that this language does not bar, but in fact compels NHTSA to consider the environmental implications of energy conservation, including effects on climate change. In 1988, the U.S. Court of Appeals for the D.C. Circuit highlighted that the Energy Policy and Conservation Act contains no statutory command prohibiting environmental considerations, recognizing "no conflict" between considering "environmental consequences" with "the factors NHTSA must weigh under EPCA[79]. The court further approved of the Department of Transportation's interpretation that the reference to "need of the Nation to conserve energy" "requires consideration of . . . environmental . . . implications"[80]. More recently, in 2008, the U.S. Court of Appeals for the Ninth Circuit indicated that, due to advancements in "scientific knowledge of climate change and its causes," "[t]he need of the nation to conserve energy is even more pressing today than it was at the time of EPCA's enactment"[81]. Accordingly, the court concluded, "EPCA does not limit NHTSA's duty … to assess the environmental impacts, including the impact on climate change, of its rule"[82].

Nowhere does EPCA restrict consideration of climate impacts to those effects that occur within the nation's borders, as confirmed in a recent case from the U.S. Court of Appeals for the Seventh Circuit. In that case, industry groups challenged a Department of Energy efficiency standard that was promulgated under EPCA, specifically objecting to the alleged "mismatch in the [social cost of carbon] analysis looking to global benefits." According to the petitioners, "EPCA authorizes [the agency] to conduct only a national analysis. There are no references to global impacts in the statute"[83]. The Seventh Circuit rejected that argument, holding that DOE "acted reasonably" in considering the "global benefits" of its EPCA standards[84]. Although that case concerned a different provision of EPCA, the statutory factors for DOE's efficiency standards at issue in that case are very similar to the statutory standards provided for NHTSA's fuel-economy standards[85]. In light of the similarities between these two provisions, the Seventh Circuit's holding—that EPCA permits consideration of global climate impacts—naturally applies to NHTSA's consideration of fuel-economy standards under that statute.

The Ninth Circuit decision discussed above provides additional support for this interpretation. In that case (discussed further below), the court held that NHTSA must monetize climate impacts as part of any cost-benefit analysis of proposed fuel-economy standards under EPCA[86]. In its ruling, the court listed several estimates of the global social cost of greenhouse gases as values that the agency could have

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[78] 9 U.S.C. § 32902(f).

[79] *Pub. Citizen v. Nat'l Highway Traffic Safety Admin*., 848 F.2d 256, 263 n.27 (D.C. Cir. 1988)

[80] *Id.; see also id*. at 265 (recognizing that Congress did not supply "precise balancing formula for the agency to apply," therefore leaving it within NHTSA's discretion to engage in a "reasonable accommodation of conflicting policies that were committed to the agency's care by the statute") (internal quotation marks omitted).

[81] *Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1197–98 (9th Cir. 2008).

[82] *Id*. at 1214.

[83] Brief for Petitioners at 28–30, *Zero Zone v. Dep't of Energy*, 832 F.3d 654 (7th Cir. 2016).

[84] *Zero Zone*, 832 F.3d at 679.

[85] *Compare* 42 U.S.C. § 6295(o)(2)(B)(i)(VI) (cited at *Zero Zone*, 832 F.3d at 679) (requiring DOE to consider "the need for national energy and water conservation) *with* 49 U.S.C. § 32902(f) (requiring NHTSA to consider "the need of the United States to conserve energy").

[86] *Ctr. for Biological Diversity*, 538 F.3d at 1198–1203.

applied[87]. By implication, the court indicated that NHTSA should consider the global externalities of greenhouse gases in setting fuel-economy standards—and not limit its analysis to effects only within the geographic borders of the United States.

This interpretation is further supported by the National Environmental Policy Act ("NEPA"). Though best known for requiring agencies to prepare environmental impact statements before taking certain actions, NEPA also much more broadly declares a national environmental policy and requires of all agencies that "to the fullest extent possible[,] the policies, regulations, and public laws of the United States *shall be interpreted and administered* in accordance with the policies set forth in this chapter[88]," including the need to "recognize the worldwide and long-range character of environmental problems" and to "lend appropriate support" to help "maximize international cooperation"[89]. In other words, especially because adopting a global perspective on climate damages will advance U.S. foreign policy goals (see the next subsection), NEPA requires NHTSA to interpret all of the laws it administers, including EPCA, in ways that recognize the worldwide character of environmental problems. Using global social cost of greenhouse gas estimates helps fulfill that requirement.

Other key legal commitments compel this same conclusion. For instance, the United Nations Framework Convention on Climate Change—to which the United States is a party[90]— declares that national "policies and measures to deal with climate change should be cost- effective so as to *ensure global benefits* at the lowest possible cost"[91]. The Convention further commits parties to evaluating global climate effects in their policy decisions, by "employ[ing] appropriate methods, for example *impact assessments* . . . with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change"[92]. The unmistakable implication of the Convention is that parties—including the United States—must account for global economic, public health, and environmental effects in their impact assessments. In

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[87] *Id*. at 1199 & n.44 (recognizing significance of climate change's "global decision context" for setting appropriate social cost values).

[88] 42 U.S.C. § 4332(1) (emphasis added).

[89] *Id*. § 4332(2)(F); *see also EDF v. Massey*, 986 F.2d 528, 536 (D.C. Cir. 1993) ("Section 102(2)(F) further supports the conclusion that Congress, when enacting NEPA, was concerned with worldwide as well as domestic problems facing the environment Compliance with one of the subsections can hardly be construed to relieve the agency from its duty to fulfill the obligations articulated in other subsections."); *NRDC v. NRC*, 647 F.2d 1345, 1387 (D.C. Cir. 1981) (J. Robinson, concurring; J. Wilkey wrote for the Court, but there was no majority opinion) (concluding that even if a conflict with another statute prevents the agency from conducting an environmental impact statement, that "does not imply that NRC may ignore its other NEPA obligations," including the "provision for multinational cooperation" and the "policy of the United States with respect to the ecological well-being of this planet"; rather, the agency "should remain cognizant of this responsibility"); *Greene County Planning Bd. v. Federal Power Comm'n*, 455 F.2d 412, 424 (2d Cir. 1972) ("The Commission's 'hands-off' attitude is even more startling in view of the explicit requirement in NEPA that the Commission 'recognize the worldwide and long-range character of environmental problems' and interpret its mandate under the Federal Power Act in accordance with the policies set forth in NEPA.").

[90] S. Treaty Doc. No. 102-38; S. Exec. Rept. No. 102-55.

[91] U.N. Framework Convention on Climate Change art. 3(3), May 9, 1992, 1771 U.N.T.S. 107 (emphasis added); *see also id*. art. 3(1) ("The Parties should protect the climate system for *the benefit of present and future generations of humankind, on the basis of equity* and in accordance with their common but differentiated responsibilities and respective capabilities.") (emphasis added); *id*. art. 4(2)(a) (committing developed countries to adopt policies that account for "the need for equitable and appropriate contributions by each of these Parties to the global effort").

[92] *Id*. art. 4(1)(f) (emphasis added); *see also id*. art. 3(2) (requiring parties to give "full consideration" to those developing countries "particularly vulnerable to the adverse effects of climate change"); *see also* North American Agreement on Environmental Cooperation art. 10(7), Jan. 1, 1994, 32 I.L.M. 1480 (committing the United States to the development of principles for transboundary environmental impact assessments).

2008, a group of U.S. senators—including then-Senator John Kerry, who helped ratify the framework convention on climate change—agreed with this interpretation of the treaty language, saying that "[u]pon signing this treaty, the United States committed itself to considering the global impacts of its greenhouse gas emissions"[93].

And under the Administrative Procedure Act, it is arbitrary and capricious for agencies to "entirely fail[] to consider an important aspect of the problem[94]"—an obligation that a federal court held requires federal agencies to consider international climate impacts. Specifically, a recent ruling from the U.S. Court for the Northern District of California struck down as arbitrary the Bureau of Land Management's ("BLM") rescission of the Waste Prevention Rule in part because the agency had abandoned the Working Group's peer-reviewed, global estimates of the social cost of greenhouse gases in favor of flawed estimates (the same estimates that NHTSA applied under the Trump administration) that looked only at effects within the U.S. borders[95]. The court found that the global values developed by the Working Group reflected "the best available science about monetizing the impacts of greenhouse gas emissions[96]," whereas "focusing solely on domestic effects has been soundly rejected by economists as improper and unsupported by science"[97].

The court reminded BLM that relevant executive orders, including Executive Order 12,866, require consideration of "all" costs and benefits, based on the "best reasonably obtainable scientific, technical, economic, and other information," and concluded that "no[] . . . regulatory rules or orders require exclusion of global impacts"[98]. More recently, Executive Order 13,990 instructed agencies to "tak[e] global damages into account," because "[d]oing so facilitates sound decision-making, recognizes the breadth of climate impacts, and support the international leadership of the United States on climate issues"[99]. This language again reinforces the instructions from NEPA that, whenever not precluded by statute from doing so, agencies should account for the environmental impacts of their actions on foreign nations.

NHTSA should draw upon these legal authorities in further explaining its reliance on global climate-damage valuations.

[Section B.] Focusing on Global Climate Damages Furthers U.S. Strategic Interests by Facilitating Reciprocity, Mitigating International Spillover Effects, and Protecting U.S. Extraterritorial Interests

NHTSA explains that the Working Group selected a global perspective in part because climate impacts occurring outside U.S. borders can directly and indirectly affect U.S. welfare through spillovers and foreign reciprocity, and that NHTSA is readopting that global perspective consistent with its approach

[93] Comment Letter from U.S. Sens. Feinstein, Snowe, Nelson, Cantwell, Sanders, Kerry, Durbin, Reed, Boxer, & Cardin to Mary Peters, Sec'y, U.S. Dep't of Transp. on Proposed Rule for Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015 (July 1, 2008).

[94] *Motor Vehicle Manufacturers Ass'n v. State Farm Mutual Auto. Ins. Co.*, 463 U.S. 29, 41–43 (1983).

[95] *Bernhardt*, 472 F. Supp. 3d at 613.

[96] *Id*. at 611.

[97] *Id*. at 613.

[98] *Id*. at 611–12 (internal quotation marks omitted).

[99] Exec. Order No. 13,990 § 5(a), 86 Fed. Reg. 7037, 7040 (Jan. 20, 2021).

from 2009–2016[100]. NHTSA should expand on this justification. In particular, NHTSA should explicitly explain why the theory and evidence for reciprocity by itself justifies a focus on the full global values, and that additional strategic and practical justifications provide further support.

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Although NHTSA makes extensive use of the social cost of greenhouse gas values in its RIA and TSD, it hardly mentions these values in its draft Environmental Impact Statement for the Proposed Rule ("EIS"). The EIS directs readers to "consult the preamble to the proposed rule" for monetized estimates of climate damages[101], and instead discusses the rule's climate benefits by modeling its physical impacts on surface temperature, sea-level rise, and ocean acidification[102], and comparing the emission reductions from the rule to baselines such as U.S. emission targets and annual emissions from the vehicle sector[103]. NHTSA should supplement its analysis by incorporating the monetized climate-benefit estimates from the RIA into the EIS.

There is extensive agency precedent for using the social cost of greenhouse gases in environmental analyses conducted under NEPA. In addition to NHTSA's own use of the social cost of greenhouse gases in its 2012 environmental impact statement for the fuel-economy standards it was then promulgating[104], numerous agencies have applied the social cost of greenhouse gases under NEPA including the Department of the Interior, U.S. Army Corps of Engineers, and U.S. Postal Service[105]. In Executive Order 13,990, President Biden recognized that the Working Group's social cost estimates are not only for regulatory impact analysis but may also be useful broadly in "decision-making, budgeting, and procurement"[106]. Numerous federal courts have also endorsed agency usage of the social cost estimates under NEPA, holding that analyses omitting those valuations are deficient[107]. Earlier this year, for instance, the U.S. Court of Appeals for the District of Columbia Circuit held that an environmental impact statement conducted by the Federal Energy Regulatory Commission was insufficient after the Commission rejected the social cost of greenhouse gases methodology[108]. As the Court explained,

[100] Proposed Rule TSD at 534.

[101] NHTSA, Draft Supplemental Environmental Impact Statement, Corporate Average Fuel Economy Standards: Model Years 2024–2026 at 5-28 (2021) ["Proposed Rule EIS"].

[102] *Id*. at 5-28 to 5-30.

[103] *Id*. at 5-38 to 5-41.

[104] NHTSA, Final Environmental Impact Statement, Corporate Average Fuel Economy Standards: Passenger Cars and Light Trucks Model Years 2017–2025 (2012) [hereinafter "2012 EIS"].

[105] For these and other examples of agency usage of the Working Group's social cost estimates under NEPA, see Federal Agencies' Use of the Social Costs of Greenhouse Gases in NEPA Analysis, THE COST OF CARBON POLLUTION, https://costofcarbon.org/scc-use-under-nepa.

[106] Exec. Order 13,990 § 5(b); *see also* IWG, 2021 TSD, *supra* note 5, at 12 nn.12–14 (highlighting application of Working Group's estimates under NEPA, as well as in federal procurement and grant-making).

[107] *Ctr. for Biological Diversity*, 538 F.3d at 1216–17 (rejecting analysis under NEPA when agency "quantifie[d] the expected amount of [carbon dioxide] emitted" but failed to "evaluate the incremental impact that these emissions will have on climate change or on the environment more generally," noting that this approach impermissibly failed to "discuss the *actual* environmental effects resulting from those emissions" or "provide the necessary contextual information about the cumulative and incremental environmental impacts" that NEPA requires); *High Country Conservation Advocates v. U.S. Forest Serv*., 52 F. Supp. 3d 1174, 1190 (D. Colo. 2014); *Mont. Envtl. Info. Ctr. v. U.S. Office of Surface Mining*, 274 F. Supp. 3d 1074, 1096–99 (D. Mont. 2017).

[108] *Vecinos para el Bienestar de la Comunidad Costera v. Fed. Energy Regul. Comm'n*, 6 F.4th 1321, 1327–31 (D.C. Cir. 2021).

applicable regulations on conducting NEPA analyses from the Council on Environmental Quality may in fact "obligate[]" agencies "to use the social cost of carbon protocol" in their environmental impact statements[109].

Without the additional context of the social cost values, moreover, the methodologies that NHTSA applies in the EIS may inadvertently trivialize the Proposed Rule's climate impacts. For instance, presenting a project's physical impacts without using the social cost of greenhouse gases could misleadingly make an action's climate impacts appear small. Because climate change is a global phenomenon with individually subtle yet collectively colossal impacts, a single project or regulation may not affect global temperatures or sea levels by more than a seemingly very small amount. Yet even seemingly small geophysical effects can have massive reverberations on a global scale. With the Proposed Rule, for instance, NHTSA reports that the regulation will reduce global temperatures by approximately 0.003°C[110]. While this may seem like a trivial impact, it actually translates into more than $30 billion in total climate benefit, as NHTSA's application of the social cost of greenhouse gases in its RIA reveals[111].

NHTSA's reliance on percentage comparisons can have a similar minimizing effect, as percentage comparisons to geographic climate targets or inventories frequently make massive amounts of emissions from an individual project or action appear relatively small when misleadingly compared to a far larger baseline denominator. As one federal court recently recognized, "[t]he global nature of climate change and greenhouse-gas emissions means that any single … project likely will make up a negligible percent of state and nation-wide greenhouse gas emissions"[112]. Yet once again, as the social cost metrics reveals, the climate benefits of the Proposed Rule are anything but negligible.

While the techniques that NHTSA employs in the EIS to assess climate benefits do provide some helpful information, the social cost of greenhouse gases is still highly useful to assess climate impacts in a manner that is salient and captures the proposal's actual impacts on human health and welfare. Accordingly, NHTSA should supplement its existing NEPA analysis by incorporating its monetized climate-benefit assessments into the EIS.

Response

While NEPA does not require agencies to incorporate monetized values in environmental analyses, a monetized analysis like the social cost of carbon (SC-CO_2) offers a potential opportunity to contextualize environmental effects of an action to enhance the understanding of the public and decision-makers. As such, NHTSA has integrated a SC-CO_2 analysis in all recent CAFE EISs, either explicitly or through incorporation by reference to other rulemaking documents. CEQ regulations encourage agencies to incorporate by reference material to cut down on bulk[113] and to combine documents to reduce duplication.[114] As discussed in Section 5.3.2, *Social Cost of Greenhouse Gas Emissions*, the SC-CO_2 analysis in Section III.G.2.b).(1) of the preamble to the final rule and Chapter 6.5.1 of the FRIA is

[109] *Id*. at 1329.

[110] Proposed Rule EIS, *supra* note 286, at 5-45.

[111] RIA at 174 fig. 6-29.

[112] *WildEarth Guardians v. Bureau of Land Mgmt*., 457 F. Supp. 3d 880, 894 (D. Mont. 2020).

[113] 40 CFR § 1502.21.

[114] 40 CFR § 1506.4.

incorporated in this SEIS by reference. This information is available to the decision-maker and the public contemporaneously with the availability of this Final SEIS, and the decision-maker had the opportunity to consider this information as part of the official record. Because one of the primary purposes of NHTSA's FRIA is to monetize and compare the potential costs and benefits of the Proposed Action and alternatives for the benefit of the decision-maker and the public, NHTSA believes that is the appropriate place for this analysis.

To complement the SC-CO_2 analysis presented in the final rule preamble and FRIA, and consistent with the global scope of physical climate effects used in the analysis methods for past CAFE EISs, NHTSA considers the global environmental impacts of the Proposed Action and alternatives in this Final SEIS. For instance, the quantitative physical effects estimates presented in Section 5.4.2, *Direct and Indirect Impacts on Climate Change Indicators*, and Section 8.6.5, *Cumulative Impacts on Greenhouse Gas Emissions*, examine the impact of the Proposed Action and alternatives on a range of global climate indicators, and also under several sensitivity cases assuming a range of future global actions to mitigate climate change effects. In addition, this SEIS provides a qualitative discussion of the potential impacts of climate change on key natural and human resources in Section 5.2, *Affected Environment*, and in Section 8.6.4, *Health, Societal, and Environmental Impacts of Climate Change.* In addition, NHTSA provides discussions of the impact of the action in Section 5.4.1.1, *Comparison to the U.S. Greenhouse Gas Targets Submitted to the United Nations Framework Convention on Climate Change*, Section 5.4.1.2, *Comparison to Annual Emissions from Passenger Cars and Light Trucks*, and Section 5.4.1.3, *Global Carbon Budget*. Some of these discussions use percentages not to minimize the impact of this rule on climate change, as the commenter suggests, but to provide the decision-maker and the public with different lenses through which to view the impact of this action.

In fact, NHTSA emphasizes the importance of this action to climate change indicators throughout this Final SEIS. For example, NHTSA emphasizes in Section 5.4.2, *Direct and Indirect Impacts on Climate Change Indicators*, that although the impacts of the Proposed Action and alternatives on climate change indicators are small, primarily due to the global and multi-sectoral nature of climate change, the impacts 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.

In accordance with EPCA, NEPA, and other statutory obligations, including those mentioned by the commenter, NHTSA carefully considered the environmental effects of the rule to support its conclusion that the final standards are maximum feasible.

10.6 Life-Cycle Assessment Implications of Vehicle Energy, Materials, and Technologies

10.6.1 Energy Sources

Comment

Docket Number: NHTSA-2021-0054-0011
Organization: EPA

EPA is providing the following technical comments for your consideration on the life cycle assessment within Chapter 6.

Figure 6.2.3.5 shows an example for grid electricity that is two-thirds from coal, using a specific example for China. EPA questions the relevance of the China example for the U.S. and suggests that the figure be deleted or replaced with a U.S.-grid-specific example from a more recent study (e.g., the recently published ICCT study: https://theicct.org/sites/default/files/publications/Global-LCA-passenger-cars-jul2021_0.pdf). If this figure is retained, then NHTSA should explain the relevance of this high coal scenario to the use of electric vehicles in the U.S.

In section 6.2.4, the biofuel lifecycle analysis does not present EPA's lifecycle GHG emissions estimates alongside other estimates. For biodiesel, lifecycle results from Argonne National Lab are presented, with no mention of EPA's results. For ethanol, results from a few studies (including from Argonne National Lab) are presented, along with a detailed discussion of a report funded by USDA (Rosenfeld 2018). EPA's estimate of the emissions associated with converting corn starch to ethanol are presented, without also showing EPA's estimates of the emissions associated with agricultural impacts and land use change. Especially given that the section on biofuels starts with a discussion of the Renewable Fuel Standard, we are concerned that the report is not presenting the EPA's lifecycle emissions estimates. The table at the following site summarizes EPA-calculated lifecycle emissions. EPA suggests that NHTSA include the results for corn starch ethanol from dry mill NG, and soybean oil biodiesel from transesterification.

- https://www.epa.gov/sites/default/files/2016-07/documents/select-ghg-results-table- v1.pdf

Response

NHTSA updated the discussion in Section 6.2.3, *Electricity*, and to refer to the more recent International Council on Clean Transportation study (Bieker 2021) and removed the graphic from Xiong et al. 2021. Although Xiong et al. originally provided insight into emissions for each phase of the vehicle, the existence of more recent analysis specific to the U.S. electricity market provides a more accurate representation of emissions from vehicles in the United States.

NHTSA amended the discussion in Sections 6.2.4.1, *Biodiesel,* and 6.2.4.2, *Ethanol*, to include findings from the EPA biofuel life-cycle studies referenced by the commenter. Additional language was added in Section 6.2.4.2, *Ethanol,* to clarify that the other studies described in the section show differing results as result of more recent data and information (Lewandrowski et al. 2020).

Comment

Docket Number: NHTSA-2021-0054-0012
Organization: Sierra Club
Commenter: Joshua Berman

NHTSA's DSEIS presents an erroneous picture of the GHG emissions impacts of battery electric vehicles (EVs). NHTSA's discussion of EV GHG emissions in its life-cycle assessment is plagued by reliance on stale data[115]. When more current data are used, the results are dramatically different and show that EVs are already superior to internal combustion engine (ICE) vehicles from a GHG emissions perspective across almost the entire country, and trends in power generation will cause EVs to further outpace ICE vehicles on emission reductions in the coming years.

NHTSA presents an assessment of the probability that the sources of electricity powering a battery electric vehicle emit carbon dioxide at a lower rate than a hybrid or internal combustion engine vehicle, DSEIS at 6-26, Fig. 6-2.3-10, and looks at how this probability is influenced by use of consumption-based versus generation-based emissions accounting and the timing of EV charging. NHTSA's assessment suggests that in many parts of the country, the sources of electricity powering BEVs are unlikely to emit carbon dioxide (CO_2) at a lower rate than a hybrid or ICE vehicle. This is erroneous and must be corrected in the final SEIS.

NHTSA's assessment relies on data that are far out of date and radically different from more current CO_2 emission data from the power grid. NHTSA's Figure 6.2.3-10 is based on a paper by Tamayao et al. published six years ago in 2015[116]. The data sources used by Tamayao et al. are even further out of date[117]. Tamayao et al. relied on information from EPA's eGRID 2012 for their subregional annual CO_2 emission rates, which relied on marginal grid emission data from 2009[118]—12 years ago. In 2009, coal—the most CO_2-intense source of power generation— accounted for 44 percent of utility-scale power generation in the United States[119]. By 2019, that percentage had dropped to less than 24 percent[120]. At the same time, the share of zero marginal CO_2 emitting utility-scale power generation (hydro, wind, solar, nuclear) increased from just over 30 percent in 2009 to more than 37 percent in 2019, with significant additional solar generation coming from small scale generation[121]. The increase in zero

[115] NHTSA acknowledged but did not address this limitation in the DSEIS. DSEIS at 6-16 ("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.").

[116] Tamayao, M.A.M., et al. 2015. Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States. Environmental Science & Technology 49(14):8844-8855. doi:10.1021/acs.est.5b00815.

[117] *See* Tamayao, M.A.M. et al, Supplemental Information for Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States, attached as Exhibit 2.

[118] *Id*. at 5.

[119] EIA, Table 3.1.A. Net Generation by Energy Source: Total (All Sectors), 2009 – 2019, available at https://www.eia.gov/electricity/annual/html/epa_03_01_a.html. (coal accounted for 1.755 billion MWh out of 3.950 billion MWh of total generation at utility-scale facilities in 2009).

[120] EIA, Table 3.1.A. Net Generation by Energy Source: Total (All Sectors), 2009 – 2019 (coal accounted for 964 million MWh out of 4.126 billion MWh of total generation at utility-scale facilities in 2019).

[121] EIA, Table 3.1.A. Net Generation by Energy Source: Total (All Sectors), 2009 – 2019 (utility scale nuclear + hydroelectric convention + solar + renewable sources excluding hydroelectric and solar accounted for 1.217 billion MWh in 2009 and 1.537 billion MWh in 2019).

emitting utility-scale generation is driven almost entirely by additional renewable resources (solar and wind)[122].

Table 1 below illustrates the change in CO_2 emission rate between eGRID 2012—the data set relied upon by NHTSA in its DSEIS—and eGRID 2019[123], for the different eGRID subregions in the continental United States. As the table shows, all eGRID subregions experienced a decline in annual CO_2 emission rate during this time, with 16 of the 22 eGRID subregions experiencing a decline of at least 20 percent, 8 experiencing a decline of at least 30 percent, and one experiencing a decline of more than 50 percent.

Table 1: Change in Annual CO_2 Emission Rate from eGRID 2012 to eGRID 2019

eGRID subregion acronym	eGRID subregion name	eGRID 2012 subregion annual CO2 emission rate (lb/Mwh)	eGRID 2019 subregion annual CO2 emission rate (lb/MWh)	Percent Reduction (%)
FRCC	FRCC All	1175	861	26.7
MORE	MRO East	1588	1503	5.4
MROW	MRO West	1626	1098	32.5
NYLI	NPCC Long Island	1344	1209	10.1
NEWE	NPCC New England	726	489	32.7
NYCW	NPCC NYC/Westchester	609	554	9.1
NYUP	NPCC Upstate NY	497	232	53.3
RFCE	RFC East	946	695	26.5
RFCM	RFC Michigan	1657	1189	28.2
RFCW	RFC West	1518	1068	29.6
SRMW	SERC Midwest	1747	1584	9.3
SRMV	SERC Mississippi Valley	1001	807	19.4
SRSO	SERC South	1322	1002	24.2
SRTV	SERC Tennessee Valley	1355	950	29.9
SRVC	SERC Virginia/Carolina	1034	675	34.7
SPNO	SPP North	1813	1070	41.0
SPSO	SPP South	1595	1002	37.2
ERCT	ERCOT All	1179	869	26.3
CAMX	WECC California	658	453	31.1
NWPP	WECC Northwest	818	715	12.6
RMPA	WECC Rockies	1822	1243	31.8
AZNM	WECC Southwest	1188	952	19.8

[122] EIA, Table 3.1.A. Net Generation by Energy Source: Total (All Sectors), 2009 – 2019) (utility-scale solar increased by a factor of 9 from 819,000 MWh in 2009 to 71.9 million MWh in 2019, and other non-solar, non-hydro renewables more than doubled from 143 million MWh in 2009 to 367 million MWh in 2019).

[123] U.S. EPA, eGRID Data Explorer, available at https://www.epa.gov/egrid/data-explorer.

When NHTSA's Figure 6.2.3-10 is updated with more current data, the picture looks very different. The Union of Concerned Scientists calculated EV mile-per-gallon equivalence—the combined city/highway fuel economy rating of a gasoline vehicle would have global warming emissions equivalent to driving an EV—for all eGRID subregions using eGRID 2019 data[124]. As the updated map (below) shows, in only two eGRID subregions in the continental US do EVs have a GHG mpg equivalence below 50 mpg. In 17 of the 22 eGRID subregions in the Lower 48 States, EVs have a GHG mpg equivalence of 60 mpg or higher.

[See original comment for map of EV Emissions as Gasoline MPG Equivalent]

NHTSA also presents marginal emission factors (MEFs) in Figure 6.2.3-13 to assess the emissions impact of EVs. The data underpinning these MEFs are also stale. These data were drawn from Siler-Evans et al. (2012), which analyzed data from 2007 to 2009[125], and from Graff Zivin et al. (2014), which analyzed data from 2006 to 2011[126]. As discussed above, the composition of the grid has changed dramatically in the past 10 years and marginal emission data from 10 to 15 years ago are no longer representative. In addition, the Siler-Evans et al. data are further skewed because the authors assumed fossil fuel generation to be on the margin at all times and looked only at the marginal emission rate of fossil fuel generators[127]. Finally, particularly in light of the growth of energy storage, which can result in a temporal displacement of generation, it is not clear that MEFs are the appropriate tool for analyzing EV emissions equivalence. Not only can storage effectively shift what generation is on the margin, EV load can also be actively managed, as utilities are already beginning to do[128]. With active third-party managed charging, it is possible to time vehicle charging for optimization based on a variety of metrics including, for example, the GHG-intensity of the power grid, to minimize emissions impacts from new EV electric load.

NHTSA's relative emissions analysis is also problematic because it is static, depicting a snapshot in time (indeed, a very out-of-date one, as explained above). But the GHG emissions intensity of the electric grid continues to decline in response to economic and regulatory factors. According to the Energy Information Administration, "[a]s of September 2020, 38 states and the District of Columbia had established [a Renewable Portfolio Standard] or renewable goal, and in 12 of those states (and the District of Columbia), the requirement is for 100% clean electricity by 2050 or earlier"[129]. NHTSA itself notes that "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," and appropriately recognizes that "[w]hen considered with the projected cleaner U.S. grid

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[124] Reichmuth, D., Plug In or Gas Up? Why Driving on Electricity is Better than Gasoline (June 7, 201), available at https://blog.ucsusa.org/dave-reichmuth/plug-in-or-gas-up-why-driving-on-electricity-is-better-than-gasoline/. UCS notes that the comparison includes gasoline and electricity fuel production emissions estimates for processes like extraction, transportation, and refining using Argonne National Laboratory's GREET 2020 model and that the 93 mpg US average is a sales-weighted average based on where EVs were sold in 2011 through 2020. *Id*.

[125] Siler-Evans, K. et al., Marginal Emissions Factors for the U.S. Electricity System, Envtl. Sci. & Tech. (2012), dx.doi.org/10.1021/es300145v.

[126] Graff Zivin, J.S., et al., Spatial and temporal heterogeneity of marginal emissions: Implications for electric cars and other electricity-shifting policies, J. Econ. Behavior & Org. (2014), http://dx.doi.org/10.1016/j.jebo.2014.03.010.

[127] *See* Zivin et al. (2014) (explaining limitations of Siler-Evans et al. including reliance on the assumption that only fossil fuel power plants in EPA's continuous emissions monitoring system data supply marginal electricity output).

[128] *See, e.g.*, National Grid, Niagara Mohawk Power Corporation d/b/a National Grid Residential Electric Vehicle (EV) Managed Charging Proposal, N.Y. P.S.C. Case No. 18-E-0138 (June 4, 2020), attached as Exhibit 3.

[129] EIA, Renewable Energy Explained: Portfolio Standards, https://www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php.

mix, this life-cycle GHG benefit will grow in future years." DSEIS at 6-16. NHTSA must correct the patent errors in the emissions comparison for EVs and ICE vehicles for its life-cycle analysis in its final SEIS.

Response

NHTSA agrees that the 2015 marginal emission factors (MEFs) study (based on 2013 electricity data) is not representative of the U.S. electric grid in 2021, nor future years. NHTSA has updated Section 6.2.3.1, *Charging Locations*, to use more appropriate and current emission factors to assess the CO_2 impacts from electric vehicle (EV) charging locations and behaviors. MEFs are no longer used, and Figure 6.2.3-10 (from Tamayao et al. 2015) has been removed. The section was restructured to put an emphasis on the effect of the carbon intensity of the local grid in addition to behavioral charging habits (e.g., time of charge, charging location of home versus work) on the life-cycle GHG emissions of an EV. The reference to the Tamayao et al. 2015 study was kept in the chapter text because it is still the reference for some of the language used around Marginal Grid and Marginal Emission Factors that are still discussed in Section 6.2.3.2, *Marginal Grid Greenhouse Gas Intensity*. The discussion in Section 6.2.3.1, *Charging Locations*, has also been updated to note the decline in CO_2 emission rates for most EPA Emissions & Generation Resource Integrated Database (eGRID) subregions between 2012 and 2019.

Comment

Docket Number: NHTSA-2021-0054-0012
Organization: Sierra Club
Commenter: Joshua Berman

NHTSA should correct its omission of the environmental impacts of transporting oil in its final SEIS. In Chapter 6 of the DSEIS, NHTSA explains that a life-cycle analysis looks at five phases: (1) raw material extraction; (2) manufacturing; (3) vehicle use; (4) end of life management; and (5) transportation (i.e., how materials and product are moved between these phases). DSEIS at 6-2. Yet, NHTSA's actual life-cycle analysis for EVs and ICE vehicles presented in the DSEIS fails to address the transportation phase. This omission is significant because transport of crude oil—the feedstock for the fuel for ICE vehicles—over the past decade has been responsible for numerous spills, fires, and explosions causing massive damage to natural environments and wildlife, and incurring billions of dollars in cleanup costs. In its final SEIS, NHTSA must consider and discuss the impacts of transporting materials, including crude oil, between the phases of the life-cycle analysis.

Crude oil can be transported in several ways including via pipelines, by ship, and by rail. Each mode of transport can result in spills and serious damage to the environment. According to data from the Pipeline and Hazardous Materials Safety Administration (PHMSA), between 2001 and 2020, there were 1,158 significant pipeline system incidents involving crude oil resulting in 725,755 barrels spilled and more than $3 billion in costs[130]. Oil spills can cause a wide array of deleterious effects—both direct and indirect—on wildlife and wildlife habitat[131] including trapping animals, destroying the insulating ability of mammal fur and the water repellency of bird feathers, increasing the risk of hypothermia, impacts to

[130] U.S. DOT, PHMSA, Pipeline Incident 20 Year Trends: Significant Incident 20 Year Trend, available from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends.

[131] Heron, S.F., How Does an Oil Spill Affect the Environment? Sciencing (Nov. 22, 2019), https://sciencing.com/oil-spill-affect-environment-4616883.html.

lungs, immune function and reproduction due to inhalation[132]. As NHTSA acknowledges, "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." DSEIS at 8-10. As the PHMSA pipeline data cited above show, spills are an inherent danger associated with the transport of oil via pipelines and must be considered and addressed in the final DSEIS.

Transport of crude oil in railcars raises additional environmental concerns that must be evaluated in the final SEIS. Although the volume of transport of crude oil by rail has declined in recent years from its peak in the mid-2010's, a large amount of crude oil in North America is still transported via railcar. According to data from the Department of Transportation, in 2018 there were still nearly 13,000 rail tank cars transporting crude oil (down from a high of more than 35,000 in 2014)[133]. Crude oil transport via rail has resulted in a number of catastrophic spills and fires including the destructive blaze at Lac-Mégantic, and the major derailments in Aliceville, Alabama, and Casselton, North Dakota[134]. The Province of Québec sought C$400 million in reimbursement of the clean-up costs associated with the Lac-Mégantic derailment and explosion[135]. In 2013 alone, over 1.1 million gallons of crude oil spilled in the United States, more than the total amount spilled between 1975 and 2012[136]. Despite the ongoing transport of crude oil by rail, the DSEIS includes no reference to or discussion of rail transport. NHTSA must correct this in the final SEIS.

Finally, transport of oil sands crude—whether by pipeline or rail—raises still other environmental concerns not addressed in the DSEIS. Although current oil prices have suppressed extraction of oil sands oil for the moment, as NHTSA recognizes, there is "uncertainty in the long-term growth of oil sands production." DSEIS at 6-7. Oil sands crudes are distinct from other forms of crude oil due to the unique chemical composition of the bitumen itself and the presence of large quantities of volatile diluent containing high levels of VOCs, toxic air contaminants and hazardous air pollutants. U.S. Geological Survey reports that "natural bitumen," the source of oil sands-derived oils, contains 102 times more copper, 21 times more vanadium, 11 times more sulfur, six times more nitrogen, 11 times more nickel, and 5 times more lead than conventional oil[137]. Oil stands crudes contain large amounts of neurotoxic and carcinogenic[138] volatile organic compounds benzene, toluene, ethyl-benzene, and xylenes (BTEX)

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[132] NOAA, How does oil impact marine life? https://oceanservice.noaa.gov/facts/oilimpacts.html.

[133] U.S. Dept. of Transp. Bureau of Transp. Stats., Fleet Composition of Rail Tank Cars Carrying Flammable Liquids: 2019 Report, at 6, Fig. 2.

[134] *See* Comments of the Natural Resources Defense Council, Sierra Club and Oil Change International on behalf of Earthjustice, ForestEthics, Public Citizen, Friends of the Earth, Spokane Riverkeeper, Columbia Riverkeeper, Puget Soundkeeper Alliance, Friends of Grays Harbor, Natural Resources Council of Maine, Benicia Good Neighbor Steering Committee, Community In-power and Development Association, Vermont Chapter of the Sierra Club, Audubon Society of New Hampshire regarding Advance Notice of Proposed Rulemaking: Hazardous Materials: Rail Petitions and Recommendations to Improve the Safety of Railroad Tank Car Transportation, PHMSA-2012- 0082 (HM-251) (Dec. 5, 2013), at 8-10, attached as Exhibit 4; Petition to the Secretary of Transportation to Issue an Emergency Order Prohibiting the Shipment of Bakken Crude Oil in Unsafe Tank Cars Submitted by Earthjustice on behalf of Sierra Club and ForestEthics (July 15, 2014), at 3, attached as Exhibit 5.

[135] Allan Woods, Quebec submits $400 million claim for Lac-Mégantic train disaster, Toronto Star (June 16, 2014), https://www.thestar.com/news/canada/2014/06/16/quebec_claims_400_million_for_lacmgantic_train_disaster.html.

[136] Curtis Tate, More Oil Spilled from Trains in 2013 than in Previous 4 Decades, Federal Data Show, McClatchy DC (Jan. 20, 2014), available at.

[137] Meyer, R.F., et al., Heavy Oil and Natural Bitumen Resources in Geological Basins of the World, U.S. Geological Survey Open-File Report 2007-1084 (2007), at 14, Tbl. 1, Available at http://pubs.usgs.gov/of/2007/1084/OF2007-1084v1.pdf.

[138] U.S. Dept. of Health & Human Servs., Interaction Profiles for: Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) (May 2004), available at https://www.atsdr.cdc.gov/interactionprofiles/ip-btex/ip05.pdf.

and other heavy metals such as lead[139]. When blended with diluents, oil sands "DilBit" crudes contain even higher concentrations of BTEX compounds, which have a high potential to be released by way of transport as well as process related emissions[140].

In addition, oil sands crudes are highly corrosive. The Total Acid Number (TAN) is a measure of high organic acid content, typically naphthenic acids. These acids are known to cause corrosion at high temperatures. Crude oils with a TAN number greater than 0.5 mgKOH/g33 are considered to be potentially corrosive and indicates a level of concern. A TAN number greater than 1.0 mgKOH/g is considered to be very high. Canadian oil sands crudes are high TAN crudes. The DilBits, for example, range from 0.98 to 2.42 mgKOH/g[141]. Due to its corrosivity, oil sands crudes create a greater risk for spills during transport.

Spills involving DilBit can be environmentally catastrophic. As EPA explained in commenting on the proposed Keystone XL pipeline project in 2013, three years after a major spill of DilBit in the Kalamazoo River in Michigan, heavy oil remained at the bottom of the river and cleanup costs exceeded $1 billion in public funds[142]. NHTSA must consider the impacts of its proposals on future use and transport-related environmental impacts of oil sands oil in the final SEIS.

Response

NHTSA updated Section 6.2.1, *Diesel and Gasoline*, in the Final SEIS to add further discussion on the risks to the environment and human health of both oil sands development and oil sands crude-related spills that can occur during transport. The updated Final SEIS discussion references the potential dangers of transporting oil sands crude by pipeline and rail and provides some specific examples of previous incidents of spills in footnotes.

Comment

Docket Number: NHTSA-2021-0054-0016
Organization: Environmental Defense Fund

Section 6.2.2 of the DSEIS reviews the emissions related to the production of natural gas. It states that natural gas can be used directly in vehicles, as well as in the production of electricity. This is true. However, natural gas is also used in refineries, especially to provide heat for process units, in the production of hydrogen used to split heavier hydrocarbon molecules into lighter ones (cracking) and in removing contaminants, such as sulfur, nitrogen, metals, etc. (hydrotreating).[143] The same GREET model

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[139] Fox, P., Ph.D., PE, Comments on Environmental Impact Report for the Phillips 66 Rail Spur Expansion Project, Santa Maria, California (Jan. 27, 2014), at 24, attached as Exhibit 6.

[140] *Id*.

[141] *Id*. at 21 (citing www.crudemonitor.ca).

[142] EPA, Comment Letter to US Department of State Regarding the Supplemental Draft Environmental Impact Statement from TransCanada's Proposed Keystone XL project (2013), available at http://www.epa.gov/Compliance/nepa/keystone-xl-project-epa-comment-letter-20130056.pdf.

[143] https://www.digitalrefining.com/article/1000557/natural-gas-fuels-the-integration-of-refining-and-petrochemicals#.YXS1YPrMJPY.

used by NHTSA as a source of emission factors in this section clearly shows substantial volumes of natural gas used in crude oil production and refining.[144] NHTSA should make this clear in its analysis.

The chapter also provides basic information on the sources of natural gas tracked by GREET. It does not describe if or how methane leaks are included in GREET emission estimates. Because NHTSA uses GREET to estimate upstream emissions for gasoline and electricity, it is critical that NHTSA provide detailed information on the assumptions it uses.

Methane emissions are the second largest source of GHG emissions in the U.S. and worldwide, following emissions of carbon dioxide.[145] Therefore, it is important that NHTSA quantify the methane emissions from natural gas and crude oil production and distribution (i.e., emission factors) to be used to estimate the environmental impacts of the proposal.

Response

In Section 6.2.2.1, *Methane Emissions from Oil and Natural Gas*, NHTSA expanded the discussion of the use of natural gas in the fossil fuel production and refining process that produces gasoline and fuel oils. Additionally, NHTSA added a clarification of the emission sources included in the GREET model, which includes methane leaks from pipelines. Further discussion of how NHTSA used the GREET model to calculate upstream emissions is included in Chapter 5 of the TSD.

10.6.2 Vehicle Materials and Technologies

Comment

Docket Number: NHTSA-2021-0054-0016
Organization: Environmental Defense Fund

The DSEIS states that, "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."[146] The study cited is more than five years old and does not reflect the current state of battery recycling. Tesla is already working on recycling lithium from lithium batteries.[147] While NHTSA concludes that 20-70 percent of battery material could potentially be recycled in the 2040-2050 timeframe, Tesla indicates that it is already aiming for 92 percent recyclability for its current battery recycling program.[148] Tesla has also developed a technology that avoids the use of cobalt though the use of a silicon-based lithium battery.[149] Ford

[144] GREET, Petroleum worksheet, rows 48, 91, 110, and 127.

[145] https://www.epa.gov/ghgemissions/overview-greenhouse-gases, https://www.epa.gov/gmi/importance- methane.

[146] Hendrickson, T.P., O. Kavvada, N. Shah, R. Sathre, and C.D. Scown. 2015. Life-cycle implications and supply chain logistics of electric vehicle battery recycling in California. Environmental Research Letters. 10(1):014011. doi:10.1088/1748-9326/10/1/014011. Available at: http://iopscience.iop.org/article/10.1088/1748-9326/10/1/014011/pdf.

[147] Jill Ettinger, EV Batteries Are a Recycling Nightmare, Tesla Says It's Found a Solution, ETHOS (aug. 23, 2021), https://the-ethos.co/tesla-ev-batteries-recycling/.

[148] Id.

[149] Nick Flaherty, Tesla moves to cobalt-free silicon battery cell with a new form factor, EENEWS POWER MANAGEMENT (Sept. 23, 2020), https://www.eenewspower.com/news/tesla-moves-cobalt-free-silicon-battery-cell-new-form-factor.

Motor Company and Redwood Materials recently announced they are working together to build out battery recycling and a domestic battery supply chain for electric vehicles. Redwood's recycling technology can recover, on average, more than 95 percent of the elements like nickel, cobalt, lithium and copper so they can be reused in a closed loop with Redwood moving to produce anode copper foil and cathode active materials for future battery production.[150] In the Final SEIS, NHTSA should update the agency's analysis to reflect the latest information and developments on battery production and recycling.

Response

NHTSA expanded upon the discussion in Section 6.3.3, *Vehicle Batteries*, to address a number of the commenter's points. NHTSA revised Section 6.3.3 to include information and references to reflect on the state of battery recycling activities in the United States, based on more recent studies. The section now includes discussion of the recent investments by industry and the Federal Government to advance research, development, and implementation of battery recycling methodologies. NHTSA also updated the discussion to note that battery recycling is viewed as an economic opportunity for many industry players, as the recovery of lithium batteries can generate highly valuable metals. The Final SEIS continues to include language on the challenges that are limiting large-scale operations of dedicated battery recycling facilities, including process costs and efficiency, and the need for strong partnerships to enable a closed-loop supply chain framework in which large-scale battery recycling will be effective.

10.7 Other Impacts

10.7.1 Endangered Species Act

Comment

Docket Number: NHTSA-2021-0053-1549-1
Organization: Center for Biological Diversity

The Center for Biological Diversity ("Center") appreciates the opportunity to submit this letter on the National Highway Traffic Safety Administration's ("NHTSA") proposed Corporate Average Fuel Economy Standards for Model Years 2024-2026 Passenger Cars and Light Trucks (hereinafter, the "Rule"). Should NHTSA finalize the Rule, the Center urges you to undertake interagency consultation as required pursuant to Section 7 of the Endangered Species Act, 16 U.S.C. §§ 1531-44 ("ESA") ("Section 7 consultation"). Because the Rule will have an appreciable, cumulative impact on climate-threatened species as wells as species susceptible to criteria air pollution, NHTSA must consult with both the National Marine Fisheries Service and the U.S. Fish and Wildlife Service (collectively the "Services")[151]. NHTSA's failure to undertake such consultation would violate both the procedural requirements of Section 7(a)(2) of the ESA as well as NHTSA's substantive duty to ensure against jeopardy of federally-listed species and the adverse modification of their habitats.

[150] Ford, Ford, Redwood Materials teaming up on closed loop battery recycling, U.S. supply chain (Sept. 22, 2021), https://media.ford.com/content/fordmedia/fna/us/en/news/2021/09/22/ford-redwood-materials-battery-recycling.html.

[151] In *Massachusetts v. EPA*, the Supreme Court found that U.S. vehicle emissions represented a "meaningful contribution" to global emissions, and even addressing a fraction of these emissions was sufficient for standing purposes and requires EPA to take action. *Massachusetts v. EPA*, 549 US 497 (2007).

As explained below, while NHTSA's Rule reduces the total amount of greenhouse gas and other emissions that would have been emitted under the previous administration's Safer Affordable Fuel Efficient ("SAFE") Vehicles Rule, NHTSA's decision to finalize *this* Rule will nonetheless allow cars and light trucks to emit millions of metric tons of greenhouse gases and tens of thousands of tons of criteria pollutants. The impacts may be somewhat less harmful than those under the SAFE Rule, but they still exist. And by undergoing consultation under the ESA, NHTSA could make discretionary decisions—such as regarding stringency levels and uses of credits and other flexibilities—that mitigate these effects. Consultation is also consistent with President Biden's "whole of government" approach to addressing the climate crisis, as well as Executive Order 13990, which states that all federal agencies "must be guided by the best science and be protected by processes that ensure the integrity of Federal decision-making."

I. LEGAL BACKGROUND ON THE ENDANGERED SPECIES ACT

Congress enacted the Endangered Species Act, 16 U.S.C. §§ 1531-44 ("ESA"), in response to growing concern over the extinction of plants, fish, and wildlife[152], and recognized that certain species "have been so depleted in numbers that they are in danger of or threatened with extinction"[153]. To that end, one primary purpose of the ESA is "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, [and] to provide a program for the conservation of such . . . species"[154]. According to the U.S. Supreme Court, in passing the ESA, Congress made a deliberate choice "to give endangered species priority over the 'primary missions' of federal agencies"[155]. Accordingly, Section 2(c) of the ESA establishes that it is "the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of the purposes of this Act"[156]. The ESA defines "conservation" to mean "the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary[157]. Even with a global threat to biodiversity such as climate change, "the plain intent of Congress in enacting this statute was to halt and reverse the trend toward species extinction, *whatever the cost*[158].

To reach these goals, Section 7(a)(2) of the ESA requires federal agencies to "insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of [the critical] habitat of such species"[159]. "Action" is broadly defined to include "all activities or programs of any kind authorized, funded, or carried out, in whole or in part" by federal agencies and includes

[152] 16 U.S.C. § 1531(a)(1).

[153] *Id*. § 1531(a)(2).

[154] *Id*. § 1531(b).

[155] *Tenn. Valley Authority v. Hill ("TVA")*, 437 U.S. 153, 185 (1978) (emphasis added).

[156] 16 U.S.C. § 1531(c)(1).

[157] *Id*. § 1532(3).

[158] *TVA*, 437 U.S. at 184.

[159] *Id*. § 1536(a)(2); 50 C.F.R. § 402.14(a).

conservation measures, granting permits and licenses, as well as actions that may directly or indirectly cause modifications to the land, water, or *air*[160].

While many of the ESA's provisions work to effectuate the conservation goals of the statute, the "heart of the ESA" is the interagency consultation requirements of Section 7 of the ESA[161]. At the first step of the consultation process, the "agency shall conduct a biological assessment" to identify species likely to be affected[162]. If the agency determines that an action *may affect* a species—even if the effect is small, indirect, or the result of cumulative actions—it must formally consult with the Services[163]. However, if the agency determines, after a biological assessment or through informal consultation with the Services, that the proposed action *may affect*, but is *not likely to adversely affect*, any listed species or habitat[164], then it must obtain the written concurrence of the Services, and no further consultation is required[165]. In making these "effects determinations," agencies must use the "best scientific and commercial data available"[166].

The only exception to the consultation requirement for a discretionary federal action is if the agency concludes its action will have *no effect* on listed species or critical habitat[167]. The "inability to 'attribute[]' environmental harms 'with reasonable certainty' to [the action]. . . is not the same as a finding that [it] 'will not affect' or 'is not likely to adversely affect' listed species or critical habitat," and does not absolve the agency of its the duty to consult[168].

Under the formal consultation process, if the Services find that the action will jeopardize a species or result in the destruction or adverse modification of critical habitat, they must identify "reasonable and prudent alternatives" for the action that comply with Section 7[169]. If the action will not result in jeopardy, the Services will still provide the action agency with a biological opinion, evaluating how the proposed action will affect listed species or habitat and recommending "reasonable and prudent measures" necessary to avoid jeopardy, as well as an "incidental take statement," which provides the action agency legal coverage for take that is unavoidable[170]. Thus, "because the procedural requirements [i.e., consultation] are designed to ensure compliance with the substantive provisions,"

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160 50 C.F.R. § 402.02.

161 *Western Watersheds Project v. Kraayenbrink*, 632 F.3d 472, 495 (9th Cir. 2011); 16 U.S.C. § 1536.

162 16 U.S.C. § 1536(c)(1).

163 50 C.F.R. §§ 402.02, 402.14(a), (g).

164 A finding that the action "may affect" but is "not likely to adversely affect" means all effects are expected to be "discountable, insignificant, or completely beneficial." *Id*. at xv, 3-12, 3-13.

165 16 U.S.C. § 1536(c); 50 C.F.R. §§ 402.13(a), 402.14(b)(1).

166 16 U.S.C. §§ 1536(a)(2), (c)(1).

167 50 C.F.R § 402.14(b); *Am. Fuel*, 937 F.3d at 597. However, NHTSA is still encouraged to obtain written concurrence from the Services. *See* U.S. Fish &Wildlife Service National Marine Fisheries Service, *Endangered Species Consultation Handbook Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act* (1998), [hereinafter ESA Consultation Handbook] at B-55, and definitions of "Formal consultation" and "Informal consultation" at xiv, xv, *available at* https://www.fws.gov/endangered/esa-library/pdf/esa_section7_handbook.pdf.

168 *Am. Fuel Mfrs*., 937 F.3d at 597-598 (D.C. Cir. 2019) ("the EPA concluded that it is impossible to know whether the 2018 [Renewable Fuels Program] Rule will affect listed species or critical habitat. That is not the same as determining that the 2018 Rule 'will not' affect them.")

169 16 U.S.C. § 1536(b)(3)(A); 50 C.F.R. § 402.14(h)(3).

170 16 U.S.C. § 1536(b); 50 C.F.R. §§ 402.14(h), (i).

"the strict substantive provisions of the ESA justify *more* stringent enforcement of its procedural requirements"[171].

II. THE ENDANGERED SPECIES ACT REQUIRES INTERAGENCY CONSULTATION ON THE ADOPTION OF THE REVISED VEHICLES RULE

A. NHTSA's adoption of the Rule triggers its duty to consult under Section 7 of the ESA.

The proposed Rule triggers NHTSA's procedural duty to undergo Section 7 consultation. First, the Rule is a discretionary federal action. Section 7 consultation is required on an agency action "so long as the agency has 'some discretion' to take action for the benefit of a protected species"[172]. If "an agency has *any* statutory discretion over the action in question, that agency has the authority, and thus the responsibility, to comply with the ESA"[173]. Second, as explained above, "action" is broadly defined to include "all activities or programs of any kind authorized, funded, or carried out, in whole or in part" by federal agencies[174]. The ESA's implementing regulations provide that actions triggering ESA consultation include those that "directly or indirectly caus[e] modifications to the land, water, *or air*"[175].

Here, NHTSA's adoption of the Rule is a discretionary government action that directly causes modifications to the air, and indirectly modify land and water, thus triggering the ESA Section 7 consultation requirement. For instance, NHTSA is making the discretionary decision to adopt the proposal rather than a more stringent alternative, and in doing so, is making the discretionary decision to allow millions of metric tons more greenhouse gases to be emitted than if it chose a different alternative. What is more, NHTSA is making the discretionary decision to include a number of different regulatory flexibilities and credits, which allow manufacturers to avoid or delay producing vehicles that would reduce their emissions[176]. Each of these discretionary decisions affects the greenhouse gas and criteria emissions over the next several years, and thus "may affect" endangered species or their habitat.

According to the Draft Supplemental Environmental Impact Statement, while the Rule (i.e., Alternative 2) projects a reduction in greenhouse gas emissions compared to the Trump administration's SAFE Rule

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[171] *Thomas v. Peterson*, 753 F.2d 754, 764 (9th Cir. 1985).

[172] *NRDC v. Jewell*, 749 F.3d 776, 779-80 (9th Cir. 2014). *See also Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv.*, 524 F.3d 917, 929 (9th Cir. 2008) ("When an agency, acting in furtherance of a broad Congressional mandate, chooses a course of action which is not specifically mandated by Congress and which is not specifically necessitated by the broad mandate, that action is, by definition, discretionary and is thus subject to Section 7 consultation").

[173] *Am. Rivers v. United States Army Corps of Eng'rs*, 271 F.Supp.2d 230, 251 (D.D.C. 2003) (emph. added)). Consultations are not required only where Congress has eliminated all discretion and the statute compels an agency to act in a specific manner. *See Nat'l Ass'n of Home Builders v. Defenders of Wildlife*, 551 U.S. 644 (2007).

[174] 50 C.F.R. § 402.02. *See Karuk Tribe of Cal. v. U.S. Forest Serv.*, 681 F.3d 1006, 1011 (9th Cir. 2012) ("There is 'agency action' under Section 7 of the ESA whenever an agency makes an affirmative, discretionary decision about whether, or under what conditions, to allow private activity to proceed.").

[175] *Karuk Tribe of Cal.*, 681 F.3d at 1020 (citing 50 C.F.R. § 402.02) (emphasis added) (agency's approval of mining permits for activities in endangered coho salmon's habitat constitutes "agency action" for purposes of Section 7 consultation). *See also Washington Toxics Coalition v. EPA*, 413 F. 3d 1024, 1031 (9th Cir. 2005) (ESA consultation triggered by EPA's registration of pesticide ingredients that are aerially applied and may harm endangered fish).

[176] *See* Joint Summary Comments of Environmental, Advocacy, and Science Organizations, on behalf of The Center for Biological Diversity, Earthjustice, Environmental Law & Policy Center, Natural Resources Defense Council, Public Citizen, Inc., Sierra Club, Southern Environmental Law Center, and Union of Concerned Scientists, Re: Corporate Average Fuel Economy Standards for Model Years 2024-2026 Passenger Cars and Light Trucks, 86 Fed. Reg. 49, 602, submitted to Docket No. NHTSA-2021-0053.

rollback, it would still allow millions of metric tons of greenhouse gases and other criteria pollutants to be emitted. This is especially stark when the proposal is compared to NHTSA's suggested Alternative 3, which would save 29 million metric tons CO_2 and 1 metric ton of methane compared with the proposal through 2100[177]. In other words, by making the decision to adopt the proposal instead of Alternative 3, NHTSA is, in its discretion, authorizing an addition 29 million metric tons of CO_2, in addition to other greenhouse gases and increased criteria pollution. Of course, NHTSA could have also analyzed other alternatives stronger than Alternative 3, which would have made these emissions savings even higher. And as noted in our Joint Comments submitted with other NGOs, NHTSA relied on several inaccurate technical assumptions in its modeling, which understate the reductions in greenhouse gases and criteria pollutants that would result from stronger regulations[178].

These numbers are not insignificant, and they can be directly tied to harm to species or critical habitat, such as to precise losses of sea ice and sea ice days in the Arctic[179]. This loss will have devastating consequences for polar bears, as described below.

The increased methane emissions are particularly alarming. Immediate, deep reductions in methane emissions are critical for lowering the rate of global warming in the near-term, preventing the crossing of irreversible planetary tipping points, and avoiding harms to species and ecosystems from methane's intensive near-term heating effects and ground-level ozone production[180]. Methane is a super-pollutant 87 times more powerful than CO_2 at warming the atmosphere over a 20-year period[181], and is second only to CO_2 in driving climate change during the industrial era[182]. Methane also leads to the formation of ground-level ozone, a dangerous air pollutant, that harms ecosystems and species by suppressing plant growth and reducing plant productivity and carbon uptake[183]. Because methane is so climate-damaging but also comparatively short-lived with an atmospheric lifetime of roughly a decade, cutting methane has a relatively immediate effect in slowing the rate of temperature rise in the near-term. Critically, deep cuts in methane emissions of ~45% by 2030 would avoid 0.3°C of warming by 2040 and are considered necessary to achieve the Paris Agreement's 1.5°C climate limit and prevent the worst damages from the climate crisis[184]. Deep cuts in methane emissions that reduce near-term temperature rise are also critical for avoiding the crossing of planetary tipping points—abrupt and irreversible

[177] National Highway Traffic Safety Administration, Draft Supplemental Environmental Impact Statement for Model Year 2024-2026 Corporate Average Fuel Economy Standards (2021), Table 5.4.1-2.

[178] *See* Joint Summary Comments of Environmental, Advocacy, and Science Organizations, *supra* note 26.

[179] Declaration of Steven Amstrup, *Competitive Enterprise Inst. et al. v. National Highway Traffic Safety Admin. et al.*, Case No. 20-1145, Document No. 1880214 (filed Jan. 14, 2021).

[180] United Nations Environment Programme and Climate and Clean Air Coalition, Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions, Nairobi: United Nations Environment Programme (2021) [hereinafter Global Methane Assessment], https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions, at 11.

[181] Myhre, G. et al., Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F. et al. (eds.)] (2013), *available at* https://www.ipcc.ch/report/ar5/wg1/ at Table 8.7.

[182] Global Methane Assessment at 11.

[183] *Id.* at 11, 69.

[184] *Id.* at 11.

changes in Earth systems to states wholly outside human experience, resulting in severe physical, ecological and socioeconomic harms[185].

Accordingly, NHTSA's discretionary actions meet the broad—and extremely low—"may affect" threshold under the ESA and its implementing regulations that trigger NHTSA's Section 7 consultation duty[186]. The "may affect" standard includes "[a]ny possible effect, whether beneficial, benign, adverse or of an undetermined character"[187]. As discussed below, the increases in greenhouse gas and criteria emissions—associated with the agency decisions described above—may impact the hundreds of federally protected species and their critical habitats that are imperiled due specifically to exacerbated climate change, nitrogen deposition, and greater levels of particular air pollutants from vehicle emissions. Courts have found that similar agency actions resulting in increases of criteria air pollutants may impact federally-listed species and result in environmental harms[188].

In light of the Rule's effects, "[i]n no uncertain terms, the [ESA] mandates that [EPA] shall engage in consultation before taking any action that could jeopardize the continued existence of any endangered species or threatened species"[189]. Separately, the finalization of the proposed Rule also triggers NHTSA's substantive duty under Section 7(a)(2) of the ESA to "insure" against a likelihood of jeopardizing federally-listed species which would be impacted by the Rule's adoption[190]. Agencies are required to give the benefit of the doubt to federally-listed species, thus placing the ultimate burden of protecting species against risk and uncertainty on the agency itself[191]. Accordingly, should NHTSA adopt the Rule without undergoing Section 7 consultation, NHTSA will have failed its substantive duty to insure that the Rule will not jeopardize listed species or adversely modify their critical habitat.

B. NHTSA's Vehicles Rule Will Affect Federally Protected Species.

As discussed above, the "may affect" threshold for triggering Section 7 consultation is low. NHTSA's decision to finalize its proposal will allow cars and light trucks to emit millions of metric tons of greenhouse gases and tens of thousands of tons of criteria pollutants—even though NHTSA has the discretion to reduce them. These emissions will affect climate change, air quality, and species and their habitats in ways that are direct and predictable.

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185 Hoegh-Guldberg, O. et al., Impacts of 1.5°C Global Warming on Natural and Human Systems, In: Global Warming of 1.5°C, An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V. et al. (eds)] (2018), https://www.ipcc.ch/sr15/chapter/chapter-3/, at 262.

186 50 C.F.R. § 402.02.

187 *Karuk Tribe*, 681 F.3d at 1027 (quoting 51 Fed. Reg. 19,926, 19,949 (June 3, 1986)).

188 *See, e.g., Center for Biological Diversity v. EPA*, 861 F.3d 174, 183 (D.C. Cir. 2017) (holding EPA's registration of a certain pesticide without ESA consultation created a demonstrable risk to identified listed species because crops on which the product could be used were located near the species or their critical habitat); *Massachusetts v. EPA*, 549 U.S. 497, 524 (2007) (holding that decrease in U.S. vehicle emissions, though small on global scale, could nonetheless reduce the risk of harm to plaintiffs caused by climate change).

189 *Center for Biological Diversity v. EPA*, 861 F.3d at n. 10.

190 *Id*. § 1536(a)(2).

191 *Sierra Club v. Marsh*, 816 F.2d 1376, 1386 (9th Cir. 1987).

i. Climate change has clear and documented adverse impacts on federally protected species.

This section describes the hundreds of federally-listed species—including the iconic polar bear[192]—whose very existence is jeopardized by increasing GHG emissions and exacerbated climate change—as legally determined by the Services in response to these species' listing petitions. The proposal, if finalized, would directly contribute to significantly higher GHG emissions and exacerbate climate change, and thus jeopardize the endangered and threatened species, as well as their critical habitats, that are specifically at risk due to exacerbated climate change.

a. An overwhelming international scientific consensus has established that human- caused climate change is already causing severe and widespread harms to life on Earth, and these threats are becoming more dangerous as greenhouse gas emissions continue unabated.

An overwhelming international scientific consensus has established that human-caused climate change is already causing severe and widespread harms and that climate change threats are becoming increasingly dangerous. The Intergovernmental Panel on Climate Change (IPCC), the international scientific body for the assessment of climate change, concluded in its *Climate Change 2021: The Physical Science Basis* report that: "[i]t is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred," and further that "[t]he scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years"[193].

The U.S. federal government has repeatedly recognized that human-caused climate change is causing widespread and intensifying harms across the country in the authoritative National Climate Assessments, scientific syntheses prepared by hundreds of scientific experts and reviewed by the National Academy of Sciences and federal agencies. Most recently, the Fourth National Climate Assessment, comprised of the 2017 *Climate Science Special Report* (Volume I)[194] and the 2018 *Impacts, Risks, and Adaptation in the United States* (Volume II)[195], concluded that "there is no convincing alternative explanation" for the observed warming of the climate over the last century other than human activities[196]. It found that "evidence of human- caused climate change is overwhelming and continues to strengthen, that the impacts of climate change are intensifying across the country, and that climate-related threats to Americans' physical, social, and economic well-being are rising"[197]. The Fourth National Climate Assessment warns that "climate change threatens many benefits that the natural

[192] *See, e.g*, U.S. Fish and Wildlife Service, Determination of Threatened Status for the Polar Bear (*Ursus maritimus*) Throughout Its Range, 73 Fed. Reg. 28212, 28293 (May 15, 2008) (to be codified at 50 CFR Pt. 17) (listing polar bear as threatened due to climate change effects on the species' habitat).

[193] Intergovernmental Panel on Climate Change, Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021), https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ at SPM-5 and SPM-9.

[194] U.S. Global Change Research Program, Climate Science Special Report: Fourth National Climate Assessment, Vol. I (2017) [Wuebbles, D.J. et al. (eds.)] [hereinafter Fourth National Climate Assessment, Vol. I], https://science2017.globalchange.gov/.

[195] U.S. Global Change Research Program, Impacts, Risks, and Adaptation in the United States, Fourth National Climate Assessment, Vol. II (2018) [Reidmiller, D.R. et al. (eds.)] [hereinafter Fourth National Climate Assessment Vol. II], https://nca2018.globalchange.gov/.

[196] Fourth National Climate Assessment, Vol. I at 10.

[197] Fourth National Climate Assessment, Vol. II at 36.

environment provides to society," and that "extinctions and transformative impacts on some ecosystems" will occur "without significant reductions in global greenhouse gas emissions"[198].

As detailed in the National Climate Assessments, the widespread, intensifying, and often long-lived harms from climate change include soaring air and ocean temperatures; more frequent and intense heat waves, floods, and droughts; more destructive hurricanes and wildfires; coastal flooding from sea level rise and increasing storm surge; declining food and water security; accelerating species extinction risk; melting Arctic sea ice, glaciers, and ice sheets; the collapse of Antarctic ice shelves; ocean acidification; and the collapse of coral reefs[199].

b. Fossil fuels are the dominant driver of the climate crisis.

The National Climate Assessments decisively recognize the dominant role of fossil fuels in driving climate change. As stated by the Third National Climate Assessment: "observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas"[200]. In parallel, the Fourth National Climate Assessment reported that "fossil fuel combustion accounts for approximately 85 percent of total U.S. greenhouse gas emissions[201]," which is "driving an increase in global surface temperatures and other widespread changes in Earth's climate that are unprecedented in the history of modern civilization"[202].

c. The choices made now on reducing greenhouse gas pollution will affect the severity of the climate change damages that will be suffered in the coming decades and centuries.

The National Climate Assessments make clear that the harms of climate change are long- lived, and the choices we make now on reducing greenhouse gas pollution will affect the severity of the climate change damages that will be suffered in the coming decades and centuries: "[t]he impacts of global climate change are already being felt in the United States and are projected to intensify in the future—but the severity of future impacts will depend largely on actions taken to reduce greenhouse gas emissions and to adapt to the changes that will occur"[203]. As the Fourth National Climate Assessment explains: "[m]any climate change impacts and associated economic damages in the United States can be substantially reduced over the course of the 21st century through global-scale reductions in greenhouse gas emissions, though the magnitude and timing of avoided risks vary by sector and region. The effect of near-term emissions mitigation on reducing risks is expected to become apparent by mid-century and grow substantially thereafter"[204]. Similarly, a 2014 White House report found that the cost of delay on

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[198] *Id*. at 51.

[199] Melillo, Jerry M. et al. (eds.), Climate Change Impacts in the United States: The Third National Climate Assessment, U.S. Global Change Research Program (2014) [hereinafter Melillo 2014]; Fourth National Climate Assessment, Vol. I; Fourth National Climate Assessment, Vol. II.

[200] Melillo 2014 at 2. *See also* Report Finding 1 at 15: "The global warming of the past 50 years is primarily due to human activities, predominantly the burning of fossil fuels."

[201] Fourth National Climate Assessment, Vol. II at 60.

[202] *Id*. at 39.

[203] *Id*. at 34.

[204] *Id*. at 1347.

reducing emissions is not only extremely steep but also potentially irreversible, and the costs rise exponentially with continued delays[205]. As summarized by the National Research Council:

Emissions of carbon dioxide from the burning of fossil fuels have ushered in a new epoch where human activities will largely determine the evolution of Earth's climate. Because carbon dioxide in the atmosphere is long lived, it can effectively lock Earth and future generations into a range of impacts, some of which could become very severe. [E]mission reduction choices made today matter in determining impacts experienced not just over the next few decades, but in the coming centuries and millennia[206].

d. The IPCC 2018 Special Report, as reinforced by the 2021 IPCC Sixth Assessment Report, make clear that global greenhouse gas emissions must be halved by 2030 to avoid catastrophic damages of climate change.

In 2018, the IPCC issued a *Special Report on Global Warming of 1.5°C* that quantified the devastating harms that would occur at 2°C warming, highlighting the necessity of limiting warming to 1.5°C to avoid catastrophic impacts to people and life on Earth[207]. The IPCC 2018 *Special Report* provides overwhelming evidence that aggressive reductions in emissions within this decade are essential to avoiding catastrophic climate change harms.

The *Special Report* quantifies the harms that would occur at 2°C warming compared with 1.5°C, and the differences are stark. According to the IPCC's analysis, the damages that would occur at 2°C warming compared with 1.5°C include dramatically increased species extinction risk, including a doubling of the number of vertebrate and plant species losing more than half their range, and the virtual elimination of coral reefs; significantly more deadly heatwaves, drought and flooding; 10 centimeters of additional sea level rise within this century; a greater risk of triggering the collapse of the Greenland and Antarctic ice sheets with resulting multi- meter sea level rise; 1.5 to 2.5 million more square kilometers of thawing permafrost area with the associated release of methane, a potent greenhouse gas; and a tenfold increase in the probability of ice-free Arctic summers[208].

The IPCC report concludes that pathways to limit warming to 1.5°C with little or no overshoot require "a rapid phase out of CO_2 emissions and deep emissions reductions in other GHGs and climate forcers"[209]. In pathways consistent with limiting warming to 1.5°C, global net anthropogenic CO_2 emissions must decline by about 45 percent from 2010 levels by 2030, reaching net zero around 2050[210].

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[205] The White House, The Cost of Delaying Action to Stem Climate Change (July 29, 2014), *available at* https://obamawhitehouse.archives.gov/the-press-office/2014/07/29/white-house-report-cost-delaying-action-stem-climate-change at 2.

[206] National Research Council, Warming World: Impacts by Degree, based on Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia (2011) at 3.

[207] Intergovernmental Panel on Climate Change, Global Warming of 1.5°C, An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (2018) [hereinafter IPCC 1.5°C Report 2018].

[208] IPCC 1.5°C Report 2018 at SPM-8 to SPM-14.

[209] *Id.* at 2-28.

[210] *Id*. at SPM-15.

Similarly, the IPCC *Climate Change* 2021 report concludes that global warming will exceed 1.5°C and 2°C by 2100 unless we make immediate, deep reductions in CO_2 and other greenhouse gas emissions[211]. Only the most stringent emissions reduction scenario—SSP1-1.9 in which global emissions fall steeply in the near-term, reach net zero in 2050, and become net negative afterward—is consistent with a 1.5°C climate target. In this low emissions SSP1-1.9 scenario, global average surface temperature is projected to reach 1.5°C above pre-industrial in the near-term (2021-2040), overshoot and peak at 1.6°C in the mid-term (2041-2060), and drop down to 1.4°C in the long-term (2081-2100)[212].

In short, the IPCC Assessment Reports, U.S. National Climate Assessments, and tens of thousands of studies make clear that fossil-fuel driven climate change is a "code red for humanity,"[213] and that every additional ton of CO_2 and fraction of a degree of temperature rise matters. As warned by the IPCC, "every tonne of CO_2 emissions adds to global warming"[214].

e. Climate change has clear and documented adverse impacts on biodiversity.

The best available science shows that anthropogenic climate change is causing widespread harm to life across the planet, disrupting species' distribution, timing of breeding and migration, physiology, vital rates, and genetics—in addition to increasing species extinction risk[215]. Climate change is already affecting 82% of key ecological processes that underpin ecosystem function and support basic human needs[216]. Climate change-related local extinctions are widespread and have occurred in hundreds of species, including almost half of the 976 species surveyed[217]. Nearly half of terrestrial non-flying threatened mammals and nearly one-quarter of threatened birds are estimated to have been negatively impacted by climate change in at least part of their range[218]. Furthermore, across the globe, populations of terrestrial birds and mammals that are experiencing greater rates of climate warming are more likely to be declining at a faster rate[219]. Genes are changing, species' physiology and physical features such as

[211] Intergovernmental Panel on Climate Change, Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021), https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ at SPM-17.

[212] *Id*. at Table SPM.1.

[213] United Nations Secretary-General, *Secretary-General's statement on the IPCC Working Group 1 Report on the Physical Science Basis of the Sixth Assessment*, Aug. 9, 2021, https://www.un.org/sg/en/content/secretary-generals-statement-the-ipcc-working-group-1-report-the-physical-science-basis-of-the-sixth-assessment.

[214] IPCC Climate Change 2021, Summary for Policymakers at SPM-37.

[215] Warren, Rachel et al., Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise, 106 Climatic Change 141 (2011).

[216] Scheffers, Brett R. et al., The broad footprint of climate change from genes to biomes to people, 354 Science 719 (2016).

[217] Wiens, John J., Climate-related local extinctions are already widespread among plant and animal species, 14 PLoS Biology e2001104 (2016).

[218] Pacifici, Michela et al., Species' traits influenced their response to recent climate change, 7 Nature Climate Change 205 (2017). The study concluded that "populations of large numbers of threatened species are likely to be already affected by climate change, and … conservation managers, planners and policy makers must take this into account in efforts to safeguard the future of biodiversity."

[219] Spooner, Fiona E.B. et al., Rapid warming is associated with population decline among terrestrial birds and mammals globally, 24 Global Change Biology 4521 (2018).

body size are changing, species are moving to try to keep pace with suitable climate space, species are shifting their timing of breeding and migration, and entire ecosystems are under stress[220].

Species extinction risk will accelerate with continued greenhouse gas pollution. One million animal and plant species are now threatened with extinction, with climate change as a primary driver[221]. At 2°C compared with 1.5°C of temperature rise, species' extinction risk will increase dramatically, leading to a doubling of the number of vertebrate and plant species losing more than half their range, and a tripling for invertebrate species[222]. Numerous studies have projected catastrophic species losses during this century if climate change continues unabated: 15 to 37% of the world's plants and animals committed to extinction by 2050 under a mid-level emissions scenario[223]; the potential extinction of 10 to 14% of species by 2100[224]; global extinction of 5% of species with 2°C of warming and 16% of species with business-as-usual warming[225]; the loss of more than half of the present climatic range for 58% of plants and 35% of animals by the 2080s under the current emissions pathway, in a sample of 48,786 species[226]; and the loss of a third or more of animals and plant species in the next 50 years[227].

As summarized by the Third National Climate Assessment, "landscapes and seascapes are changing rapidly, and species, including many iconic species, may disappear from regions where they have been prevalent or become extinct, altering some regions so much that their mix of plant and animal life will become almost unrecognizable"[228].

f. Greenhouse gas pollution has clear and documented adverse impacts on federally protected species.

Greenhouse gas emissions harm endangered species in ways that are not only measurable but also causally understood. Climate change impacts such as sea ice loss, ocean heat stress and ocean acidification, sea level rise, the increasing frequency of extreme weather events, decreasing snowpack, and elevational and latitudinal shifts in habitat are several of the ways that greenhouse gas emissions

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[220] Parmesan, Camille & Gary Yohe, A globally coherent fingerprint of climate change impacts across natural systems, 421 Nature 37 (2003); Root, Terry L. et al., Fingerprints of global warming on wild animals and plants, 421 Nature 57 (2003); Parmesan, Camille, Ecological and evolutionary responses to recent climate change, 37 Annual Review of Ecology Evolution and Systematics 637 (2006); Chen, I-Ching et al., Rapid range shifts of species associated with high levels of climate warming, 333 Science 1024 (2011); Maclean, Ilya M. D. & Robert J. Wilson, Recent ecological responses to climate change support predictions of high extinction risk, 108 PNAS 12337 (2011); Warren, Rachel et al., Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise, 106 Climatic Change 141 (2011); Cahill, Abigail E. et al., How does climate change cause extinction?, 280 Proceedings of the Royal Society B 20121890 (2012).

[221] Brondizio, E.S. et al. (eds.), IPBES, Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES secretariat, Bonn, Germany (2019), *available* at https://ipbes.net/global-assessment.

[222] IPCC Climate Change 2021, Summary for Policymakers.

[223] Thomas, Chris. D. et al., Extinction risk from climate change, 427 Nature 145 (2004).

[224] Maclean, Ilya M. D. & Robert J. Wilson, Recent ecological responses to climate change support predictions of high extinction risk, 108 PNAS 12337 (2011).

[225] Urban, Mark C., Accelerating extinction risk from climate change, 348 Science 571 (2015).

[226] Warren, Rachel et al., Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss, 3 Nature Climate Change 678 (2013).

[227] Román-Palacios, Cristian & John J. Wiens, Recent responses to climate change reveal the drivers of species extinction and survival, 117 PNAS 4211 (2020).

[228] Melillo 2014 at 196.

harm hundreds of federally protected species—and has been recognized as such in federal listing determinations under the Endangered Species Act.

The Polar Bear (Ursus maritimus) and Loss of Sea Ice. In 2008, the FWS listed the polar bear (Ursus maritimus) as a threatened species due to climate change and the loss of sea ice[229]. *See also In re Polar Bear Endangered Species Act Listing*, 709 F.3d 1 (D.C. Cir. 2013) (affirming FWS's decision to federally list the polar bear as threatened due to the effects of global climate change on polar bear habitat).

[See original comment for Figure 1. Polar Bear (*Ursus maritimus*) © National Geographic]

The loss of sea ice is one of the clearest and most obvious consequences of global warming. As highlighted by the Fourth National Climate Assessment, Alaska and the Arctic have experienced some of the most severe and rapid warming associated with climate change, with temperatures rising at twice the rate of the rest of the globe on average[230]. Arctic summer sea ice extent and thickness have decreased by 40% during the past several decades,[231] with each metric ton of CO_2 emissions causing a sustained loss of three square meters of summer sea ice area[232]. The Arctic lost 95% of its oldest and thickest sea ice during the past three decades, and the remaining thinner, younger ice is more vulnerable to melting[233]. Sea ice loss has accelerated since 2000, with Alaska's coast suffering some of the fastest losses[234]. The length of the sea ice season is shortening as ice melts earlier in spring and forms later in autumn[235]. Along Alaska's northern and western coasts, the sea ice season has already shortened by more than 90 days[236]. As summarized by the Fourth National Climate Assessment:

Since the early 1980s, annual average arctic sea ice has decreased in extent between 3.5% and 4.1% per decade, become thinner by between 4.3 and 7.5 feet, and began melting at least 15 more days each year. September sea ice extent has decreased between 10.7% and 15.9% per decade (*very high confidence*). Arctic- wide ice loss is expected to continue through the 21st century, *very likely* resulting in nearly sea ice-free late summers by the 2040s (*very high confidence*)"[237].

It is precisely this sea ice loss, and the lack of adequate regulatory mechanisms addressing greenhouse gas pollution, that led FWS to list the polar bear (*Ursus maritimus*) as a threatened species in 2008[238]. As

[229] 73 Fed. Reg. 28212 at 28293.

[230] Fourth National Climate Assessment, Vol. II at 92.

[231] Meier, Walter N. et al., Arctic sea ice in transformation: A review of recent observed changes and impacts on biology and human activity, 51 Reviews of Geophysics 185 (2014); Fourth National Climate Assessment, Vol. I at 29, 57, 303; Fourth National Climate Assessment, Vol. II at 1192-1193; IPCC Climate Change 2021, Summary for Policymakers at SPM-6.

[232] Notz & Stroeve 2016.

[233] Osborne, Emily, et al. (eds.), Arctic Report Card 2018, NOAA (2018), https://www.arctic.noaa.gov/Report-Card/Report-Card-2018 at 2.

[234] Fourth National Climate Assessment, Vol. I at 305.

[235] Parkinson, Claire L., Spatially mapped reductions in the length of the Arctic sea ice season, 41 Geophysical Research Letters 4316 (2014).

[236] Fourth National Climate Assessment, Vol. I at 307.

[237] *Id*. at 29, 303.

[238] 73 Fed. Reg. 28212 at 28293: "On the basis of our thorough evaluation of the best available scientific and commercial information regarding present and future threats to the polar bear posed by the five listing factors under the Act, we have determined that the polar bear is threatened throughout its range by habitat loss (i.e., sea ice recession). We have determined

a top Arctic predator, the polar bear relies on sea ice for all its essential activities, including hunting for prey, moving long distances, finding mates, and building dens to rear cubs[239]. Separately, recognizing the critical importance of sea ice for polar bear survival, FWS designated sea ice habitat off Alaska as critical habitat for the polar bear in 2010[240].

Federal documents acknowledge that shrinkage and premature breakup of sea ice due to climate change is the primary threat to the species, leaving bears with vastly diminished hunting grounds, less time to hunt, and a shortage of sea ice for other essential activities such as finding mates and resting[241]. As summarized in FWS's 2017 5-year review, sea ice loss and a shorter sea ice season makes hunting calorie-rich seals more difficult for polar bears, leading to nutritional stress, reduced body mass, and declines of some populations[242]. As the sea ice retreats, polar bears have been forced to swim longer distances[243], which is more energetically costly[244], and they are spending more time on land where they have reduced access to food[245]. Females are denning more often on land than on ice, increasing the potential for conflicts with humans[246]. Because polar bears have high metabolic rates, increases in movement resulting from loss and fragmentation of sea ice result in higher energy costs and are likely to lead to reduced body condition, recruitment and survival[247].

In the southern Beaufort Sea of Alaska, polar bears declined by 40 percent over a recent 10-year period[248], and this decrease has been attributed to sea ice loss that limited access to prey over multiple

that there are no known regulatory mechanisms in place at the national or international level that directly and effectively address the primary threat to polar bears—the rangewide loss of sea ice habitat."

[239] *Ibid*.

[240] U.S. Fish and Wildlife Service, Designation of Critical Habitat for the Polar Bear (*Ursus maritimus*) in the United States, 75 Fed. Reg. 76086 (Dec. 7, 2010) (to be codified at 50 CFR Pt. 17).

[241] 73 Fed. Reg. 28212 at 28303; U.S. Fish and Wildlife Service, Polar bear (*Ursus maritimus*) Conservation Management Plan, Final. U.S. Fish and Wildlife Service, Region 7, Anchorage, Alaska (2016) [hereinafter Polar Bear Conservation Management Plan 2016]; U.S. Fish and Wildlife Service, Polar Bear (*Ursus maritimus*) 5-Year Review: Summary and Evaluation, U.S. Fish and Wildlife Service, Marine Mammals Management, Anchorage, Alaska (Feb. 3, 2017) [hereinafter Polar Bear 5-Year Review 2017].

[242] Polar Bear 5-Year Review 2017 at 16.

[243] Durner, George M. et al., Consequences of long-distance swimming and travel over deep-water pack ice for a female polar bear during a year of extreme sea ice retreat, 34 Polar Biology 975 (2011); Pagano, Anthony M. et al., Long-distance swimming by polar bears (*Ursus maritimus*) of the southern Beaufort Sea during years of extensive open water, 90 Canadian Journal of Zoology 663 (2012); Pilfold, Nicholas W. et al., Migratory response of polar bears to sea ice loss: to swim or not to swim, 40 Ecography 189 (2017).

[244] Griffen, Blaine D., Modeling the metabolic costs of swimming in polar bears (*Ursus maritimus*), 41 Polar Biology 491 (2018).

[245] Cherry, Seth G. et al., Fasting physiology of polar bears in relation to environmental change and breeding behavior in the Beaufort Sea, 32 Polar Biology 383 (2009) [hereinafter Cherry 2009]; Whiteman, John P. et al., Summer declines in activity and body temperature offer polar bears limited energy savings, 349 Science 295 (2015) [hereinafter Whiteman 2015].

[246] Olson, J.W. et al., Collar temperature sensor data reveal long-term patterns in southern Beaufort Sea polar bear den distribution on pack ice and land, 564 Marine Ecology Progress Series 211 (2017); Polar Bear 5-Year Review 2017 at 20-21.

[247] Polar Bear 5-Year Review 2017 at 17; Pagano, Anthony M. et al., High-energy, high-fat lifestyle challenges an Arctic apex predator, the polar bear, 359 Science 568 (2018).

[248] Bromaghin, Jeffrey F. et al., Polar Bear Population Dynamics in the Southern Beaufort Sea during a Period of Sea Ice Decline, 25 Ecological Applications 634 (2015) [hereinafter Bromaghin 2015].

years[249]. For the bears in this population, research has linked sea ice loss to decreases in survival[250], lower success in rearing cubs[251], shrinking body size[252], and increases in fasting and nutritional stress[253]. The loss of sea ice also jeopardizes the polar bear's sea-ice dependent prey species—the ringed seal and bearded seal—which were listed as threatened in 2012 due to sea ice loss from climate change[254].

If current greenhouse gas emissions trends continue, scientists estimate that two-thirds of global polar bear populations will be lost by 2050, including the loss of both of Alaska's polar bear populations, while the remaining third will near extinction by the end of the century due to the disappearance of sea ice[255]. However, aggressive emissions reductions will allow substantially more sea ice to persist and increase the chances that polar bears will survive in Alaska and across their range[256]. Highlighting the importance of reducing greenhouse gas emissions to protect sea ice and sea-ice dependent species, one recent study estimated that each metric ton of CO_2 emission results in a sustained loss of 3 ± 0.3 m^2 of September Arctic sea ice area based on the robust linear relationship between monthly-mean September sea ice area and cumulative CO_2 emissions[257]. Similar to other research[258], the study concluded that limiting warming to 2°C is not sufficient to allow Arctic summer sea ice to survive, but that a rapid reduction in emissions to achieve a 1.5°C global warming target gives Arctic summer sea ice "a chance of long-term survival at least in some parts of the Arctic Ocean"[259].

As such, FWS's 2016 Final Polar Bear Conservation Management Plan clearly stated that the polar bear cannot be recovered without significant reductions in the greenhouse gas emissions driving Arctic warming and sea ice loss: "It cannot be overstated that the single most important action for the

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[249] Obbard, Martyn E. et al., eds, Polar Bears: Proceedings of the 15th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June–3 July 2009 (2010) at 52 ("Thus, the SB subpopulation is currently considered to be declining due to sea ice loss"); Bromaghin 2015.

[250] Regehr, Eric V. et al., Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice, 79 Journal of Animal Ecology 117 (2010); Bromaghin 2015.

[251] Regehr, Eric V. et al., Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice, 79 Journal of Animal Ecology 117 (2010); Bromaghin 2015.

[252] Rode, Karyn D. et al., Reduced body size and cub recruitment in polar bears associated with sea ice decline, 20 Ecological Applications 768 (2010).

[253] Cherry 2009); Whiteman 2015.

[254] National Marine Fisheries Service, Threatened Status for the Arctic, Okhotsk, and Baltic Subspecies of the Ringed Seal and Endangered Status for the Ladoga Subspecies of the Ringed Seal, 77 Fed. Reg. 76706 (Dec. 28, 2012) (to be codified at 50 CFR pts. 223 and 224); National Marine Fisheries Service, Threatened Status for the Beringia and Okhotsk Distinct Population Segments of the *Erignathus barbatus nauticus* Subspecies of the Bearded Seal, 77 Fed. Reg. 76,740 (Dec. 28, 2012) (to be codified at 50 CFR Pt. 223).

[255] Amstrup, Steven C. et al., Forecasting the Range-wide Status of Polar Bears at Selected Times in the 21st Century, U.S. Department of the Interior and U.S. Geological Survey, USGS Science Strategy to Support U.S. Fish and Wildlife Service Polar Bear Listing Decision, Reston, Virginia (2007); Amstrup, Steven C. et al., Greenhouse Gas Mitigation Can Reduce Sea Ice Loss and Increase Polar Bear Persistence, 468 Nature 955 (2010) [hereinafter Amstrup 2010].

[256] Amstrup 2010; Atwood, Todd C. et al., Forecasting the Relative Influence of Environmental and Anthropogenic Stressors on Polar Bears, 7 Ecosphere e01370 (2016); Regehr, Eric V. et al., Conservation status of polar bears (*Ursus martimus*) in relation to projected sea-ice declines, 12 Biology Letters 20160556 (2016) [hereinafter Regehr 2016].

[257] Notz & Stroeve 2016.

[258] Schleussner, Carl-Friedrich et al., Science and policy characteristics of the Paris Agreement temperature goal, 6 Nature Climate Change 827 (2016) at 830.

[259] Notz & Stroeve 2016 at 3-4.

recovery of polar bears is to significantly reduce the present levels of global greenhouse gas (GHG) emissions, which are the primary cause of warming in the Arctic”[260].

If the Rule is finalized as proposed, greenhouse gases emitted will exacerbate the loss of sea ice, causing the likelihood of survival and recovery of the polar bear to diminish appreciably. NHTSA must consult on how the Rule would affect sea ice loss for a listed species like the polar bear.

Elkhorn, Staghorn and other Coral Species & Ocean Heat Stress and Ocean Acidification. As of the date of this letter, 22 species of corals are listed under the Endangered Species Act due primarily to threats from ocean warming and ocean acidification, direct consequences of climate change. In 2006, NMFS listed elkhorn and staghorn corals (*Acropora palmata* and *A. cervicornis*) as threatened, citing ocean warming as a key threat to these species[261]. In 2014 NMFS reaffirmed that ocean warming due to climate change and ocean acidification are primary threats to these species[262]. In 2014 NMFS listed 20 additional corals as threatened, including five Caribbean coral species and fifteen Indo-Pacific coral species[263] The five Caribbean coral species are *Dendrogyra cylindrus, Orbicella annularis, Orbicella faveolata, Orbicella franksi, and Mycetophyllia ferox*; and the fifteen Indo-Pacific coral species are *Acropora globiceps, Acropora jacquelineae, Acropora lokani, Acropora pharaonis, Acropora retusa, Acropora rudis, Acropora speciosa, Acropora tenella, Anacropora spinosa, Euphyllia paradivisa, Isopora crateriformis, Montipora australiensis, Pavona diffluens, Porites napopora, and Seriatopora aculeata*.], determining that the most important threats contributing to extinction risk for these species are ocean warming, disease (as related to climate change), and ocean acidification[264]. NMFS stated that “these impacts are currently occurring, and are expected to worsen, posing increasingly severe effects on the species considered in this final rule”[265].

Ocean warming and ocean acidification, two incontrovertible environmental impacts caused by greenhouse gas pollution, are wreaking havoc on marine ecosystems and causing a global collapse of coral reefs. The world’s oceans have absorbed more than 90 percent of the excess heat caused by greenhouse gas warming, resulting in average sea surface warming of 1.3°F (0.7°C) per century since 1900[266]. Marine heat waves—periods of extreme warm surface temperature—have become longer-lasting and more frequent due to climate change, with the number of heat wave days doubling between 1982 and 2016 and projected to increase 23 times under 2°C warming[267]. At present, 87 percent of marine heat waves are attributable to human- induced warming[268]. Global average sea surface temperature is projected to rise by 4.9°F (2.7°C) by the end of the century under a higher emissions

[260] Polar Bear Conservation Management Plan 2016 at 11.

[261] National Marine Fisheries Service, Endangered and Threatened Species: Final Listing Determinations for Elkhorn Coral and Staghorn Coral, 71 Federal Register 26852 (May 9, 2006) (to be codified at 50 CFR Pt. 223) at 26859.

[262] National Marine Fisheries Service, Endangered and Threatened Wildlife and Plants: Final Listing Determinations on Proposal to List 66 Reef-Building Coral Species and to Reclassify Elkhorn and Staghorn Corals, 79 Fed. Reg. 53852 (Sept. 10, 2014) at 53965, 53973.

[263] *Id*.

[264] *Id. at* 53885, 53886.

[265] *Id*. at 53885.

[266] Fourth National Climate Assessment, Vol. I at 364, 367.

[267] Frolicher, Thomas L. et al., Marine heatwaves under global warming, 560 Nature 360 (2018).

[268] *Id*.

scenario, with even greater warming in the coastal waters of the Northeastern U.S. and Alaska[269]. Rapid ocean warming has widespread impacts on species and ecosystems, contributing to rising sea levels, declining ocean oxygen levels, increasing rainfall intensity, and ice loss from glaciers, ice sheets and polar sea ice, and is the primary driver of mass coral bleaching events that are devastating coral reef ecosystems[270].

Exacerbating the harms from rising temperatures, the global oceans have absorbed more than a quarter of the CO_2 emitted to the atmosphere by human activities, which has significantly increased the acidity of the surface ocean in a process called ocean acidification, and has reduced the availability of key chemicals—aragonite and calcite—that many marine species use to build their shells and skeletons[271]. Ocean acidification caused by the ocean's absorption of anthropogenic CO_2 has already resulted in more than a 30 percent increase in the acidity of ocean surface waters, at a rate likely faster than anything experienced in the past 300 million years[272]. Ocean acidity could increase by 150 percent by the end of the century if CO_2 emissions continue unabated[273]. In the United States, the West Coast, Alaska, and the Gulf of Maine are experiencing the earliest, most severe changes due to ocean acidification[274], although regions of the East and Gulf Coasts are also vulnerable[275].

Ocean acidification negatively affects a wide range of marine species by hindering the ability of calcifying marine creatures like corals, oysters, and crabs to build protective shells and skeletons and by disrupting metabolism and critical biological functions[276]. The adverse effects of ocean acidification are already being observed in wild populations, including reduced coral calcification rates in reefs worldwide[277], severe shell damage to pteropods (marine snails at the base of the food web) along the U.S. west coast[278], and mass die-offs of larval Pacific oysters in the Pacific Northwest[279]. A U.S. expert science panel concluded in 2016 that "growth, survival and behavioral effects linked to OA [ocean acidification] extend throughout food webs, threatening coastal ecosystems, and marine-dependent

[269] Fourth National Climate Assessment, Vol. I at 368.

[270] Cheng, Liging et al., How fast are the oceans warming?, 363 Science 128 (2019).

[271] Fourth National Climate Assessment, Vol. I at 371-372.

[272] Hönisch, Bärbel et al., The geological record of ocean acidification, 335 Science 1058 (2012); USGCRP Vol I 2017 at 372, 374.

[273] Orr, James C. et al., Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, 437 Nature 681 (2005); Feely, Richard et al., Ocean acidification: Present conditions and future changes in a high CO_2 world, 22 Oceanography 36 (2009).

[274] Feely, Richard A. et al., Evidence for upwelling of corrosive 'acidified' water onto the continental shelf, 320 Science 1490 (2008); Ekstrom, Julia A. et al., Vulnerability and adaptation of U.S. shellfisheries to ocean acidification, 5 Nature Climate Change 207 (2015) [hereinafter Ekstrom 2015]; Mathis, Jeremy T. et al., Ocean acidification in the surface waters of the Pacific-Arctic boundary regions, 28 Oceanography 122 (2015) [hereinafter Mathis 2015]; Chan, F. et al., The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions, California Ocean Science Trust (April 2016) [hereinafter Chan 2016].

[275] Ekstrom 2015.

[276] Fabry, Victoria J. et al., Impacts of ocean acidification on marine fauna and ecosystem processes, 65 ICES Journal of Marine Science 414 (2008); Kroeker, Kristy J. et al., Impacts of ocean acidification on marine organisms: quantifying sensitivities and interactions with warming, 19 Global Change Biology 1884 (2013).

[277] Albright, Rebecca et al., Reversal of ocean acidification enhances net coral reef calcification, 531 Nature 362 (2016).

[278] Bednaršek, N. et al., *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem, 281 Proceedings of the Royal Society B 20140123 (2014).

[279] Barton, Alan et al., The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects, 57 Limnology and Oceanography 698 (2012).

industries and human communities"[280]. As stated by the 2018 IPCC *Special Report on Global Warming of 1.5°C*, "[t]he level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, e.g., from algae to fish (*high confidence*)[281].

Rising ocean temperatures and ocean acidification driven by greenhouse gas pollution threaten the continued survival of corals and coral reef ecosystems due to the increasing frequency of mass bleaching events and the dissolution of corals due to ocean acidification[282]. Scientific research has definitely linked anthropogenic ocean warming to the catastrophic, mass coral bleaching events that have been documented since 1980 and are increasing in frequency and intensity as atmospheric CO_2 increases[283]. Severe bleaching events have increased five-fold in the past several decades and now occur every six years on average, which is too frequent to allow full recovery of coral reefs[284]. The global coral bleaching event that lasted from 2014 to 2017 was the longest, most widespread, and almost certainly most destructive on record, affecting more reefs than any previous mass bleaching event and causing mass bleaching of reefs that had never bleached before, with U.S. reefs particularly hard-hit[285]. For example, in Papahanaumokuakea Marine National Monument in Northwestern Hawaiian Islands, a 2017 study concluded that "heat stress in 2014 was unlike any previous event and that the exposure of corals to the bleaching-level heat stress has increased significantly in the northern PMNM since 1982, highlighting the increasing threat of climate change to reefs"[286]. In the Caribbean, many important reef-building corals have not recovered from repeated bleaching events due to climate change[287]. According to a 2021 study that projected changes in coral reef growth (net carbonate production) under ocean warming and acidification across 183 reefs worldwide, 94% of coral reefs globally will be eroding by 2050 if greenhouse gas emissions continue unabated. In contrast, if emissions are immediately and drastically reduced (i.e., RCP 2.6 emissions scenario), coral reef growth will still decline dramatically, but 63% of reefs will still be able to grow at the end of the century[288]. A 2017 scientific review concluded that "unless rapid advances to the goals of the Paris Climate Change Agreement occur over the next decade" that "coral reefs are likely to degrade rapidly over the next 20 years, presenting fundamental challenges

[280] Chan 2016 at 4.

[281] IPCC 1.5°C Report 2018 at SPM-10-11.

[282] Hoegh-Guldberg, Ove et al., Coral reefs under rapid climate change and ocean acidification, 318 Science 1737 (2007) [hereinafter Hoegh-Guldberg 2007]; Eakin, C. Mark et al., Caribbean corals in crisis: record thermal stress, bleaching, and mortality in 2005, 5 PLoS ONE e13969 (2010) [hereinafter Eakin 2010].

[283] Hoegh-Guldberg 2007; Donner, Simon D., et al, Coping with commitment: projected thermal stress on coral reefs under different future scenarios, 4 PLoS ONE e5712 (2009) [hereinafter Donner 2009]; Eakin 2010; National Marine Fisheries Service, Recovery Plan for Elkhorn Coral (*Acropora palmata*) and Staghorn Coral (*A. cervicornis*), Southeast Regional Office (March 3, 2015) [hereinafter Coral Recovery Plan 2015] at 51; Hughes, Terry P. et al., Spatial and temporal patterns of mass bleaching of corals in the Anthropocene, 359 Science 80 (2018) [hereinafter Hughes 2018].

[284] Hughes 2018 at 80.

[285] Eakin, C. Mark et al., Unprecedented three years of global coral bleaching 2014-17. In: State of the Climate in 2017, 99 Bulletin of the American Meteorological Society S74 (2018).

[286] Couch, Courtney S. et al., Mass coral bleaching due to unprecedented marine heatwave in Papahanaumokuakea Marine National Monument (Northwestern Hawaiian Islands), 12 PLoS ONE e0185121 (2017).

[287] Neal, Benjamin P. et al., Caribbean massive corals not recovering from repeated thermal stress events during 2005-2013, 7 Ecology and Evolution 1339 (2017).

[288] Cornwall, Christopher E. et al., Global declines in coral reef calcium carbonate production under ocean acidification and warming, 118 PNAS e2015265118 (2021), https://doi.org/10.1073/pnas.2015265118.

for the 500 million people who derive food, income, coastal protection, and a range of other services from coral reefs"[289].

As discussed, 22 species of corals are listed under the Endangered Species Act due primarily to threats from ocean warming and ocean acidification. Specifically, listed elkhorn and staghorn corals—once abundant throughout the Caribbean Sea—precipitously declined by 92 to 97 percent, largely due to disease. Research indicates that the outbreaks of white-band disease that decimated these corals were driven by heat stress from rising ocean temperatures[290]. Research has also documented that ocean warming increases the susceptibility to disease, fragmentation, and mortality of elkhorn and staghorn corals, while ocean acidification decreases their fertilization, settlement success, growth and calcification[291]. For listed pillar corals (*Dendrogyra cylindrus*) which have suffered catastrophic declines in Florida in recent years, research indicates that black band disease first emerged following bleaching events in 2014 and 2015 spurred by abnormally high water temperatures[292]. The three listed star corals in the Caribbean—boulder star coral (*Orbicella franksi*), mountainous star coral (*Orbicella faveolate*), and lobed star coral (*Orbicella annularis*)—have experienced long-term declines in reproduction following bleaching events caused by high water temperatures, which scientists warned "may be catastrophic for the long-term maintenance of the population"[293].

[See original comment for Figure 2. Mountainous star coral (*Orbicella faveolate*) © Van K. D'Alessandro, Ph.D., University of Miami Rosenstiel School of Marine and Atmospheric Science]

Scientific research and federal documents conclude that greenhouse gas emissions must be immediately and rapidly reduced—with the target of keeping global average temperature rise below 1.5°C and returning atmospheric CO_2 levels below 350 ppm—to prevent catastrophic loss and degradation of corals. For example, a 2012 study concluded that protecting at least half of the world's coral reefs requires limiting global average temperature rise to 1.2°C, while preserving greater than 10 percent of the world's reefs would require limiting warming to below 1.5°C[294]. Similarly, a 2014 study projected that under the low emissions pathway (RCP 2.6) that limits temperature rise below 2°C, the vast

[289] Hoegh-Guldberg, Ove et al., Coral reef ecosystems under climate change and ocean acidification, 4 Frontiers in Marine Science Article 158 (2017).

[290] 71 Fed. Reg. 26,852 at 26,872.; Randall, C. J. & R. van Woesik, Contemporary white-band disease in Caribbean corals driven by climate change, 5 Nature Climate Change 375 (2015); van Woesik, R. & C.J. Randall, Coral disease hotspots in the Caribbean, 8 Ecosphere e01814 (2017).

[291] Albright, Rebecca et al., Ocean acidification compromises recruitment success of the threatened Caribbean coral *Acropora palmata*, 107 PNAS 20400 (2010); Roth, L. et al., Tracking *Acropora* fragmentation and population structure through thermal-stress events, 263 Ecological Modelling 223 (2013); Enochs, I.C. et al., Effects of light and elevated pCO_2 on the growth and photochemical efficiency of *Acropora cervicornis*, 33 Coral Reefs 477 (2014); Camp, E.F. et al., Acclimatization to high-variance habitats does not enhance physiological tolerance of two key Caribbean corals to future temperature and pH, 283 Proceedings of the Royal Society B 20160442 (2016); Williams, D.E. et al., Thermal stress exposure, bleaching response, and mortality in the threatened coral *Acropora palmata*, 124 Marine Pollution Bulletin 189 (2017); Langdon, Chris et al., Two threatened Caribbean coral species have contrasting responses to combined temperature and acidification stress, 63 Limnology and Oceanography 2450 (2018); Muller, Erinn M. et al., Bleaching causes loss of disease resistance within the threatened coral species *Acropora cervicornis*, 7 eLife e35066 (2018).

[292] Lewis, Cynthia L. et al., Temporal dynamics of black band disease affecting pillar coral (*Dendrogyra cylindrus*) following two consecutive hyperthermal events on the Florida Reef Tract, 36 Coral Reefs 427 (2017).

[293] Levitan, Don R. et al., Long-term reduced spawning in *Orbicella* coral species due to temperature stress, 515 Marine Ecology Progress Series 1 (2014).

[294] Frieler, K., et al., Limiting global warming to 2ºC is unlikely to save most coral reefs, 3 Nature Climate Change 165 (2012) [hereinafter Frieler 2012].

majority (88%) of global reef locations would still experience severe bleaching events annually by the end of the century, indicating that 2°C of warming would be devastating for corals[295]. The 2018 IPCC *Special Report on Global Warming of* 1.5°C stated that coral reefs "are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2ºC (*very high confidence*)[296]. As summarized by a 2018 study:

Even the aspirational Paris Agreement target of constraining global warming to 1.5°C above pre-industrial levels is unlikely to be sufficient to prevent drastic modifications and reconfigurations of the community structure and make-up of coral reefs. For the 100 reef locations examined here and given current rates of warming, the 1.5°C global warming target represents twice the thermal stress they experienced in 2016. The 2°C global target would result in 3 times the 2016 level of thermal stress and 3 °C, which is currently being tracked with the NDCs, would be over 6 times the 2016 level of stress[297].

Based on this evidence, coral scientists have recommended returning the atmospheric CO_2 concentration to less than 350 ppm to protect coral reefs, and have suggested a target of 320 ppm which is the level that pre-dates the onset of mass bleaching events[298].

NMFS' 2015 Final Recovery Plan for Elkhorn and Staghorn Corals states that ocean warming and acidification are "among the greatest threats" to these corals, and recommends actions to reduce greenhouse gas emissions to reduce these threats: "the combination of rising temperature and ocean acidification both resulting primarily from anthropogenic increases in atmospheric CO_2, are likely to have synergistic effects and are among the greatest threats to elkhorn and staghorn coral recovery"[299] and "therefore, actions must be taken to address ocean warming and acidification impacts on these species"[300]. NMFS's recovery plan includes a recovery criterion with specific targets for ocean surface temperatures and ocean acidification levels[301] that are lower than today's levels and are consistent with a return to an atmospheric CO_2 concentration of less than 350 ppm[302], as recommended by numerous scientific studies that have examined coral species viability in response to ocean warming and ocean

[295] van Hooidonk, R. et al., Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs, 20 Global Change Biology 103 (2014).

[296] IPCC 1.5°C Report 2018 at SPM-10.

[297] Lough, J.M. et al., Increasing thermal stress for tropical coral reefs: 1871-2017, 8 Scientific Reports 6079 (2018).

[298] Veron, John E.N. et al., The coral reef crisis: the critical importance of <350 ppm CO_2, 58 Marine Pollution Bulletin 1428 (2009) [hereinafter Veron 2009].

[299] Coral Recovery Plan 2015 at I-31-32.

[300] *Id*. at ix.

[301] *Id. See* Recovery Criterion 5: "Sea surface temperatures across the geographic range have been reduced to Degree Heating Weeks less than 4; and Mean monthly sea surface temperatures remain below 30°C during spawning periods; and Open ocean aragonite saturation has been restored to a state of greater than 4.0, a level considered optimal for reef growth."

[302] As stated by the Recovery Plan: "Current projections of increases in ocean temperature, coupled with the numerous other stressors acting on these depleted species, will inhibit recovery. Thus, reducing atmospheric CO_2 levels is likely needed to support recovery of elkhorn and staghorn corals. Model simulations by Donner et al. (2009) suggest that atmospheric CO_2 concentrations may need to be stabilized below 370 ppm to avoid degradation of coral reef ecosystems. Veron et al. (2009), based on the recent history of frequent mass bleaching events and correlated climate conditions, advocated the importance of atmospheric CO_2 concentrations of less than 350 ppm for coral reef health, as mass bleaching events, often associated with El Niño, began when atmospheric CO_2 concentrations were approximately 340 ppm. Veron et al. (2009) also discussed the 1997/98 mass bleaching event, when atmospheric CO_2 concentrations were 350 ppm, as the beginning of a decline in coral reef health from which there has been no significant long-term recovery."

acidification[303]. The Recovery Plan also recognizes that a primary threat to listed corals is the inadequacy of existing regulations to control greenhouse gas emissions. It specifies a recovery criterion calling for the adoption of "adequate domestic and international regulations and agreements" to abate threats from increasing atmospheric CO_2 concentrations[304], including a recovery action to "develop and implement U.S. and international measures to reduce atmospheric CO_2 concentrations to a level appropriate for coral recovery"[305]."155 As acknowledged by the Recovery Plan:

The final listing rule (NMFS 2006) identified inadequacy of regulatory mechanisms as a threat contributing to the threatened status of elkhorn and staghorn corals. Additionally, the 2014 final rule maintaining the threatened status of elkhorn and staghorn corals (NMFS 2014) identifies the inadequacy of existing regulations to control greenhouse gas emissions, and thus the high importance threats linked to climate change, as contributing to the status and risk of extinction of these two species. Because existing regulatory mechanisms are insufficient to provide appropriate threat abatement for elkhorn and staghorn corals, they are impeding recovery of these species. The threat posed by inadequacy of existing regulatory mechanisms is high (4) throughout the region (see Table 1) because several of the major threats affecting these species are amenable to regulation, albeit with difficulty. National and international efforts are needed to address global climate change while additional international protections are needed to protect populations of elkhorn and staghorn corals throughout their ranges[306].

Since the ocean has absorbed more than 90 percent of the excess heat caused by greenhouse gas warming and more than a quarter of the CO_2 emitted by human activities[307], it is critical for the survival of the elkhorn and staghorn corals to prevent many additional millions of tons of CO_2 from being released. At a minimum, NHTSA must assess how the increases in carbon dioxide emissions will affect these climate-sensitive ocean species.

Other Coastal Species and Sea Level Rise. Global average sea level rose by seven to eight inches (0.2 m) since 1901 as the oceans have gotten hotter and land-based ice has melted[308]. Global average sea level has risen faster since 1900 than in any other century in at least the last 3,000 years[309]. Sea level rise is accelerating in pace: the recent rate of sea level rise has nearly tripled compared with the rate between 1901-1971 (3.7 mm per year from 2006-2018 versus 1.3 mm per year from 1901-1971)[310]. The Fourth National Climate Assessment estimated that global sea level is very likely to rise by 1.0 to 4.3 feet by the

[303] These studies include: (1) Veron et al. (2009) which recommends an atmospheric CO_2 concentration of less than 350 ppm to protect coral reef health, and suggests a target of 320 ppm which is the level that pre-dates the onset of mass bleaching events; (2) Donner (2009) which suggests an atmospheric CO_2 concentration target below 370 ppm to avoid degradation of coral reef ecosystems; (3) Simpson et al. (2009) which correlates a Caribbean open-ocean aragonite saturation state of 4.0, which is recommended by the Recovery Plan, with an atmospheric CO_2 level at 340 to 360 ppm; and (4) Frieler et al. (2012) which shows that limiting warming to ~1ºC above pre-industrial levels is needed to protect Caribbean coral reefs from degradation. Veron 2009; Donner 2009; Simpson, M.C. et al., An overview of modeling climate change impacts in the Caribbean Region with contribution from the Pacific Islands, United Nations Development Programme (2009); Frieler 2012.

[304] Coral Recovery Plan 2015, *See* Recovery Criterion 8.

[305] *Id., See* Recovery Action 9.

[306] *Id*. at I-37.

[307] Fourth National Climate Assessment, Vol. I at 364.

[308] IPCC Climate Change 2021, Summary for Policymakers at SPM-6.

[309] *Id*. at SPM-9.

[310] *Id*. at SPM-6.

end of the century relative to the year 2000, with sea level rise of 8.2 feet possible[311]. Sea level rise will be much more extreme without strong action to reduce greenhouse gas pollution. By the end of the century, global mean sea level is projected to increase by 0.8 to 2.6 feet under a lower emissions RCP 2.6 scenario, compared with 1.6 to 6 feet under a high emissions RCP 8.5 scenario[312].

According to the IPCC's *Climate Change 2021* report, even under a very low GHG emissions scenario, it is likely that global sea level rise by 2100 will be about one to two feet (0.28-0.55 m) compared to 1995-2014. Under an intermediate scenario, sea level rise is likely to be as high as 2.5 feet (0.44-0.76 m), and under a very high GHG emissions scenario it is likely to be close to three feet (0.37-0.86 m). Sea level rise above the likely range, approaching seven feet (2 m) by 2100 under a very high GHG emissions scenario cannot be ruled out due to uncertainty around the melting of ice sheets. Regardless, the impacts of sea level rise will be long-lived: under all emissions scenarios, sea levels will continue to rise for many centuries[313].

Scientific research and federal documents recognize that many coastal listed species are threatened by sea level rise driven by climate change. According to a 2013 analysis, on the current emissions trajectory, rising seas driven by warming temperatures threaten at least 17 percent of our nation's federally protected species, totaling 233 species in 23 coastal states[314]. For example, more than half of Florida's endangered species are threatened by rising sea levels and associated groundwater contamination[315]. Recent FWS listing rules for Florida coastal species have determined that sea level rise resulting from climate change, and the inadequacy of existing regulatory mechanisms to address climate change, are primary threats endangering these species, including the Florida bonneted bat (*Eumops floridanus*)[316], Cape Sable thoroughwort (*Chromolaena frusrata*)[317], Florida semaphore cactus (*Consolea corallicola*)[318], aboriginal prickly-apple (*Harrisa aboriginum*)[319], and Florida bristle fern (*Trichomanes punctatum ssp. Floridanum*)[320].

Research and federal documents have also highlighted sea-level rise as a primary threat to sea turtles by eroding nesting beaches and reducing nesting success[321]. For example, most (87 percent) loggerhead sea

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[311] Fourth National Climate Assessment, Vol. II at 74, 487, 758.

[312] Fourth National Climate Assessment, Vol. I at 344.

[313] IPCC Climate Change 2021, Summary for Policymakers at SPM-28.

[314] Center for Biological Diversity, Deadly Waters: How Rising Seas Threaten 233 Endangered Species (Dec. 2013) [hereinafter Center for Biological Diversity 2013].

[315] *Id*.

[316] U.S. Fish and Wildlife Service, Endangered and Threatened Wildlife and Plants; Endangered Species Status for the Florida Bonneted Bat, 78 Federal Register 61004 (Oct. 2, 2013) (to be codified at 50 CFR Pt. 17) at 61004.

[317] U.S. Fish and Wildlife Service, Endangered and Threatened Wildlife and Plants; Determination of Endangered Status for *Chromolaena frustrata* (Cape Sable Thoroughwort), *Consolea corallicola* (Florida Semaphore Cactus), and Harrisia aboriginum (Aboriginal Prickly-Apple), 78 Fed. Reg. 63796 (Oct. 24, 2013) at 63816.

[318] *Id*. at 63817.

[319] *Id*. at 63817.

[320] U.S. Fish and Wildlife Service, Endangered and Threatened Wildlife and Plants; Endangered Species Status for *Trichomanes punctatum ssp. Floridanum* (Florida Bristle Fern), 80 Fed. Reg. 60440 (Oct. 6, 2015) at 60440.

[321] Fuentes, M.M.P.B. et al., Potential impacts of projected sea-level rise on sea turtle rookeries, Aquatic Conserv: Mar. Freshw. Ecosyst. (2009); Hawkes, Lucy A. et al., Climate change and marine turtles, 7 Endang. Species. Res. 137 (2009); Witt, M. J. et al.,

turtle (*Caretta caretta*) nesting occurs on the east coast of Florida[322], where 43 percent of the turtle's nesting beaches are projected to disappear with just 1.5 feet of sea level rise[323]. The listing rules for the green sea turtle[324] and loggerhead sea turtle[325] conclude that sea level rise is likely to have negative effects on these species through beach loss and reduced nesting success.

[See original comment for Figure 3. Loggerhead sea turtle (*Caretta caretta*) © National Wildlife Federation]

Finalizing the Rule is likely to result in a significant increase of CO_2 emissions and worsen sea level rise. The proposed Rule thus triggers NHTSA's legal duty under the ESA to consult on how continued habitat loss due to sea level rise will adversely affect the loggerhead sea turtle and other listed species threatened by sea level rise.

Sample of Recent Species Listed Due to Climate Change. In addition, the Environmental Groups' analysis of federal listing rules found that FWS and/or NMFS determined that human- caused climate change was a current or potential threat for more than 70 percent of all species listed during 2012 to 2015. The table below includes examples of species listed during 2006 to 2015 for which climate change was a listing factor. Climate change is also a growing threat to many threatened and endangered species that were first listed for other reasons.

[See original comment for Table 1. ESA-Listed Species Threatened By Climate Change (Listed during 2006-2015)]

In sum, the single most important action to avoid further jeopardizing climate-threatened species is achieving emissions reductions that keep warming below 1.5°C and meaningfully lessens carbon dioxide-induced ocean acidification[326]. Section 7 consultation under the ESA is the critical first step to preventing the worst impacts of climate change and ocean acidification on endangered species. As described above, the Rule, if finalized, would directly contribute to significantly higher emissions and their attendant climate change and ocean acidification effects, and thus triggers the duty to consult on those impacts to climate-threatened species—including polar bears and corals—to ensure that any final agency is not

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Predicting the impacts of climate change on a globally distributed species: the case of the loggerhead turtle, 213 J. of Experimental Biology 901 (2010); Fuentes, M.M.P.B. et al., Vulnerability of sea turtle nesting grounds to climate change, 10 Global Change Biology 140 (2010); Chaloupka, Milani et al., Is climate change affecting the population dynamics of the endangered Pacific loggerhead sea turtle? 356 J. of Experimental Marine Biology and Ecology 136 (2008).

322 National Oceanic and Atmospheric Administration, Proposed Listing of Nine Distinct Population Segments of Loggerhead Sea Turtles as Endangered or Threatened, 75 Fed. Reg. 12598 (2010) (to be codified at 50 CFR pts. 223 and 224).

323 Reece, Joshua S. et al., Sea level rise, land use, and climate change influence the distribution of loggerhead turtle nests at the largest USA rookery (Melbourne Beach, Florida), 493 Marine Ecology Progress Series 259 (2013).

324 U.S. Fish and Wildlife Service and National Marine Fisheries Service, Endangered and Threatened Wildlife and Plants; Final Rule To List Eleven Distinct Population Segments of the Green Sea Turtle (*Chelonia mydas*) as Endangered or Threatened and Revision of Current Listings Under the Endangered Species Act, 81 Fed. Reg. 20058 (Apr. 6, 2016) (to be codified at 50 CFR pt. 17) at 20078.

325 U.S. Fish and Wildlife Service, National Marine Fisheries Service, Endangered and Threatened Species; Determination of Nine Distinct Population Segments of Loggerhead Sea Turtles as Endangered or Threatened, 76 Fed. Reg. 58868 (Sept. 22, 2011) (to be codified at 50 CFR pt. 17) at 58910.

326 IPCC 1.5°C Report 2018.

likely to jeopardize these and other species or result in the adverse modification of their critical habitat. Failure to conduct this consultation would render any final Rule unlawful.

ii. Nitrogen pollution from vehicle exhaust has documented adverse impacts on federally protected species, and NHTSA's adoption of the proposed Rule will allow cars and light trucks to emit nitrogen pollution and impact these federally-listed species.

This section describes the numerous federally-listed species whose existence is jeopardized by increases in nitrogen oxide (NO_x) emissions. Once NHTSA corrects its technical assumptions, as described in the Joint Comments submitted with other NGOs, it will be clear that increasing stringency while reducing available credits could save even more NO_x than Alternative 2 alone. Consequently, the Rule, if finalized, would directly contribute to NO_x emissions from vehicle exhaust and increase nitrogen deposition in the areas where such vehicles are operating. Accordingly, increased levels of nitrogen deposition may impact critically imperiled species, including the bay and quino checkerspot butterflies and desert tortoise, whose populations are at heightened risk of extinction directly due to increased nitrogen pollution in their locations and critical habitats. Yet NHTSA has declined consultation to study the effects of the proposal on endangered species.

Fossil fuel combustion from vehicles produces nitrogen oxide (NO_x) air pollutants including nitrous oxide (N_2O), as well as nitric acid (HNO_3), nitrate (NO_3-), and ammonia (NH_3), which have contributed to the significant increase in nitrogen deposition globally and in many parts of the United States[327], resulting in widespread impacts to species and ecosystems[328].

A recent study of the effects of nitrogen pollution on federally-listed species, based on analysis of USFWS and NMFS documents, found that this threat is "substantial" and "geographically widespread"[329]. The study found evidence for harm from nitrogen pollution for at least 78 federally protected taxa[330]. This includes at least 50 invertebrates such as mollusks and anthropods, at least 18 vertebrate species of fish, amphibians, and reptiles, and at least 8 plants[331]. Harms from nitrogen pollution fell into four main categories: (1) direct toxicity or lethal effects of nitrogen, (2) eutrophication lowering dissolved oxygen levels in water or causing algal blooms that alter habitat by covering up substrate, (3) nitrogen pollution increasing nonna- tive plant species that directly harm a plant species through competition, and (4) nitrogen pollution increasing nonnative plant species that indirectly harm animal species by excluding their food sources[332].

Bay checkerspot butterfly (*Euphydryas editha bayensis*) Nitrogen deposition from vehicle exhaust is a well-documented threat to the bay checkerspot butterfly (*Euphydryas editha bayensis*), which is

[327] Fowler, David et al., The global nitrogen cycle in the twenty-first century, 368 Phil Trans R Soc B 20130164 (2013).

[328] Fenn, Mark E., Ecological effects of nitrogen deposition in the Western United States, 53 BioScience 404 (2003) [hereinafter Fenn 2003]; Hernandez, Daniel L. et al., Nitrogen pollution is linked to US listed species declines, 66 BioScience 213 (2016) [hereinafter Hernandez 2016].

[329] Hernandez 2016 at 220.

[330] *Id*. at 215, 220.

[331] *Id*. at 216-217 at Tables 1, 2, 3.

[332] *Id*. at 215-217.

restricted to patches of low-nutrient serpentinite soil in the San Francisco Bay area[333]. Nitrogen deposition has allowed exotic grasses to replace native forbs, including the bay checkerspot's larval host plant, leading to butterfly population declines and local extirpations[334]. USFWS in its most recent 5-year review for the bay checkerspot butterfly found that nitrogen deposition from smog created soil conditions that allowed for invasion of non- native plants, where the level of impact increased with proximity to a major interstate highway:

[See original comment for Figure 4. Bay checkerspot butterfly Euphydryas editha bayensis) © Wikimedia Commons]

Weiss (1999, p. 1476) determined that while the initial cause of the butterfly declines were the result of rapid invasion by nonnative annual grasses that crowded out the butterfly's larval host plants, the evidence indicated that dry nitrogen deposition from smog was responsible for creating soil conditions that allowed the observed grass invasion. Weiss (1999, p. 1482) estimated nitrogen deposition rates south of San Jose to be 10-15 kg of nitrogen per hectare per year (kg-N/ha/yr). Weiss (2002, p. 31) further demonstrated these effects by analyzing the pattern of non-native grass invasion resulting from nitrogen deposition at Edgewood Park, and observed that the cover of non-native Italian ryegrass (*Lolium multiflorum*) decreased with distance from Interstate Highway 280 (I-280), while *Plantago erecta* cover increased with distance. *Plantago erecta* cover was also higher upwind of I-280 than downwind[335].

In its 5-year review, USFWS concluded that "the butterfly is still at great risk from invasion of non-native vegetation, exacerbated by nitrogen deposition from air pollution"[336].

Presidio clarkia (*Clarkia franciscana*) Endangered plant species such as the Presidio clarkia (*Clarkia franciscana*)—a beautiful flowering plant native to California serpentine grasslands—are also being harmed by nitrogen deposition from vehicle pollution which gives a competitive advantage to nonnative plants[337]. USFWS in its most recent 5-year review for the Presidio clarkia identified nitrogen deposition from air pollution as a principal threat, explaining that "elevated inputs of atmospheric nitrogen deposition from air pollution have further accelerated the encroachment of native shrubs and nonnative shrubs and nonnative grasses and forbs…into *Clarkia franciscana* habitat"[338].

[See original comment for Figure 5. Presidio clarkia (*Clarkia franciscana*) © California Fish and Wildlife Department]

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[333] Fenn 2003; U.S. Fish and Wildlife Service, Quino checkerspot butterfly (*Euphydryas editha bayensis*) 5-Year Review: Summary and Evaluation, Sacramento Fish and Wildlife Office (August 2009) [hereinafter USFWS Bay checkerspot butterfly 5-Year Review]; Hernandez 2016.

[334] Weiss, Stuart B., Cars, cows and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species, 13 Conservation Biology 1476 (1999); Huenneke Laura F. et al., Effects of soil resources on plant invasion and community structure in Californian serpentine grassland, 71 Ecology 478 (1990); Vallano, Dena M. et al., Simulated nitrogen deposition enhances the performance of an exotic grass relative to native serpentine grassland competitors, 213 Plant Ecology 1015 (2012).

[335] USFWS Bay checkerspot butterfly 5-Year Review at 13.

[336] *Id*. at 18 and 31.

[337] Hernandez 2016 at 218, Table 3.

[338] U.S. Fish and Wildlife Service, *Clarkia franciscana* (Presidio clarkia) 5-Year Review: Summary and Evaluation, Sacramento Fish and Wildlife Office (2010) at 43.

The USFWS 5-year review specifically highlights vehicle pollution as a key contributor to the nitrogen deposition harming the Presidio clarkia:

Elevated atmospheric nitrogen deposition from air pollution is particularly harmful to the nutrient-poor serpentine grasslands where the *Clarkia franciscana* occurs because nitrogen is the primary limiting nutrient for plant growth on serpentine soils (Weiss 1999). The use of catalytic converters on vehicles has increased the availability of nitrogen in a form that is directly absorbed by plants (EBRPD 2009a). The excess nitrogen deposited leads to increases in nonnative annual grasses which outcompete the native flora (Fenn *et al*. 2003, Weiss 1999).

The displacement of *Clarkia franciscana* and native bunchgrasses from serpentine soils in the Oakland Hills is attributed to the dry deposition of 10 – 15 kilograms nitrogen per hectare per year from smog allowing for the invasion of nonnative annual grasses, especially Italian ryegrass at Redwood Regional Park (EBRPD 2009a, Tonnesen *et al*. 2007). … Thus, *Clarkia franciscana* in the serpentine grasslands in the Oakland Hills continues to be threatened by elevated atmospheric nitrogen deposition from air pollution enabling the invasion of nonnative annual grasses into otherwise nutrient-poor soils[339].

The USFWS 5-year review identifies other potential harms to the Presidio clarkia from nitrogen deposition such as decreased diversity of mycorrhizal communities and predisposing plants to environmental stresses such as elevated concentrations of ozone, drought, frost, or insect attacks[340].

Other Species Threatened by Nitrogen Pollution. Similarly, USFWS has determined that nitrogen pollution threatens the federally protected Quino checkerspot butterfly (*Euphydryas editha quino*) and the desert tortoise (*Gopherus agassizii*) by facilitating the spread of non-native species that displace the butterfly's host plants[341] and the tortoise's forage plants, reducing the nutritional quality of available food for the desert tortoise[342].

A review on the effects of nitrogen deposition in the western United States highlighted the need for policy changes at the national level for reducing air pollution to protect endangered species from nitrogen deposition: "local land management strategies to protect these endangered species may not succeed unless they are accompanied by policy changes at the regional or national level that reduce air pollution"[343].

i. Sulfur dioxide pollution has clear and documented adverse impacts on federally protected species, and NHTSA's adoption of the proposed Rule will allow cars and light trucks to emit sulfur dioxide pollution and impact these federally-listed species.

This section describes the myriad federally-listed species whose existence is jeopardized by increases in sulfur dioxide ("SO_2") emissions. As with NO_x, once NHTSA corrects its technical assumptions, as

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339 *Id*. at 50.

340 *Id*. at 50.

341 USFWS Bay checkerspot butterfly 5-Year Review at 13, 15, 18.

342 Nagy, Kenneth A. et al., Nutritional quality of native and introduced food plants of wild desert tortoises, 32 Journal of Herpetology 260 (1998); Allen, Edith B. et al., Impacts of atmospheric nitrogen deposition on vegetation and soils at Joshua Tree National Park, pages 78-100. In: The Mojave Desert: Ecosystem Processes and Sustainability [Webb, R.H. et al. (eds.)]. University of Nevada Press, Las Vegas (2009); U.S. Fish and Wildlife Service, Mojave population of the desert tortoise (*Gopherus agassizii*) 5-Year Review: Summary and Evaluation, Desert Tortoise Recovery Office (Sept. 2010) at 24, 33.

343 Fenn 2003 at 416.

described in the Joint Comments submitted with other NGOs, it will be clear that increasing stringency while reducing available credits could save even more SO_2 than Alternative 2 alone. Consequentially, the Rule, if finalized as proposed, would directly contribute to SO_2 emissions and jeopardize numerous critically imperiled bird species and plant species, whose populations are at heightened risk of extinction directly due to increased sulfur dioxide pollution in their locations and critical habitats. Yet NHTSA has declined consultation to study the effects of the proposal on endangered species.

Strong evidence shows that SO_2, as well as precursors such as sulfur oxides ("SO_x"), harm endangered plant and animal species as well as aquatic and terrestrial ecosystems. As reviewed by EPA, the negative ecological effects of SO_2 pollution include acidification of aquatic and terrestrial ecosystems, nutrient enrichment of aquatic and terrestrial ecosystems, and facilitation of mercury methylation in aquatic ecosystems[344]. Acute and chronic exposure to SO_2 also leads to phytotoxic effects on plants, including foliar injury, decreased photosynthesis, and decreased growth[345].

In its 2017 final Integrated Review Plan for Secondary Standards for Oxides of Sulfur, EPA acknowledged that there is "sufficient evidence to infer causal relationships" between exposure to SO_2 and SO_x and (a) aquatic acidification and the loss of acid-sensitive species, where more species are lost with greater acidification[346]; (b) changes in terrestrial biota due to acidifying sulfur deposition, such as decreased growth and increased susceptibility to disease and injury in sensitive tree species[347]; (c) increased mercury methylation in aquatic environments[348]; and (d) injury to vegetation, including decreased photosynthesis, decreased growth, and visible foliar injury[349].

In terms of harms to endangered species, EPA acknowledged that acidifying sulfur deposition in aquatic ecosystems can cause the loss of acid-sensitive species, such as salmonids (many of which are endangered), and that disruption of food web dynamics can cause changes to the diet, breeding distribution and reproduction of bird species[350]. EPA further stated that current rates of acidifying SO_x deposition are still well above pre-acidification conditions in areas such as the Adirondacks and Shenandoah, and that sulfur and nitrogen deposition loadings of many Adirondack lakes and streams are at levels that can harm aquatic biota (e.g., levels associated with loss of fitness in species such as the Blacknose Dace)[351]. EPA also acknowledged that there is a "causal relationship between Sulfur deposition *at current levels* and increased Hg methylation in aquatic environments[352]," which is problematic because mercury is highly neurotoxic and, once methylated, can be taken up by zooplankton and macroinvertebrates, and bioaccumulate up the food web[353].

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[344] U.S. Environmental Protection Agency, Integrated Review Plan for the Secondary National Ambient Air Quality Standards for Ecological Effects of Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter, EPA-452/R-17-002 (January 2017) [hereinafter USEPA IRP NAAQS No_X, So_X, PM 2017] at 2-4 and 2-5.

[345] *Id*. at 2-3 and 3-9.

[346] *Id*. at 3-13.

[347] *Id*. at 2-5 and 2-6.

[348] *Id*. at 3-14 and 3-15.

[349] *Id*. at 2-3 and 3-9.

[350] *Id*. at 2-5.

[351] *Id*. at 2-5.

[352] *Id*. at 3-14.

[353] *Id*. at 3-14 and 3-15.

Indeed, EPA's Integrated Review Plan acknowledges that SO_2 has the potential to negatively affect endangered species. The Risk and Exposure Assessment (REA) identified a range of ecosystem services that are affected by terrestrial acidification including "decreased habitat for threatened and endangered species"[354].

[See original comment for Figure 5. Heller's Blazing Star (Liatris helleri) © BlueRidgeKitties via Flickr]

At-risk Plant Species. Federal wildlife agencies, and in particular FWS, have identified numerous federally endangered and threatened species that are negatively affected by atmospheric pollution from SO_2 and SO_x. Federally protected plant species identified by FWS as threatened by or susceptible to acidification and atmospheric pollution include the Harperella (*Ptilimnium nodosum*)[355], Zuni Fleabane (*Erigeron rhizomaxs*)[356], Mancos Milkvetch (*Astragalus humillimus*)[357], Blue Ridge Goldenrod (*Solidago spithamaea*)[358], Heller's Blazing Star (*Liatris helleri*)[359], Rock Gnome Lichen (*Gymnodema lineare*)[360], and Roan Mountain Bluet ([*Hedyotis purpurea var. montana*)[361]. For example, Heller's Blazing Star is a rare plant endemic to a limited area in the Blue Ridge Mountains of North Carolina, with only a few populations currently known to exist. The recovery plan for this species names acid precipitation as a "pervasive" threat[362]. The FWS recovery plan for the Rock Gnome Lichen, which is endemic to the Southern Appalachians, flags that "there is a high likelihood that current and previous air pollution levels, especially from sulfates, may be contributing to the decline of this species"[363].

At-risk Animal Species.FWS has also identified numerous animal species as being threatened by or susceptible to acidification and atmospheric pollution, including the Shenandoah Salamander (*Plethodon Shenandoah*)[364], Cheat Mountain Salamander (*Plethodon neftiigi*)[365], Chiricahua Leopard Frog (*Rana chiricahuensis*)[366], Whooping Crane (*Grus americana*)[367], Roanoke Logperch (*Percina rex*)[368], Dwarf

[354] *Id*. at 4-11.

[355] U.S. Fish and Wildlife Service, Harperella (*Ptilimnium nodosum*) Rec

[356] U.S. Fish and Wildlife Service, Recovery Plan for Zuni Fleabane (*Erigeron rhizomaxs* Cronquist) (1988) at 12.

[357] U.S. Fish and Wildlife Service, Mancos Milkvetch (*Astragalus humillimus*) Recovery Plan (1989) at 13.

[358] U.S. Fish and Wildlife Service, Blue Ridge Goldenrod (*Solidago spithamaea* Curtis) Recovery Plan (1987) at 7, 20.

[359] U.S. Fish and Wildlife Service, Heller's Blazing Star ([*Liatris helleri*) Recovery Plan (2000) [hereinafter Heller's Blazing Star Recovery Plan 2000] at iii, 7.

[360] U.S. Fish and Wildlife Service, Recovery Plan for Rock Gnome Lichen (*Gymnodema lineare*) (1997) [hereinafter Rock Gnome Lichen Recovery Plan 1997] at 4, 9.

[361] U.S. Fish and Wildlife Service, Recovery Plan for Roan Mountain Bluet (*Hedyotis purpurea var. montana*) (1996) at 20.

[362] Heller's Blazing Star Recovery Plan 2000 at 7.

[363] Rock Gnome Lichen Recovery Plan 1997 at 4.

[364] U.S. Fish and Wildlife Service, Shenandoah Salamander (*Plethodon Shenandoah*) Recovery Plan (1994) at 1, 8- 10.

[365] U.S. Fish and Wildlife Service, Cheat Mountain Salamander (*Plenthodon nettingi*) Recovery Plan (1991) at 12.

[366] U.S. Fish and Wildlife Service, Chiricahua Leopard Frog (*Rana chiricahuensis*) Final Recovery Plan (2007) [hereinafter Chiricahua Leopard Frog Final Recovery Plan 2007] at 23-25, 35, 40.

[367] U.S. Fish and Wildlife Service, International Recovery Plan: Whooping Crane (*Grus americana*): Third Revision (2007) at C-1.

[368] U.S. Fish and Wildlife Service, Roanoke Logperch (*Percina rex*) Recovery Plan (1992) at 17.

Wedge Mussel (*Alasmidonta heterodon*)[369], Mobile River Basin mussels[370], and seven species of Southeast mussels[371]. For example, the recovery plan for the Chiricahua Leopard Frog states that acid rain has been found to adversely affect Chiricahua Leopard Frog populations[372], likely through reduced hatching of eggs and reduced growth rates[373].

[See original comment for Figure 6. Whooping Crane (Grus americana) © National Wildlife Federation]

Consultation under the ESA about impacts to species is essential. NHTSA's Proposal, if finalized, would directly contribute to higher emissions of SO_2, and thus triggers the duty to consult on those impacts to species at risk from atmospheric pollution from SO_2 and SO_x. Failure to conduct this consultation would render any final repeal unlawful.

III. CONCLUSION

The scientific evidence demonstrates that the Rule, if adopted as proposed, may affect hundreds of threatened and endangered species, and their critical habitats, due to the Rule's resulting increase in emissions of GHG, NO_x, SO_2 and other criteria air pollutants. Accordingly, the finalization of the Rule triggers NHTSA's mandatory duty to initiate Section 7 consultation under the ESA to ensure that the Rule will not jeopardize the existence of these endangered species and their habitats, which have been legally identified by the Services as being at risk precisely due to the emissions of these air pollutant emissions. The Center urges NHTSA to undergo Section 7 consultation with the Services immediately.

Response

Under Section 7(a)(2) of the Endangered Species Act (ESA), federal agencies must ensure that actions they authorize, fund, or carry out are "not likely to jeopardize" federally listed threatened or endangered species or result in the destruction or adverse modification of the designated critical habitat of these species.[374] If a federal agency determines that an agency action may affect a listed species or designated critical habitat, it must initiate consultation with the appropriate Service—the U.S. Fish and Wildlife Service of the Department of the Interior and/or National Oceanic and Atmospheric Administration's National Marine Fisheries Service of the Department of Commerce, depending on the species involved—in order to ensure that the action is not likely to jeopardize the species or destroy or

[369] U.S. Fish and Wildlife Service, Dwarf Wedge Mussel (*Alasmidonta heterodon*) Recovery Plan (1993) at 14.

[370] U.S. Fish and Wildlife Service, Recovery Plan for Mobile River Basin Aquatic Ecosystem (2000) at 12, 13; U.S. Fish and Wildlife Service, Recovery Plan for Six Mobile River Basin Snails (Cylindrical Lioplax, Flat Pebblesnail, Plicate Rocksnail, Painted Rocksnail, Round Rocksnail and Lacy Elimia) (2005) at 16.

[371] U.S. Fish and Wildlife Service, Recovery Plan for Fat Threeridge (*Amblema neislerii*), Shinyrayed Pocketbook (*Lampsilis subangulata*), Gulf Moccasinshell (*Medionidus penicillatus*), Ochlockonee Moccasinshell (*Medionidus simpsonianus*), Oval Pigtoe (*Pleurobema pyriforme*), Chipola Slabshell (*Elliptio chipolaensis*), and Purple Bankclimber (*Elliptoideus sloatianus*) (2003) at 56.

[372] Chiricahua Leopard Frog Final Recovery Plan 2007 at 40.

[373] *Id*. at 44.

[374] 16 U.S.C. § 1536(a)(2).

adversely modify designated critical habitat.[375] Under this standard, the federal agency taking action evaluates the possible effects of its action and determines whether to initiate consultation.[376]

NHTSA disagrees with the commenter that, "the Rule, if finalized, would directly contribute to significantly higher emissions and their attendant climate change and ocean acidification effects." As shown in the Final SEIS, NHTSA's Preferred Alternative (Alternative 2.5) would result in reduced air pollutant emissions, air toxics, and GHG emissions. The commenter notes that there are increases in emission of NO_X; however, as discussed in Chapter 4, *Air Quality*, the increases in NO_X emissions for the Preferred Alternative occur in 2025, but the NO_X emissions show decreases in 2035 and 2050. Regarding SO_2 increases, as noted in Chapter 4, the increases in SO_2 emissions reflect the projected increase in EV use in 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.

NHTSA emphasizes the importance of this action to climate change indicators throughout this Final SEIS. In the Final SEIS, NHTSA includes analysis on many of the topics addressed by the commenter, including in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, which discusses changes in surface temperature, sea-level rise, ocean temperature changes, and sensitivities to coral reef and coastal ecosystems. In addition, the quantitative estimates presented in Section 8.6, *Greenhouse Gas Emissions and Climate Change*, examine the impact of the Proposed Action and alternatives on a range of global climate indicators and under several sensitivity cases assuming a range of future global actions to mitigate climate change effects, including discussion of polar bears and loss of sea ice.

NHTSA has reviewed applicable ESA regulations, case law, guidance, and rulings in assessing the potential for impacts on threatened and endangered species from the proposed CAFE standards. Although there is a general association between the actions undertaken in the final rule and environmental impacts described in the preamble to the final rule and this Final SEIS, the action of setting CAFE standards results in no effect on listed species or designated critical habitat and, therefore, does not require consultation under Section 7(a)(2) of the ESA. In addition, NHTSA sets the standards as part of the final rulemaking action; however, implementation of the standards is beyond NHTSA's jurisdiction.

NHTSA believes that the agency's action of setting CAFE standards, which will result in nationwide fuel savings and, consequently, emissions reductions from what would otherwise occur in the absence of the agency's CAFE standards, does not require consultation with the National Marine Fisheries Service or the U.S. Fish and Wildlife Service under section 7(a)(2) of the ESA. For additional discussion of the agency's rationale, see Section VIII.D.6. in the preamble to the final rule In the interest of eliminating duplication, NHTSA addresses the issues raised by these comments in Section VIII.D.6. of the final rule preamble. NHTSA's conclusion regarding Section 7(a)(2) of the ESA, which is contained in the final rule preamble, is incorporated by reference in this Final SEIS. Accordingly, NHTSA has concluded its review of this action under Section 7 of the ESA.

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[375] See 50 CFR § 402.14.

[376] See 51 FR 19926, 19949 (Jun. 3, 1986).

10.7.2 Environmental Justice

Comment

Docket Number: NHTSA-2021-0054-0011
Organization: EPA

EPA is providing the following technical comments for your environmental justice analysis within Chapter 7.

On pages 7-14, 7-15, with regard to electric vehicle (EV) distributional effects, NHTSA references Holland et al., 2019. EPA recommends that NHTSA should note that this study relies on outdated data. In the Holland et al., 2019 paper, emissions for power plants were based on 2010-12 data, and EV ownership data were from 2014. The same authors have updated these data in a newer paper (see sub- bullet below) and found that EVs were cleaner than gas vehicles in most of the country (unlike the results underlying the 2019 paper). The newer paper also notes that the geographic distribution of changes was not uniform; as a result, the distributional effects of the new results would not be the same as the old effects. EPA recommends that NHTSA note that the input data Holland et al. (2019) used to support their findings have changed significantly since that time. Conclusions about the distribution of benefits across income could be substantially different if the analysis reflected updated information about recent trends in electricity generation (see Holland et al., 2020).

Holland et al. (same authors) (2020). "Decompositions and Policy Consequences of an Extraordinary Decline in Air Pollution from Electricity Generation." *American Economic Journal: Economic Policy* 12(4): 244–274

Response

NHTSA updated references of the Holland et al. (2019) paper in Section 7.5.1.4, *Distributed Benefits of Electric Vehicles*, to the new Holland et al. (2020) paper, which resulted in NHTSA discussing changes in emission rates and power generation occurring in the last decade has led to EVs being cleaner on average than gas-powered vehicles. NHTSA retained some text from Holland et al. (2019) about environmental benefits of EV adoption not being dispersed homogeneously and benefits decreasing with income, but NHTSA notes that the findings in the 2019 were based on data from 2010 through 2017. NHTSA also added a statement regarding the distribution of benefits likely would be affected by updates to this data.

In addition to the Holland et al. (2020) paper inclusion, NHTSA made other updates in Section 7.5.1.4, *Distributed Benefits of Electric Vehicles*, related to distributed benefits of EVs. One of these updates includes references to incentive programs to increase EV use amongst low-income individuals, such as California's Enhanced Fleet Modernization (EFMP) Program and EFMP Plus-up Pilot Program. NHTSA also added references to the California Energy Commission findings on the need for additional chargers to meet electricity demand for EVs, projected numbers from Advanced Energy Economy (AEE 2021) for EV-related job growth, and statements on the potential for EVs to serve as distributed energy resources and the equity considerations that should be considered alongside them.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

The projected impacts of NHTSA's proposed standards are likely to be magnified in communities with higher percentages of Black, Asian American, and Latinx residents because refineries and major roadways are disproportionately located in those communities.[377] 86 Fed. Reg. at 49,795. For instance, nearly 700,000 people live within three miles of the seventeen refineries that reported actual annual benzene fenceline concentrations in 2020 above the level set by EPA that requires the refinery to take action to clean up emissions. Of these 700,000 people, 62% are African-American, Hispanic, Asian/Pacific Islander, or American Indian residents, and nearly 45% have incomes below the poverty level.[378] As another example, the community of Wilmington, Carson, and West Long Beach in Los Angeles, California is affected by pollution from major freeway junctions, as well as freight, port, and rail operations, oil and gas production, and five petroleum refineries.[379] A majority of this community is considered disadvantaged under California law, scoring higher than the state average on key indicators of vulnerability, including criteria pollutant exposure, health status, and socio-economic criteria.[380] In the Northeast and Mid-Atlantic Region, average concentrations of exposures to PM2.5 are 75%, 73%, and 61% higher for Latinx residents, Asian American residents, and Black residents, respectively, than they are for white residents.[381] PM2.5 and NO_2 concentrations are also highest for Black and Latinx communities in Massachusetts, in part because of their proximity to industrial facilities and highways, and these concentrations have increased even though overall exposure to those pollutants has decreased in the Commonwealth.[382] Improvements in air quality anticipated by the proposal will serve our States and Cities' environmental justice goals, by improving air quality in communities historically impacted by greater pollution.

Response

NHTSA incorporated peer-reviewed sources the commenter cited, including the following:

- Section 7.5.1.1, *Proximity to Oil Production and Refinin*g, NHTSA referenced the new data from the Environmental Integrity Project (2021) that found minority and low-income populations are more likely to experience refinery emissions exceeding EPA standards, particularly benzene concentrations.

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377 CARB, Benefits of California's Zero-Emission Vehicle Standards on Community-Scale Emission Impacts (Jul. 6, 2021), App. B to Comments of States and Cities in Support of EPA Reversing Its SAFE 1 Actions.

378 Environmental Integrity Project, Environmental Justice and Refinery Pollution: Benzene Monitoring Around Oil Refineries Showed More Communities at Risk in 2020 7, n.6 (Apr. 28, 2021), available at https://environmentalintegrity.org/wp-content/uploads/2021/04/Benzene-report-4.28.21.pdf.

379 CARB, supra note 134, at 31-32.

380 Id. at 31–39.

381 Union of Concerned Scientists, Inequitable Exposure to Air Pollution from Vehicles in the Northeast and Mid- Atlantic (June 2019), https://www.ucsusa.org/sites/default/files/attach/2019/06/Inequitable-Exposure-to-Vehicle- Pollution-Northeast-Mid-Atlantic-Region.pdf.

382 Office of Massachusetts Attorney General Maura Healey, supra note 108, at 5.

- Section 7.5.1.2: *Proximity to High-Traffic Roadways and Air Pollution*, NHTSA included updated text from a study (Rosofsky et al. 2018) that showed increased PM2.5 and nitrogen dioxide concentrations for Black and Latinx communities in Massachusetts.

In addition, NHTSA incorporated new sources into the updated text that provided additional data points on public health and vulnerable populations. In Section 7.5.1.3, *Disproportionate Health Effects of Air Pollution*, NHTSA included new studies (Kiomourtzoglou et al. 2016; Di et al. 2017; Tessum et al. 2021) on public health and air quality referenced in the 2021 EPA report on Climate Change and Social Vulnerability in the United States. From these studies, NHTSA included findings about the relationship between higher air pollution exposure and vulnerable populations (low-income individuals and people of color). NHTSA also included a finding from the 2019 EPA Integrated Science Assessment which found that Black individuals are particularly exposed to health effects caused by PM2.5.

NHTSA also added new information to Section 7.5.1.5, *Differential Vulnerabilities to Climate Change*, from the 2021 EPA report on Climate Change and Social Vulnerability in the United States. The Final SEIS includes information on increasing PM2.5 and ozone concentrations due to climate change and disproportionate exposure to PM2.5 of Black individuals.

NHTSA agrees that improvements in air quality anticipated by the final rule will have a positive impact on environmental justice communities.

Comment

Docket Number: NHTSA-2021-0054-0015
Organization: Institute for Policy Integrity at NYU School of Law
Commenter: Meredith Hankins

NHTSA should similarly analyze the relative distributional effects of the more stringent Alternative 3 as compared to NHTSA's Preferred Alternative 2.[383] NHTSA should consider the economic effects to lower-income households as well as the environmental justice effects from changes to criteria and toxic pollution, and the environmental justice gains associated with the increased climate benefits from more stringent alternatives.[384]

Response

In the Final SEIS, NHTSA added Alternative 2.5 and selected it as the Preferred Alternative, which is somewhat more stringent that Alternative 2, the Preferred Alternative in the Draft SEIS. NHTSA's evaluation of environmental justice effects focuses on a literature review of the relationship between communities and various impacts or benefits of the Proposed Action and alternatives. In Chapter 7, *Other Impacts*, NHTSA addresses health effects of air pollution, proximity to high-traffic roadways and air pollution, and proximity to oil production and refining on environmental justice populations. NHTSA reviewed the referenced documents provided by the commenter, the guidance of which aligns with the

[383] See Jack Lienke et al., Inst. for Pol'y Integrity, Making Regulations Fair: How Cost-Benefit Analysis Can Promote Equity and Advance Environmental Justice (2021), https://policyintegrity.org/files/publications/Making_Regulations_Fair_2021.08.31.pdf (for guidance on integrating such an analysis).

[384] See Iliana Paul et al., Inst. for Pol'y Integrity, Improving Environmental Justice Analysis: Executive Order 12,898 and Climate Change (Policy Integrity Report 2021), https://policyintegrity.org/publications/detail/improving-environmental-justice-analysis (on the distributional effects of climate change).

approach taken in Chapter 7 to identify environmental justice concerns associated with the Proposed Action and alternatives. NHTSA also reviewed EPA's 2016 Technical Guidance for Assessing Environmental Justice in Regulatory Analysis (EPA 2016h). The EPA 2016 Technical Guidance states: "The terms difference or differential indicate an analytically discernible distinction in impacts or risks across population groups."

Under any alternative, total emissions from passenger cars and light trucks are expected to decrease over time compared to existing (2021) conditions (see Chapter 4, *Air Quality*) and the differences in results between Alternative 2 and 3 are discernible, as the commenter requested. 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. Adverse health impacts are projected to decrease nationwide under each of the action alternatives. The regional emissions analysis provided in this SEIS provides valuable information for the decision-maker and the public and includes a discussion of the limitations of the approach. In addition, NHTSA's results from full-scale photochemical modeling, included in Final SEIS Appendix D, *Air Quality Modeling and Health Impacts Assessment*, provides additional perspective by sharing the spatial and temporal detail to estimate changes in ambient pollutant levels and their associated impacts on human health and welfare. While there are only small differences between the action alternatives, all action alternatives show benefits to human health that NHTSA anticipates would be attributed to disproportionately affected communities. NHTSA agrees with the commenter that improvements in air quality anticipated by the final rule will have a positive impact on environmental justice communities.

Comment

Docket Number: NHTSA-2021-0054
Organization: American Lung Association
Commenter: Paul Billings

Air pollution is a major threat to public health and is discriminative to Black and Brown communities and [Indiscernible] communities. Thousands of people die prematurely each year in the U.S. and motor vehicles are a leading source for emissions of great ozone [Indiscernible] pollution. American Lung Association's most recent state of the air reported that 135 million people in the United States countered unhealthy air pollution. The report also stated that people of color are much more likely to live in counties with failing grades of ozone [Indiscernible] pollution. Transportation is also a leading contributor of climate change. [Indiscernible] near roadways or gas operations, refineries disproportionate burden of air pollution and climate changes make the pollution worse. Let me repeat this, climate change is making the air quality worse.

Docket Number: NHTSA-2021-0054
Organization: Environmental Law & Policy Center
Commenter: Ann Jaworski

Stronger fuel economy standards mean less pollution [Indiscernible] and low income communities and communities of color tend to live closer to large highways and suffer disproportionate health harms. They stand to benefit from these fuel economy standards. Fuel-efficient cars save Americans at the gas pump. That fuel savings outweighs any increased purchase price of the car. Fuel-efficient cars are especially important for millions of Americans who spend greater proportions of their incomes on gasoline. Ensuring that new cars sold today and in the next two years are as efficient as possible means that a few years later fuel-efficient used cars will be available on the market.

Docket Number: NHTSA-2021-0054
Organization: Alliance of Nurses for Healthy Environments
Commenter: Julia McLaughlin

My name is Julia McLaughlin I'm a registered nurse and part of the alliance for healthy environments, the only national organization focused solely on how the environment impacts human health. Our organization strongly supports creating the strongest possible fuel economy standards. I would like to thank Pres. Biden and his administration for acknowledging the importance of addressing climate solutions from the transportation sector which is the largest emitter of greenhouse gas emissions in the United States. Gasoline and diesel-powered cars, SUVs, and pickup trucks pollute the air and drive climate change. [Indiscernible] are taking care of people in communities that are most affected by climate change from extreme heat and extreme weather and [Indiscernible] applies to more frequent and intense wildfires affecting air-quality. Without immediate actions these health risks from climate change will only increase. Reducing air pollution and addressing climate change is an environmental issue. The American lung Association 2021 stated in their reports that people of color are over three times as likely as white people to live in the most polluted areas. The current proposal is a step in the right direction to address cleaner car standards that were rolled back by the previous administration. I urge you to finalize the strongest possible version in your proposed rule to alternately drive the United States towards a zero emission vehicles. The strongest possible fuel economy standards have to drive down vehicle pollution and protect public health. It is critically important that automakers [Indiscernible] loopholes that give them away to give them credit for technology and better overall fuel economy. In this proposal alternative most rigid and [Indiscernible] of protecting her health and environment. The Bidens administration’s environmental justice is issuing a stronger clean car standards will help address key transportation related impacts by local, income, black, indigenous and people of color [Indiscernible] from vehicle pollution with increased rates of asthma and other respiratory illnesses. Alternative [Indiscernible] should be a solution. Climate change is a health emergency and the Biden administration must use all tools to promote carbon pollution reduction measures. Please finalize this proposal quickly and [Indiscernible] fuel efficiency standards for cars, light trucks and SUVs that will accelerate the transition to zero in mission vehicles. We must take action at every level [Indiscernible] and reduce vehicle pollution to protect human health.

Docket Number: NHTSA-2021-0054
Organization: Asthma and Allergy Foundation of America
Commenter: Jenna Rimenschneider

Founded in 1953 (the Asthma and Allergy Foundation of America) is the oldest and largest organization for those with asthma and allergic disease. We support the administration's proposal to tighten fuel efficiency standards for passenger cars, SUVs and light trucks for MYs 2024 through 2026 and urge NHTSA to finalize standards at least as strong as alternative three in the proposal. 25 million Americans have asthma including up to 6 million children and 5600 people die each year from asthma. A chronic disease that causes your airways to become inflamed making it hard to breathe. There is no cure for asthma. In the United States, the burden of asthma falls disproportionately on the black, Hispanic, American Indian or Alaska native population. Especially on children. These groups have disproportionately higher rates of poor asthma outcomes including hospitalizations and deaths. In fact as documented in [Indiscernible] 2020 asthma disparities in the American reports black Americans are three times more likely to die of asthma than white Americans and five times more likely to be treated in emergency rooms. Black women have the highest [Indiscernible] numbers of any other group. Poor air quality and exposure to air pollution are very significant risk factors both for developing as men for those who already have an asthma diagnosis. Clean air and adjusting the climate crisis are particularly important to the asthma and allergy community. Especially those in racial and ethnic minority. A leading contributor to air pollution of the largest source of climate pollution in the United States, the transportation sector represents immense opportunity for public health benefits. Nationwide transition to zero emission vehicles will reduce the burden of pollution. First, populations are highly benefit environment. Second other communities will benefit from the upstream pollution reduction associated with extraction transportation and [Indiscernible] control products. As we know the communities impacted most for disparate initially lower income largely racial and ethnic minority populations. Making a finalization at the strongest possible standards and environmental justice imperative. [Indiscernible] support screen is safe air for everyone but especially for vital population like those with chronic asthma and chronic respiratory disease. It's a good start to adjusting the previous administration rollback of cleaner car standards but, more must be done. NHTSA must make haste and finalize the rule this year to make sure model year 2024 is covered and to set up more protective health standards beyond that. We know climate change is a public health emergency and we cannot afford to delay action.

Docket Number: NHTSA-2021-0054
Organization: GreenLatinos
Commenter: Andrea Marpillero-Colomina

My name is Andrea and I am the clean advocate at Greenlatinos. We are an active [Indiscernible] of Latinos environmental and [Indiscernible] fighting against climate change in [Indiscernible] that intensifies systemic, social and health and economic injustice in a community spirit. I'm really grateful to be here today at this hearing. It has been an exciting and informing [Indiscernible] of the Biden administration. Was the president promised bold action to reverse [Indiscernible] emission efficiency standards for passenger cars and trucks. I thank the administration for acting so swiftly on this issue. Last month I was delighted to learn about the newly proposed CAFE standards, strong fuel standards are not only important for consumers but also for the health of our children's lungs and the well-being of our most vulnerable communities. I am here today to urge NHTSA to ensure the CAFE standards in order to create the strongest possible [Indiscernible] of vehicle pollution, only stronger standards can have the power to grow the economy by saving consumers money at the pump, spurring innovation in the development of new clean-air technologies and the electrification of the transportation sector and perhaps most importantly drive down vehicle pollution to protect public health. Specifically NHTSA's alternative three proposal could deliver on the Biden administration's stated commitment to environmental justice. Issuing stronger clean car standards will help address key transportation related impacts including mitigation of the disproportionate burden and harm that low income communities and communities of color experience of vehicle pollution. The last point is really why am here today. There is an urgent need to create and support the implementation a stringent clean vehicle standard in order to mitigate the impact of emissions in Latino communities. As you may know a recent nationwide study found Latino children are three times more likely than non-Hispanic white children to live in counties where air quality standards are exceeded. Nearly 1/3 of Latino children live in counties where its hazardous air pollution concentrations exceed a one in 10,000 level. Latinos are twice as likely [Indiscernible] to be seen in emergency rooms for asthma. Latino children are twice as likely to die from it than their white counterparts. Strong standards can prevent exposure to the vehicle [Indiscernible] and protect against completely unnecessary deaths while saving energy and supporting economic growth. By implementing the strongest possible fuel economy standards NHTSA can follow through on the administration's stated commitment to environmental justice. I urge NHTSA to finalize alternative three which will push automakers to make the most fuel-efficient and clean vehicles they can.

Docket Number: NHTSA-2021-0054
Organization: New Mexico Interfaith Power and Light
Commenter: Ruth Striegel

People with low incomes, who are most in need of fuel-efficient transportation, are the most likely to purchase used vehicles and thus be the last to benefit from stronger fuel economy standards. The same people are the most likely to suffer from asthma, or other respiratory diseases, and to be exposed to vehicle pollution because they live near highways. Our shameful history of building interstates through communities of color and forcing people of color to rent or purchase housing in undesirable areas, as meant poor health for many of these, many in these communities. The least we can do is work to reduce vehicle pollution through strong fuel economy standards.

Docket Number: NHTSA-2021-0054
Organization: National Parks Conservation Association
Commenter: Mark Rose

I have seen firsthand the impact of vehicle pollution on the health and well-being of my neighbors and friends, and we must do more to protect the citizens, especially persons of color and low-income individuals, living in the environmental justice communities across the nation with climate instability.

Docket Number: NHTSA-2021-0054
Organization: National Religious Partnership for the Environment
Commenter: Cassandra Carmichael

Transportation is the largest and fastest source of greenhouse gases in the United States. 30% of climate conditions negatively impact human health. To care for God's earth and God's people, we must have policies that in the combustion fuels and eliminate the communities, particularly communities of color, disease causing life shortening concentrations. We can improve air quality and shift to zero emission vehicles. Any transportation solution must also ensure that clean and reliable, affordable transportation is accessible to all. We know that black communities in other communities of color are disproportionately harmed from vehicle pollution, since these neighborhoods are often located closest to highways and other sources of vehicle pollution. this resulted tragically and higher rates of asthma and other respiratory illnesses among these community members. This fall, more than 20,000 people of faith, including almost 1000 black church leaders, and a vast number of pro-life evangelicals submitted comments, for robust admission standards on cars. It is not the first time the religious community has weighed in on the need for clean cars. Faith community statements and advocacy for clean cars is born of the administration for environmental health, and environmental justice. We need strong clean car standards to protect clean air in our communities and help alleviate the ongoing climate crisis.

Response

NHTSA agrees that minority and low-income populations are disproportionately affected by changes in criteria and air toxic pollutant emissions, as noted by numerous commenters. Among other environmental justice concerns, the Final SEIS, Section 7.5, *Environmental Justice*, summarizes the available literature on two major sources from which air pollutant emissions might disproportionately affect minority and low-income populations: oil refineries (upstream emissions) and roadways (downstream emissions).

NHTSA found that all action alternatives would bring benefits to air quality and human health by reducing adverse health impacts nationwide by 2025, 2035, and 2050. In general, Alternative 1 provides the largest decrease in adverse health impacts by 2025, while Alternative 3 would provide the largest decrease by 2035 and 2050. In all alternatives, adverse health impacts would decrease over time due to increasing stringency as action alternatives are implemented.

As described in Chapter 7, *Other Impacts*, the change in emissions in the Proposed Action and alternatives, relative to the No Action Alternative, would be beneficial to minority and low-income communities, particularly those near refineries and roadways. Furthermore, the Proposed Action and alternatives would not result in disproportionately high and adverse human health or environmental impacts on minority or low-income populations.

10.8 Cumulative Impacts

10.8.1 Health, Societal, and Environmental Impacts of Climate Change

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

Gasoline to power light-duty vehicles accounted for around 40% of total petroleum consumption in the United States in 2020.[385] Due to fossil fuel combustion, the transportation sector generates the largest share of total GHG emissions in the United States,[386] and light-duty vehicles account for nearly 60% of transportation sector emissions and 17% of total GHG emissions in the United States.[387] Moreover, the extraction, transport, and refining of crude oil is a significant source of GHG emissions, constituting about 5% of total global GHG emissions.[388]

"Increased fuel efficiency will reduce the amount of petroleum-based fuel consumed and refined domestically, which will decrease the emissions of carbon dioxide and other greenhouse gases that contribute to climate change . . . ." 86 Fed. Reg. at 49,722. These anticipated GHG emissions reductions are necessary to help stave off the worst effects of a climate crisis that is primarily caused by anthropogenic GHG emissions[389] and that is already afflicting our States and Cities. Just this summer,

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[385] United States Energy Information Administration, Gasoline explained: Use of oil (last updated May 26, 2021), https://www.eia.gov/energyexplained/gasoline/use-of-gasoline.php.

[386] United States Energy Information Administration, Energy and the environment explained: Where greenhouse gases come from (last updated May 21, 2021), https://www.eia.gov/energyexplained/energy-and-the- environment/where-greenhouse-gases-come- from.php#:~:text=In%202020%2C%20petroleum%20accounted%20for,total%20annual%20CO2%20emissions ("Over 90 percent of the fuel used for transportation is petroleum based, which includes gasoline and diesel.").

[387] United States Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990- 2019 ES-13, 2-30 (April 2021).

[388] Christian Lowhagen, Chalmers, New study reveals real size of crude oil's carbon footprint (Sept. 28, 2018), https://www.chalmers.se/en/departments/see/news/Pages/Crude-oil-carbon-footprint.aspx.

[389] See Richard P. Allan et al., Climate Change 2021: The Physical Science Basis, Summary for Policymakers, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (V. Masson-Delmotte et al., eds. 2021) (IPCC, Summary for Policymakers).

multiple deadly[390] heatwaves with record-breaking high temperatures ravaged the western United States. The West is also experiencing extreme drought conditions that threaten water security and fuel wildfires that have displaced thousands.[391] Meanwhile hurricanes of historic force swept across the southern and eastern United States—testing energy system resilience and producing record-breaking rainfall and fatal flash floods.[392] These types of impacts have been linked to climate change caused by anthropogenic emissions of GHGs,[393] and they are projected to worsen.[394] As average surface temperatures rise and the intensity and frequency of these types of extreme weather events increases, our States and Cities face direct and compounding challenges to protect the health and welfare of our residents, our economies, and our natural resources.

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“The past six years, including 2020, have been the six warmest years on record,”[395] an already concerning reality only amplified by the Intergovernmental Panel on Climate Change’s (IPCC) warning that “[g]lobal warming of 1.5 [degrees] C and 2 [degrees] C [above pre-industrial averages] will be exceeded during the 21st century unless deep reductions in [carbon dioxide] and other greenhouse gas emissions occur in the coming decades.”[396] See Figure 1. The IPCC has found that GHG emissions from human activities are already responsible for about 1.1[degrees]C of warming since 1850-1900[397] and that “[h]uman influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years.”[398] In other words, the world is getting hotter due to increased concentrations of GHGs in the atmosphere that are “unequivocally caused by human activities.”[399]

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[390] Sergio Olmos and Shawn Hubler, Heat-Related Deaths Increase as Temperatures Rise in the West, N.Y. TIMES (July 9, 2021, updated July 28, 2021), https://www.nytimes.com/2021/07/09/us/heat-wave-deaths.html; Thomas Frank, Heat Wave Death Toll Will Rise with Thorough Count, E&E News (July 23, 2021), https://www.scientificamerican.com/article/heat-wave-death-toll-will-rise-with-thorough-count/; Victoria Bekiempis, Record-breaking US Pacific north-west heatwave killed almost 200 people, THE GUARDIAN (July 8, 2021), https://www.theguardian.com/us-news/2021/jul/08/pacific-northwest-heatwave-deaths.

[391] See e.g., Caroline Vakil, 2,000 people displaced in southern Oregon as wildfires ravage West, THE HILL (July 15, 2021), https://thehill.com/policy/energy-environment/563312-2000-people-displaced-in-southern-oregon-as- wildfires-ravage-west.

[392] See e.g., Jesse McKinley et al., Flooding From Ida Kills Dozens of People in Four States, N.Y. TIMES (Sept. 2, 2021, updated Sept. 15, 2021), https://www.nytimes.com/live/2021/09/02/nyregion/nyc-storm.

[393] See e.g., Tom Di Liberto, Record-breaking June 2021 heatwave impacts the U.S. West, Climate.gov (June 23, 2021), https://climate.gov/print/838931; Sarah Kaplan, How climate change helped make Hurricane Ida one of Louisiana’s worst, WASHINGTON POST (Aug. 30, 2021), https://www.washingtonpost.com/climate- environment/2021/08/29/how-climate-change-helped-make-hurricane-ida-one-louisianas-worst/; Rebecca Lindsey, Preliminary analysis concludes Pacific Northwest heat wave was a 1,000-year event…hopefully, Climate.gov (July 20, 2021), https://www.climate.gov/news-features/event-tracker/preliminary-analysis-concludes-pacific-northwest- heat-wave-was-1000-year.

[394] Id. at SPM-10-11.

[395] World Meteorological Organization, State of the Global Climate 2020 5 (2021).

[396] IPCC, Summary for Policymakers, supra note 28, at SPM-17.

[397] Id. at SPM-5.

[398] Id. at SPM-7.

[399] Id. at SPM-5.

As temperatures rise, threats to public health and the environment in our States and Cities continue to mount. For example, "[w]ith higher temperatures, [hospital] admissions for acute renal failure, appendicitis, dehydration, ischemic stroke, mental health, noninfectious enteritis, and primary diabetes were significantly increased."[400] And "[m]ortality effects are observed even for small differences from seasonal average temperatures."[401] These types of heat-related health and mortality risks are not equally distributed. Socially-vulnerable populations—including children, the elderly, and low income and minority populations—experience greater impacts from higher temperatures.[402] For instance, "the average person of color lives in a census tract with higher summer daytime surface urban heat island (SUHI) intensity than non-Hispanic whites in all but 6 of the 175 largest urbanized areas in the continental United States."[403] "Warmer temperatures [also] contribute to the severity of drought conditions by leading to more precipitation falling as rain rather than snow, faster melting of winter snowpack, greater rates of evaporation, and drier soils."[404] This can result in, among other impacts, the degradation of water security[405] and ecological vulnerabilities.[406] As shown in Figure 2, a significant portion of the western U.S. is currently experiencing extreme or exceptional drought. Drought conditions are particularly severe in California, where nearly 90% of the State is facing at least extreme drought and about 45% of the State is experiencing exceptional drought.[407] The 2021 year-to-date statewide average temperature in California is almost the warmest on record,[408] and precipitation and snowpack levels in the State are well below average.[409] These conditions are impacting the State's water supply at major reservoirs, nearly all of which have far less water than the historical average as of

[400] Toki Sherbakov et al., Ambient temperature and added heat wave effects on hospitalizations in California from 1999 to 2009, 160 Environmental Research 83, 83 (2018); see also Louise Bedsworth et al., California Governor's Office of Planning and Research, Statewide Summary Report. California's Fourth Climate Change Assessment 38 (2018) ("High ambient temperatures have been shown to adversely affect public health via early death (mortality) and illness (morbidity).").

[401] Marcus C. Sarofim et al., U.S. Global Change Research Program, The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment, Chp. 2 44 (2016).

[402] See U.S. Environmental Protection Agency, Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts 32-36 (2021), available at www.epa.gov/cira/social-vulnerability-report; U.S. Global Change Research Program, supra note 41, at 45; Angel Hsu et al., Disproportionate exposure to urban heat island intensity across major U.S. cities, NATURE COMMUNICATIONS 8 (2021), available at https://doi.org/10.1038/s41467-021- 22799-5 ("Currently disadvantaged groups suffer more from greater heat exposure that can further exacerbate existing inequities in health outcomes and associated economic burdens, leaving them with fewer resources to adapt to increasing temperature.").

[403] Hsu, et al., supra note 42, at 2.

[404] Gabriel Petek, California Legislative Analyst's Office, What Can We Learn From How the State Responded to the Last Major Drought? 2 (May 2021).

[405] Public Health, Drought.gov, https://www.drought.gov/sectors/public-health (last visited Sept. 19, 2021).

[406] Shelley D. Crausbay et al., American Meteorological Society, Defining Ecological Drought for the Twenty-First Century 2545 (Dec. 2017).

[407] David Simeral, Western Regional Climate Center, U.S. Drought Monitor, California (September 7, 2021), (released Sept. 9, 2021), available at https://droughtmonitor.unl.edu/data/png/20210907/20210907_ca_trd.png.

[408] Nat'l Oceanic and Atmospheric Admin., Climate at a Glance: Statewide Time Series (Sept. 2021), available at https://www.ncdc.noaa.gov/cag/statewide/rankings/4/tavg/202108.

[409] Nat'l Oceanic and Atmospheric Admin., Percent of Average Precipitation 10/1/2020 – 9/18/2021, https://wrcc.dri.edu/cgi-bin/anomimage.pl?wrcOctPpct.png (last visited Sept. 9, 2021); Cal. Dept. of Water Resources, Statewide Snowpack Well Below Normal as Wet Season Winds Down (Apr. 1, 2021), https://water.ca.gov/News/News-Releases/2021/April-21/Statewide-Snowpack-Well-Below-Normal-as-Wet- Season-Winds-Down.

September 2021.[410] Moreover, "[f]orests are especially vulnerable to drought in a warming world."[411] For example, California's 2012-2015 drought killed more than 100 million trees, mainly in the Sierra Nevada forest.[412] The forest density and warmer temperatures "compound[ed] die-off by an estimated 55%," and "climate change is expected to . . . increas[e] Sierran tree death during drought by [about]15-20%" for each additional degree of warming.[413] And "[w]hen a drought drives changes within ecosystems, there can be a ripple effect through human communities that depend on those ecosystems for critical goods and services."[414]

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Extreme weather events pose innumerable threats to our States and Cities—from increased health risks and death, damage to infrastructure, and water scarcity,[415] to economic damage and impacts to the energy system that "threaten[] more frequent and longer-lasting power outages and fuel shortages."[416] And "[w]ith every additional increment of global warming, changes in extremes continue to become larger."[417] "For example, every additional 0.5[degrees]C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heat waves (very likely), and heavy precipitation (high confidence), as well as agricultural and ecological droughts in some regions (high confidence)."[418] "The proportion of intense tropical cyclones (categories 4-5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming (high confidence)."[419]

Not only are the frequency and intensity of extreme weather events increasing, but so too are the costs. *See* Figure 3. On average, there were 7 extreme weather events per year in the United States between 1980-2020 that cost over $1 billion, with an average annual cost of $45.7 billion; however, over the past 5 years, the average number of events per year increased to 16, with an average annual cost of $121 billion.[420] In 2020—"a historic year of extremes"[421]—"[t]here were 22 separate billion-dollar weather and climate disasters across the United States, shattering the previous annual record of 16 events" and

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[410] Cal. Dept. of Water Resources, Current Reservoir Conditions, https://cdec.water.ca.gov/cgi- progs/products/rescond.pdf (last visited Sept. 19, 2021).

[411] Gavin D. Madakumbura et al., Recent California tree mortality portends future increase in drought-driven forest die-off, 15 ENVIRON. RES. LETT. 1 (2020).

[412] Associated Press, California drought kills more than 102 million trees, raising risk of wildfires, WASHINGTON POST (Nov. 18, 2016), available at https://www.washingtonpost.com/national/california-drought-kills-more-than- 102-million-trees-raising-risk-of-wildfires/2016/11/18/03a37e68-adaf-11e6-977a-1030f822fc35_story.html.

[413] M.L. Goulden and R.C. Bales, California forest die-off linked to multi-year deep soil drying in 2012-2015 drought, 12 NATURE GEOSCIENCE 632, 632 (Aug. 2019).

[414] Crausbay et al., supra note 46, at 2543.

[415] World Meteorological Organization, supra note 35, at 31.

[416] U.S. Global Change Research Program, supra note 41, at 176.

[417] IPCC, Summary for Policymakers, supra note 28, at SPM-19.

[418] Id. at SPM-19.

[419] Id. at SPM-20.

[420] Adam B. Smith, supra note 62.

[421] Id.

"cost[ing] the nation a combined $95 billion in damages."[422] And these costs "do not take into account losses to natural capital or assets, health care related losses, or values associated with loss of life,"[423] meaning these estimates "should be considered conservative."[424]

[See original comment for NOAA bar and line graph of Billion-dollar disaster events in the U.S. between 1980 and 2021]

These costs, which are partially borne by our affected States and Cities, reflect the breadth of impacts and rippling effects of extreme weather events. For example, in 2020, Hurricane Isaias made landfall in North Carolina, producing storm surge inundation levels of 3 to 6 feet above ground level along the southern coast of North Carolina[425] before accelerating up the East Coast. After unleashing 5-8 inches of rainfall across Virginia, Maryland, Delaware, and western New Jersey, causing flooding across those states,[426] the storm's winds cut power to approximately 3.05 million customers—affecting roughly 1.4 million customers in New Jersey, 512,000 in New York, 380,000 in Pennsylvania, 264,000 in Connecticut, 218,000 in Virginia, 134,000 in North Carolina, 76,000 in Maryland, 51,000 in Delaware, 12,000 in Massachusetts, 6,000 in Vermont, and 4,000 in Rhode Island.[427] Hurricane Isaias also spawned 39 confirmed tornadoes from North Carolina to New Jersey[428] and killed a total of 9 people.[429]

More recently, in June 2021, a heat dome described as "virtually impossible without human- caused climate change"[430] descended upon the Pacific Northwest and brought record-shattering temperatures as high as 108[degrees]F in Seattle, Washington, 116[degrees]F in Portland Oregon, and 118[degrees]F in Dallesport, Washington—the highest temperature ever recorded in Washington.[431] The extreme heat not only killed billions of intertidal species along the Pacific Northwest coast,[432] but it also resulted in the

[422] Id.

[423] Nat'l Oceanic and Atmospheric Admin., supra note 66. The estimated costs include physical damage to residential, commercial, and government or municipal buildings; material assets within a building; time element losses like interruption; vehicles and boats; offshore energy platforms; public infrastructure like roads, bridges, and buildings; agricultural assets like crops, livestock, and timber; and disaster restoration and wildfire suppression costs.

[424] Id.

[425] Andy Latto et al., Hurricane Isaias, NOAA National Hurricane Center 8 (June 11, 2021), available at https://www.nhc.noaa.gov/data/tcr/AL092020_Isaias.pdf.

[426] Id.

[427] PowerOutage.us (@PowerOutage_us), Twitter (Aug. 4, 2020 1:19 PM), https://twitter.com/PowerOutage_us/status/1290744180956901379.

[428] Latto, supra note 84, at 10.

[429] Jason Samenow, Millions left in the dark and historic floods: Isaias by the numbers, WASHINGTON POST (Aug. 5, 2020), https://www.washingtonpost.com/weather/2020/08/05/isaias-power-outages/.

[430] Western North American extreme heat virtually impossible without human-caused climate change, World Weather Attribution (Jul. 7, 2021), https://www.worldweatherattribution.org/western-north-american-extreme-heat- virtually-impossible-without-human-caused-climate-change/.

[431] Jason Samenow and Ian Livingston, Canada sets new all-time heat record of 121 degrees amid unprecedented heat wave, WASHINGTON POST (June 29, 2021), https://www.washingtonpost.com/weather/2021/06/27/heat-records- pacific-northwest/.

[432] Stephen Leahy, The Billions of Victims of the Heat Dome, THE ATLANTIC (Jul. 31, 2021), https://www.theatlantic.com/ideas/archive/2021/07/billions-victims-heat-dome/619604/.

confirmed deaths of at least 96 people in Oregon[433] and 112 people in Washington.[434] “Extreme heat is already a leading cause of mortality in the United States, but without adaptation, deaths could increase more than sixfold.”[435] And, as with rising average temperatures, the effects of extreme heat are not evenly distributed: “Black and African American individuals are 40% more likely than non-Black and non-African American individuals to live in areas with the highest projected increases in extreme temperature related mortality with 2[degrees]C of global warming.”[436] “With 4[degrees]C of global warming, this estimate increases to 59%.”[437]

Our States and Cities face mounting threats from a climate crisis that is primarily caused by anthropogenic emissions of GHGs. As the transportation sector accounts for about 29% of the GHG emissions in the United States and is the largest contributing sector to U.S. GHG emissions,[438] we welcome NHTSA’s proposal to tighten fuel economy standards for light-duty vehicles.

Response

NHTSA appreciates the commenters’ summary of climate change impacts and the transportation sector’s contributions to U.S. GHG emissions. This SEIS reflects NHTSA’s careful consideration of the rule’s effect on global climate conditions, including extreme weather events. The impacts reported in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 8, *Cumulative Impacts*, reflect the best available science regarding climate change and its impacts on health, society, and the environment. NHTSA relied primarily on existing expert panel- and peer-reviewed climate change studies and reports when preparing the Draft and Final SEIS. In particular, this SEIS draws primarily on panel-reviewed synthesis and assessment reports from the IPCC and GCRP, supplemented with additional peer-reviewed literature. These reports assess numerous individual studies to draw general conclusions about the potential impacts of climate change, thus providing a hard look at the potential environmental consequences of the final rule.

NHTSA has added information on attribution of the increasing magnitude of extreme weather events to climate change in Final SEIS Section 5.2.2.1, *Climate Change Attributes*. Section 8.6.4.2, *Sectoral Impacts of Climate Change*, also contains multiple sections on the impacts of climate change on human health.

[433] Amelia Templeton and Monica Samayoa, Oregon medical examiner releases names of June heat wave victims, OPB (Aug. 6, 2021), https://www.opb.org/article/2021/08/06/oregon-june-heat-wave-deaths-names-revealed- medical-examiner/.

[434] John Ryan, 2021 heat wave is now the deadliest weather-related event in Washington history, NPR (Jul. 19, 2021), https://www.kuow.org/stories/heat-wave-death-toll-in-washington-state-jumps-to-112-people.

[435] Atlantic Council, Extreme Heat: The Economic and Social Consequences for the United States 8 (Aug. 2021).

[436] EPA, supra note 42, at 35.

[437] Id.

[438] Sources of Greenhouse Gas Emissions, U.S. Environmental Protection Agency, (last updated Jul. 27, 2021), https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#:~:text=Transportation%20(29%20percent%20of%202019,ships%2C%20trains%2C%20and%20planes.

Comment

Docket Number: NHTSA-2021-0054-0013
Organization: California Department of Justice, Office of the Attorney General et al.

Rising temperatures combined with drier conditions are also increasing the risk of wildfires.[439] "[T]he number of hot days is climbing; forests and grasslands are dried out by increased evaporation; the growing season is lengthening (providing available fuel for longer periods); and snowpack is melting earlier."[440] These conditions have significantly enhanced the size of wildfires and length of the wildfire season. "[S]ince 1984, human-induced climate change is responsible for doubling the cumulative area of forest fires across the western United States."[441] "Since the 1970s, the annual average wildfire season in the Western United States has expanded from five months to 8.5 months long."[442] "It now burns six times as many acres and consists of three times as many large fires—those defined as more than 1,000 acres."[443] And "[c]limate models project a continued increase in frequency and intensity of wildfires with rising temperatures."[444]

Consistent with this projection, the 2020 wildfire season was unprecedented. For example, wildfires in Colorado burned more than 665,000 acres—more than in any previous year—and the State's record for largest wildfire was broken twice.[445] Historic wildfires also burned 10.2 million acres across California, Oregon, and Washington.[446] With 4.1 million acres blazed, California more than doubled its previous annual record for area burned.[447] The State also experienced five of the top six largest wildfires on record in 2020[448]—a record already broken in 2021.[449]

These massive wildfires have broad impacts across our States and Cities. The 2020 wildfires— which conservatively cost an estimated $16.5 billion[450]—put 500,000 Oregonians (more than 10% of the state's

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[439] IPCC, Summary for Policymakers, supra note 28, at SPM-33-34; U.S. Global Change Research Program, Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States 241 (D.R. Reidmiller et al. eds., 2018), available at https://nca2018.globalchange.gov/; Zachary A. Holden, et al., Decreasing fire season precipitation increased recent western US forest wildfire activity, 115 PNAS E8349, E8349 (Sept. 4, 2018) ("[D]eclines in summer precipitation and wetting rain days have likely been a primary driver of increases in wildfire area burned.").

[440] Marcy Lowe and Rebecca Marx, Datu Research, Climate Change-Fueled Weather Disasters: Costs to State and Local Economies at 53 (July 2020).

[441] Id.

[442] Id.

[443] Id.

[444] Id. at 54.

[445] John Ingold, Five charts that show where 2020 ranks in Colorado wildfire history, THE COLORADO SUN (Oct. 20, 2020), https://coloradosun.com/2020/10/20/colorado-largest-wildfire-history/.

[446] Adam B. Smith, 2020 U.S. billion-dollar weather and climate disasters in historical context, Climate.gov (Jan. 8, 2021), https://www.climate.gov/print/837056.

[447] Id.

[448] Id.

[449] Hayley Smith, California hit by record-breaking fire destruction: 'Climate change is real, it's bad,' LOS ANGELES TIMES (July 12, 2021), https://www.latimes.com/california/story/2021-07-12/california-wildfires-outpacing-2020- worst-on-record.

[450] Billion-Dollar Disasters: Calculating the Costs, Nat'l Oceanic and Atmospheric Admin., https://www.ncdc.noaa.gov/monitoring-references/dyk/billions-calculations (last visited Sept. 20, 2021).

population) under evacuation warnings or orders,[451] led to the displacement of about 100,000 people in California,[452] and killed 46 people in California, Oregon, and Washington.[453] In the Pacific Northwest, more than 17 million people experienced air quality deemed 'very unhealthy' or 'hazardous' for an average of 4 days,[454] a worrisome statistic given that "wildfire-specific PM2.5 is up to 10 times more harmful on human health than PM2.5 from other sources."[455,456] This public health concern grows as the frequency and intensity of wildfires increase and is not limited to States where the wildfires are burning. The rising heat from the wildfires takes particulate matter and toxic gases in the smoke into the jet stream, which can carry those hazardous substances thousands of miles and cause harmful air pollution across the country. Indeed, during the 2020 wildfire season and again in July of 2021, smoke from wildfires burning on the West Coast caused New York City to experience some of the worst air quality in the world.[457]

Response

NHTSA appreciates the commenter's summary of climate change impacts and the increased risk of wildfires. This Final SEIS reflects NHTSA's careful consideration of the rule's effect on global climate conditions, including extreme weather events.

The impacts reported in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 8, *Cumulative Impacts*, reflect the best available science regarding climate change and its impacts on health, society, and the environment. NHTSA relied primarily on existing expert panel- and peer-reviewed climate change studies and reports when preparing the Draft and Final SEIS. In particular, this SEIS draws primarily on panel-reviewed synthesis and assessment reports from the IPCC and GCRP, supplemented with additional peer-reviewed literature.

NHTSA has added information on attribution of the increasing magnitude of extreme weather events, including wildfires, to climate change in Final SEIS Section 5.2.2.1, *Climate Change Attributes*. NHTSA

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[451] Associated Press, Oregon wildfires: 1 million acres burned; 500,000 people under some level of evacuation order, KPTV (Sept. 11, 2020), https://www.kptv.com/news/oregon-wildfires-1-million-acres-burned-500-000-people- under-some-level-of-evacuation-order/article_e355b7ae-f3cb-11ea-a6ce-93011907052d.html.

[452] World Meteorological Organization, supra note 35, at 36.

[453] Id. at 25.

[454] Audrey Carlsen et al., 1 in 7 Americans Have Experienced Dangerous Air Quality Due to Wildfires This Year, NPR (Sept. 23, 2020), https://www.npr.org/2020/09/23/915723316/1-in-7-americans-have-experienced-dangerous-air-quality-due-to-wildfires-this-ye#:~:text=Environment-
,1%20In%207%20Americans%20Have%20Experienced%20Dangerous,Due%20To%20Wildfires%20This%20Year
&text=Colorado%20State%20University-
,A%20satellite%20image%20shows%20smoke%20and%20some%20of%20the,in%20Western%20states%20on%2 0Sept.

[455] Rosana Aguilera et al., Wildfire smoke impacts respiratory health more than fine particles from other sources: observational evidence from Southern California, NATURE COMMUNICATIONS 3 (Mar. 5, 2021), available at https://doi.org/10.1038/s41467-021-21708-0.

[456] Smoke from wildfires has also been found to exacerbate risks associated with the COVID-19 virus, and one study found that "[t]housands of COVID-19 cases and deaths in California, Oregon, and Washington between March and December 2020 may be attributable to increases in fine particulate air pollution (PM2.5) from wildfire smoke." Karen Feldscher, Link Between Wildfires and COVID cases established, THE HARVARD GAZETTE (Aug. 13, 2021), https://news.harvard.edu/gazette/story/2021/08/wildfire-smoke-linked-to-increase-in-covid-19-cases-and-deaths/.

[457] Oliver Milman, New York air quality among worst in world as haze from western wildfires shrouds city, THE GUARDIAN (Jul. 21, 2021), https://www.theguardian.com/us-news/2021/jul/21/new-york-air-quality-plunges-smoke- west-coast-wildfires.

also includes information on temperature projections in Final SEIS Section 5.2, *Affected Environment*. Section 8.6.4.2, *Sectoral Impacts of Climate Change*, contains multiple sections on the impacts of climate change on human health, while Section 8.6.5.2, *Human Health*, includes information on heat-related hospital admissions, human exposure to heat, and the impacts of wildfire smoke. NHTSA recognizes the public interest in understanding the potential regional impacts of climate change in Section 8.6.4.3, *Regional Impacts of Climate Change*.

10.9 Mitigation

Comment

Docket Number: NHTSA-2021-0053-0059
Organization: Wisconsin Department of Natural Resources

NHTSA should work with EPA to offset any short-term increases in NO_x and VOC emissions associated with the rule.

In addition to addressing climate change, stringent yet technologically feasible and cost effective mobile source emissions standards are critically needed by states to reduce ozone-forming pollutants. Transportation-related emissions are significant contributors to ozone formation in Wisconsin, with the on-road sector responsible for 38% of all NO_x emissions and 17% of VOC emissions.[458] In addition, on-road NO_x and VOC emissions from the upwind states of Illinois and Indiana significantly contribute to Wisconsin's ozone levels. For example, those two states were responsible for approximately 40% of the ozone measured at Wisconsin's Chiwaukee Prairie monitor in 2017, and that percentage is projected to increase.[459] Given limited state authority to control mobile source emissions, Wisconsin, like many states, relies heavily on federal vehicle emissions standards to help attain and maintain the ozone National Ambient Air Quality Standards (NAAQS).

While NHTSA's proposal would result in long-term reductions in NO_x and VOC emissions, it is also anticipated to cause a near-term increase of these pollutants. For example, NHTSA's analysis concludes that VOC and NO_x emissions would increase in Wisconsin ozone nonattainment and maintenance areas under every alternative through 2025, and in many cases through 2035 (see tables 1 and 2, next page). While these emissions increases are relatively small, they would occur as Wisconsin will face critical ozone NAAQS attainment dates; specifically, the 2015 ozone NAAQS moderate area attainment date in 2024 and potentially the 2008 ozone NAAQS severe area attainment date in 2027. Given the many challenges states already face to attain and maintain the ozone NAAQS, any increase in NO_x or VOC emissions due to NHTSA's rule are counter to the already pressing need to further reduce emissions from this sector.

[458] 2017 National Emissions Inventory

[459] See Section 5.4 of WDNR's Attainment Plan for the Wisconsin Portion of the Chicago-Naperville (IL-IN-WI) 2008 ozone NAAQS Serious Nonattainment Area, December 2020, available at: https://dnr.wisconsin.gov/sites/default/files/topic/AirQuality/AttainmentPlanKenosha1212020.pdf.

To address this disbenefit, NHTSA should work with EPA to offset the anticipated short-term increases in NO_x and VOC emissions so that its final rule is at least neutral in its effects on those pollutants. NHTSA offers some potential mitigation measures in its draft supplemental environmental impact statement.[460]

While it notes that EPA could take certain actions to offset these criteria pollutant increases, NHTSA does not indicate whether it plans to work with EPA to explore any of these options, and largely places the burden of implementing any measures on state and local agencies. As a matter of policy, the federal government should be responsible for ensuring proper mitigation of the environmental impacts of its actions. More practically, most state and local air agencies lack the authority to regulate criteria pollutants from light duty vehicles and have a very limited ability to regulate mobile source emissions generally. Therefore, it is important that NHTSA work with EPA to explore how the agencies can use their existing statutory authorities to “net out” any near-term increases in NO_x and VOC emissions associated with this rule.

[See original attachment for Table 1. Estimated changes in NO_x emissions in Wisconsin ozone nonattainment (NA) and maintenance areas for each NHTSA alternative (Alternative 2 is NHTSA’s preferred alternative). Units are tons per year. Source: NHTSA SEIS, App. B.]

[See original attachment for Table 2. Estimated changes in VOC emissions in Wisconsin ozone nonattainment (NA) and maintenance areas for each NHTSA alternative (Alternative 2 is NHTSA’s preferred alternative). Units are tons per year. Source: NHTSA SEIS, App. B.]

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NHTSA should work with EPA to offset any increases in sulfur dioxide (SO_2) emissions associated with the rule.

NHTSA’s proposal estimates that SO_2 emissions will increase over the lifetime of its rule, culminating with a net annual increase of over 1,200 tons per year by 2050. Given that EPA recently concluded a successful, decade-long campaign to reduce SO_2 emissions from stationary sources, it is important that those gains are not subsequently undermined by rules addressing the mobile sector. As with NO_x and VOC emissions, NHTSA should work cooperatively with EPA to ensure that any potential increases in SO_2 emissions are offset in the final rule.

Response

The CEQ regulations implementing NEPA, which are applied to this SEIS, require NHTSA and other federal agencies to include in an EIS a discussion of appropriate mitigation measures.[461] Chapter 9, *Mitigation*, of the Final SEIS discusses mitigation measures for impacts related to NHTSA’s action of setting CAFE standards.[462] As explained in Chapter 9, NEPA does not obligate an agency to adopt a mitigation plan. However, NEPA requires an agency to discuss measures that could be adopted. Chapter 9 accordingly discusses possible measures that could mitigate the effects of NHTSA’s action. These measures include current and future actions that NHTSA or other federal agencies could take.

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[460] See NHTSA’s Draft Supplemental Environmental Impact Statement, Model Year 2024-2026 Corporate Average Fuel Economy Standards, Section 9.2.

[461] 40 CFR § 1502.14(f).

[462] 40 CFR § 1502.16(h).

As noted in Chapter 9, NHTSA does not have jurisdiction to regulate the criteria and toxic air pollutant emissions projected to result from the Proposed Action and alternatives. Consequently, any mitigation measures proposed are necessarily vague, as it is only within the authority of other agencies to implement them.

For example, 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.

While this final rulemaking will result in small short-term increases in criteria pollutants, the impacts of these emissions on air quality will vary from area to area depending on factors such as the composition of the local vehicle fleet and the amount of gasoline produced in the area.

Commenter Wisconsin Department of Natural Resources suggested that by NHTSA not taking certain actions to offset these criteria pollutant increases, NHTSA is largely placing the burden of implementing any measures on state and local agencies. However, it is not within NHTSA's jurisdiction to implement these measures and it lacks the expertise to conduct a full-scale analysis of their efficacy (which would necessarily include the specifics of how they were implemented and with what effect). Moreover, given the diffuse and indeterminate nature of the potential impacts—they are nationwide and, in the case of climate impacts, global—a large range of measures may serve to mitigate adverse impacts, but determining with what certainty and to what effect would require an analysis that only the authorizing agency would be capable of undertaking.

CHAPTER 11 LIST OF PREPARERS AND REVIEWERS

11.1 U.S. Department of Transportation

Table 11.1-1 identifies the preparers, contributors, and reviewers in the U.S. Department of Transportation.

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11.2 Consultant Team

The ICF Team supported NHTSA in preparing its environmental analyses and this SEIS. Table 11.2-1 identifies the consultant team and their contributions.

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	B.S., Meteorology, Lyndon State College B.A., Global Studies, Lyndon State College 10 years of experience in climate change and sustainability analysis
Deanna Lizas, Life-Cycle Assessment Lead and Climate Team	
	M.E.M., Environmental Management, Yale School of Forestry and Environmental Studies B.S., Environmental Science and Sociology, University of Michigan 14 years of experience in climate change, sustainability, and life-cycle materials management and energy analyses
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	M.P.P., Environmental Policy, George Washington University B.A., Government and International Politics, George Mason University 6 years of experience in climate change and sustainability analysis and climate change policy research
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	Ph.D. candidate, Germanic Languages and Literatures, Washington University in St. Louis M.Phil., European Literature, Lincoln College, Oxford University, Oxford, England B.A., Anthropology and German, University of California, Berkeley 15 years of experience in editing and document management
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Claire Phillips, Climate Change Team	
	B.A., Environmental Studies and Government and Legal Studies, Bowdoin College 2 years of experience in environmental research and analysis with a focus on climate
Eliza Puritz, Life-Cycle Assessment and Climate Change Teams	
	M.A., Energy and Environment, Boston University B.A., Environmental Science, Boston University 3 years of experience in climate change and sustainability analysis, and energy, policy, and supply chain research

Ajo Rabemiarisoa, Life-Cycle Assessment Team	
	M.B.A., Environmental Sustainability, Wilmington University B.S., Chemical and Environmental Engineering, McGill University 8 years in the environmental and sustainability field and 2 years of experience building technical support documentation for transportation policies and regulations
Homaira Siddiqui, Life-Cycle Assessment Team	
	M.E.Sc., Green and Environmental Engineering Specialization, Chemical Engineering, Western University, Canada B.E.Sc., Chemical Engineering, Western University, Canada 6 years of experience in emissions quantification, verification, and reduction strategies as well as decarbonization and benchmarking studies
January Tavel, Other Environmental Impacts Team, Historical and Cultural Resources Senior Advisor	
	M.H.P., Historic Preservation, University of Maryland B.A., Journalism, University of Maryland 12 years of experience in the historic preservation field and cultural resources management, Secretary of the Interior qualified professional historian and architectural historian
Claire Trevisan, Climate Change Team	
	B.S., Civil and Environmental Engineering, University of Virginia 2 years of experience in climate change and sustainability analysis
John Venezia, Climate Change Senior Advisor	
	M.S., Environmental Science and Policy, Johns Hopkins University B.S., Biology and Environmental Science and Policy, Duke University 22 years of experience analyzing climate change, greenhouse gas emission sources, and options for reducing emissions, focusing on the energy sector
Jennifer Wheaton, Other Environmental Impacts Team, Historical and Cultural Resources Analyst	
	B.A., Anthropology, Mercyhurst University 8 years of experience in Section 106 and cultural resources analysis as well as NEPA environmental permitting and planning
Carson Young, Climate Change Team	
	B.S., Natural Resource Conservation, University of Florida B.A., Sustainability Studies, University of Florida 2 years of experience in climate change analysis, focusing on natural infrastructure, vulnerability, and risk assessment

CHAPTER 12 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.

12.1 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, Office of Policy
- 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

12.2 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 State Clearinghouse, Office of Planning and Research
- California Department of Justice
- California Office of the Attorney General
- City of Los Angeles, City Attorney's Office
- County of Los Angeles, Public Health
- Connecticut Department of Environmental Protection
- Connecticut Department of Transportation
- Connecticut Office of the Attorney General
- Delaware Department of Justice
- Delaware Office of Management and Budget, Budget Development, Planning, and Administration
- District of Columbia Office of the City Administrator
- District of Columbia Office of the Attorney General

- 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 Office 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
- Maine Office of the Attorney General
- Maryland Department of Planning
- Maryland Department of Transportation
- Maryland State Clearinghouse for Intergovernmental Assistance
- Maryland Office of the Attorney General
- 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
- New York Office of the Attorney General
- North Carolina Department of Environmental Quality
- North Carolina Department of Justice
- North Dakota Department of Commerce
- Oakland City Attorney
- Oregon Department of Environmental Quality
- Oregon Office of the Attorney General
- Oregon Department of Justice, Natural Resources Section
- Pennsylvania Department of Environmental Protection
- Pennsylvania Office of the Attorney General

- Pima County, Department of Environmental Quality
- Puerto Rico Highway and Transportation Authority
- Puerto Rico Planning Board, Federal Proposals Review Office
- Regional Air Pollution Control Agency
- Rhode Island Office 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
- Washington State Office of the Attorney General
- West Virginia Development Office
- Wisconsin Department of Natural Resources

12.3 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 Honorable Ron 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 Kathy Hochul, 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 Glenn Youngkin, 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

12.4 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
- 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
- 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 Arapaho Tribe of the Wind River Reservation, Wyoming
- 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 Creek Indians
- 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
- Santo Domingo Pueblo
- 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

12.5 Manufacturers

- American Honda Motor Company, Inc.
- Aston Martin Lagonda
- BMW of North America, LLC
- BYD Motors, Inc.
- CODA Automotive, Inc.
- Elux Automotive
- 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

12.6 Stakeholders

- 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
- 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)
- ChargePoint, Inc.
- Clean Air Task Force
- Clean Fuel Development Coalition
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Conservation Law Foundation
- Consumer Action
- Consumer Assistance Council of Cape Cod
- Consumer Federation of America
- Consumer Federation of the Southeast
- Consumers for Auto Reliability and Safety
- Consumers Union
- Con-way Inc
- CoPIRG Foundation
- Criterion Economics, L.L.C.
- Crowell Moring
- CSRA
- Dale Kardos & Associates, Inc.
- Dallas Clean Energy LLC
- Dana Holding Corporation
- Defenders of Wildlife
- Ecology Center
- Edison Electric Institute
- Electric Applications Inc.
- Electric Power Research Institute
- Emmett Institute on Climate 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.

- FreedomWorks Foundation
- Friends Committee on National Legislation
- Gibson, Dunn & Crutcher LLP
- Greater Washington Interfaith Power and Light c/o Interfaith Conference of Metropolitan Washington
- Growth Energy
- HayDay Farms, Inc.
- Honeywell Transportation Systems
- ICM
- IdleAir
- Illinois Trucking Association
- Illinois Public Interest Research Group
- Indiana Corn Growers Association
- Indiana University
- Ingevity
- Insurance Institute for Highway Safety
- Institute for Policy Integrity at New York University School of Law
- International Council on Clean Transportation
- Jewish Community Relations Council
- Justice and Witness Ministries
- Kirkland & Ellis LLP
- Manufacturers of Emission Controls Association
- Manufacturers of Emission Controls Association
- Maryknoll Office of Global Concerns
- Maryland Consumer Rights Coalition
- Maryland Public Interest Research Group
- Massachusetts Consumers Council
- Massachusetts Public Interest Research Group
- Mercatus Center, George Mason University
- Metro 4/SESARM
- Michigan Tech University
- Mid-America Regional Council
- 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 (NACAA)
- 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 Conference of State Legislatures
- National Corn Growers Association
- National Council of Churches USA
- National Governors Association
- National Groundwater Association
- National League of Cities
- National Propane Gas Association
- National Wildlife Federation
- Natural Gas Vehicles (NGV) America
- Natural Resources Canada
- Natural Resources Defense Council
- New Jersey Citizen Action
- New Mexico Public Interest Research Group
- New York Corn & Soybean Growers Association
- Northeast Ohio Areawide Coordinating Agency
- Northeast States for Coordinated Air Use Management
- Novation Analytics
- NTEA - The Association for the Work Truck Industry
- NY Public Interest Research Group
- Ozone Transport Commission
- 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
- Resources for the Future
- Road Safe America
- Rocky Mountain Institute

- Rubber Manufacturers Association
- Safe Climate Campaign
- Santa Clara Pueblo
- SaviCorp, Inc.
- Securing America's Future Energy
- Sierra Club
- Socially Responsible Investing
- SUN DAY Campaign
- Susquehanna River Basin Commission
- Teamsters Joint Council 25
- Tetlin Village Council
- The Accord Group
- The Aluminum Association, Inc.
- The Council of State Governments
- The Environmental Council of the States
- The Episcopal Church
- The Hertz Corporation
- The Lee Auto Malls
- The Pew Charitable Trusts
- The Truman National Security Project
- The United Methodist Church General
- TIAX LLC
- Trillium Asset Management Corporation
- Truck Manufacturer's Association
- Tufts University
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- Union for Reform Judaism
- Union of Concerned Scientists
- United Auto Workers
- United Automobile, Aerospace and Agricultural Workers of America (UAW)
- United Church of Christ
- United Steelworkers
- University of Colorado School of Law
- University of Michigan Center for Sustainable Systems
- University of Michigan Transportation Research Institute
- University of Southern California
- US Public Interest Research Group

- Utility Consumers Action Network
- Vermont Public Interest Research Group
- Victims Committee for Recall of Defective Vehicles
- Virginia Citizens Consumer Council
- VNG.CO
- 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

12.7 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. Notification of the availability of this SEIS will also be provided electronically by email to individual commenters who provided an email address.

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CHAPTER 14 REFERENCES

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