Draft Environmental Impact Statement

Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks, Model Years 2027–2032, and Fuel Efficiency Standards for Heavy-Duty Pickup Trucks and Vans, Model Years 2030–2035

July 2023

U.S. Department of Transportation

National Highway Traffic Safety Administration

NHTSA

Draft Environmental Impact Statement for Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks, Model Years 2027–2032, and Fuel Efficiency Standards for Heavy-Duty Pickup Trucks and Vans, Model Years 2030–2035

Lead Agency

National Highway Traffic Safety Administration (NHTSA)

Cooperating Agencies

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

Overview

This Draft Environmental Impact Statement (Draft EIS) analyzes the environmental impacts of fuel economy standards and reasonable alternative standards for model year (MY) 2027–2032 passenger cars and light trucks and new fuel efficiency (FE) standards for MY 2030–2035 heavy-duty pickup trucks and vans. NHTSA is proposing these new Corporate Average Fuel Economy (CAFE) and heavy-duty pickup trucks and vans (HDPUV) FE standards under the Energy Policy and Conservation Act of 1975, as amended by the Energy Independence and Security Act of 2007. Environmental impacts analyzed in this Draft EIS include those related to fuel and energy use, air quality, and climate change. In developing the proposed CAFE 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). In developing the proposed HDPUV FE standards, NHTSA sought to achieve the maximum feasible improvement in fuel efficiency, accounting for technological feasibility, appropriateness, and cost effectiveness, including relevant environmental and safety considerations.

Public Comment Period

EPA will publish a Notice of Availability of this Draft EIS in the *Federal Register*, including the date by which comments must be received. Additionally, NHTSA will publish the public comment period end date on its website at https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy. To submit comments electronically, go to http://www.regulations.gov and follow the online instructions for submitting comments. File comments in Docket No. NHTSA-2022-0075. If sending by mail, send an original and two copies of comments to Docket Management Facility, M-30, U.S. Department of Transportation, West Building, Ground Floor, Room W12-140, 1200 New Jersey Avenue, SE, Washington, DC 20590. You must reference Docket No. NHTSA-2022-0075. Comments may also be submitted by fax to (202) 493-2251. Any announcements about public hearings will be made on the NHTSA website and in a *Federal Register* notice.

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

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Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
$\mu g/m^3$	micrograms per cubic meter
ABS	auto body sheet
AC	air conditioning
ACC	Advanced Clean Car
ACS	American Cancer Society
ACT	Advanced Clean Trucks
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
BIL	Bipartisan Infrastructure Law
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
CFRP	carbon fiber reinforced plastic
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CO2SYS	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
E.O.	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
FCAB	Federal Consortium for Advanced Batteries
FCEV	fuel cell electric vehicle
FCV	fuel cell vehicle
FE	fuel efficiency
FHWA	Federal Highway Administration
FR	Federal Register
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
GFRP	glass fiber reinforced plastic
GGE	gasoline gallon equivalents
GHG	greenhouse gas
GIS	geographic information system
GJ	gigajoule
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GSL	general service lamp
Gt	gigaton
GWP	global warming potential
HD	heavy-duty
HDPUV	heavy-duty pickup trucks and vans
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 WGI AR6	IPCC Working Group 1 Sixth Assessment Report Summary for Policymakers
IRA	Inflation Reduction Act
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
JRC	Joint Research Centre
kg	kilogram
km^2	kilometers squared
kt	kilotonne
kWh	kilowatt-hour
LABs	lead-acid batteries
LCA	life-cycle assessment
LD	light-duty
LFP	lithium iron phosphate
LMO	lithium manganese oxide
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
MJ	megajoule
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
NASA	National Aeronautics and Space Administration
NCA	National Climate Assessment

NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NHTSA	National Highway Traffic Safety Administration
Ni-MH	nickel-metal hydride
NMC	lithium nickel manganese cobalt oxide
NMP	N-Methyl-2-Pyrrolidone
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
NTP	National Toxicology Program
O_3e	ozone equivalent
objECTS	Object-Oriented Energy, Climate, and Technology Systems
ODS	Ozone-Depleting Substance
OECD	Organisation for Economic Cooperation and Development
OSPW	oil sands process-affected water
PEV	plug-in electric vehicle
pH	potential of hydrogen
PHEV	plug-in hybrid electric vehicle
PHMSA	Pipeline and Hazardous Materials Safety Administration
PM	particulate matter
PM10	particulate matter 10 microns or less in diameter
PM2.5	particulate matter 2.5 microns or less in diameter
ppm	parts per million
PRIA	Preliminary Regulatory Impact Analysis
PV	photovoltaic
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
SMR	steam methane reforming
SO_2	sulfur dioxide
SO_2e	sulfur dioxide equivalent
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
U.S.C.	U.S. Code
UV	ultraviolet
VMT	vehicle miles traveled
VOCs	volatile organic compounds
Volpe	Volpe National Transportation Systems Center
VRFBs	Vanadium redox flow batteries
W/m^2	watts per square meter
WGI	Working Group 1
WRI	World Resources Institute
ZEV	zero-emission vehicle

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.
CAFE standard action alternatives	NHTSA's four proposed action alternatives to set MY 2027–2032 CAFE standards for passenger cars and light trucks. The MY 2032 CAFE standards are "augural," in that they fall beyond the statutory 5-model-year period set out in 49 U.S.C. 32902, and thus represent what the agency would propose, based on current information. NHTSA will not be finalizing MY 2032 standards as part of this rulemaking effort.
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.

Term	Definition
coordinated rulemaking	Joint rulemaking that addresses both fuel economy standards (NHTSA) and greenhouse gas emissions standards (EPA).
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. 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.
HDPUV FE standard action alternatives	NHTSA's three proposed alternatives to set fuel efficiency standards for MY 2030–2035 heavy-duty pickup trucks and vans.
heat rate	The amount of energy (Btus) used to generate one kilowatt-hour of electricity
heavy-duty pickup trucks and vans (HDPUV)	Pickup trucks and vans with a gross vehicle weight rating (GVWR) between 8,501 pounds and 14,000 pounds (also referred to in the industry as Class 2b through 3 vehicles) and any vehicle outside of this GVWR range that manufacturers choose to certify as an HDPUV under 49 CFR 523.7(b) or (c).
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.

Term	Definition
No-Action Alternative	Assumes that no action would be taken and provides the analytical baseline against which to compare the environmental impacts of the CAFE standard and HDPUV FE standard action alternatives. When used singularly, it refers to either the CAFE No-Action Alternative or the HDPUV FE No-Action Alternative.
No-Action Alternatives	Refers to the CAFE No-Action Alternative and the HDPUV FE No-Action Alternative combined into a single dataset.
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).
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.
Proposed Action and alternatives	Includes the CAFE standards, HDPUV FE standards, and all action alternatives for both sets of standards.
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.

Term	Definition
vanadium redox flow battery (VRFB)	Emerging battery technology in which energy is stored in an electrolyte, which is replenished during charging, thereby accelerating the recharge rate relative to existing battery technologies.
vehicle mass reduction	A means of increasing fuel efficiency by reducing vehicle weight (e.g., laser welding, hydroforming, tailor-welded blanks, aluminum casting and extrusion), and substituting lighter-weight materials for heavier materials.
vehicle miles traveled (VMT)	Total number of miles driven, typically reported annually.

SUMMARY

Foreword

The National Highway Traffic Safety Administration (NHTSA) prepared this environmental impact statement (EIS) to analyze and disclose (1) the potential environmental impacts of the Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks for model years (MYs) 2027 to 2032, (2) the potential environmental impacts of the fuel efficiency (FE) standards for heavy-duty (HD) pickup trucks and vans (HDPUVs) for MYs 2030 to 2035, and (3) the cumulative impacts of the Proposed Action and alternatives that reflect the cumulative or combined impact of the two sets of standards that are being proposed by NHTSA in its proposed rule. 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 EIS compares the potential environmental impacts of the No-Action Alternative and four action alternatives for setting fuel economy standards for MY 2027–2032 passenger cars and light trucks and the No-Action Alternative and three action alternatives for setting FE standards for MYs 2030–2035 for HDPUVs. This EIS analyzes the direct, indirect, and cumulative impacts of each CAFE and HDPUV action alternative relative to the impacts of each relevant No-Action Alternative.

Background

The Energy Policy and Conservation Act of 1975 (EPCA) mandates 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.

To inform its development of the new CAFE standards and HDPUV FE standards and pursuant to NEPA,[2] NHTSA prepared this EIS to evaluate the potential environmental impacts of a reasonable range of alternatives the agency is considering for MY 2027–2032 CAFE standards and a reasonable range of alternatives NHTSA is considering for MY 2030–2035 HDPUV FE standards. 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).[3] This EIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of alternatives for both CAFE standards and HDPUV standards, including a No-Action Alternative and a Preferred Alternative for each

[1] The CEQ NEPA implementing regulations are codified at 40 Code of Federal Regulations [CFR] Parts 1500–1508; 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.

[2] 42 U.S.C. 4321–4347.

[3] 42 U.S.C. 4332.

set of standards. This EIS analyzes direct, indirect, and cumulative impacts, and discusses impacts in proportion to their significance.

Purpose and Need for the Action

In accordance with EPCA, as amended by EISA, the first purpose of NHTSA's rulemaking is to set fuel economy standards for MY 2027–2032 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."[4] 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.

NHTSA must establish separate average fuel economy standards for passenger cars and light trucks for each model year.[5] Standards must be "based on [one] or more vehicle attributes related to fuel economy" and "express[ed]…in the form of a mathematical function."[6]

In accordance with EPCA/EISA, the second purpose of this rulemaking is to set MY 2030–2035 HDPUV FE standards that are "designed to achieve the maximum feasible improvement."[7] These new HDPUV FE standards will build on the success of the Phase 1 and Phase 2 HD Fuel Efficiency Improvement Programs in furtherance of EPCA's goals of energy independence and security, as well as improving environmental outcomes and national security.

When establishing standards to improve the fuel efficiency of HD vehicles, EISA requires that NHTSA "adopt and implement appropriate test methods, measurement metrics, fuel economy standards,[8] and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for [HD vehicles]."[9]

Proposed Action and Alternatives

NHTSA's action is a rulemaking to set fuel economy standards for passenger cars and light trucks and FE standards for HDPUVs in accordance with EPCA, as amended by EISA. NHTSA has selected a reasonable range of alternatives within which to set CAFE standards and HDPUV FE standards and to evaluate the

[4] 49 U.S.C. 32902(a).

[5] 49 U.S.C. 32902(b)(1)-(2).

[6] 49 U.S.C. 32902(b)(3)(A).

[7] 49 U.S.C. 32902(k)(2).

[8] In the Phase 1 HD Fuel Efficiency Improvement Program rulemaking, NHTSA, aided by the National Academies of Sciences report, assessed potential metrics for evaluating fuel efficiency. NHTSA found that fuel economy would not be an appropriate metric for HD vehicles. Instead, NHTSA chose a metric that considers the amount of fuel consumed when moving a ton of freight (i.e., performing work). As explained in the Phase 2 HD Fuel Efficiency Improvement Program Final Rule, this metric, delegated by Congress to NHTSA to formulate, is not precluded by the text of the statute. The agency concluded that it is a reasonable way by which to measure fuel efficiency for a program designed to reduce fuel consumption. Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2; Final Rule, 81 FR 73478, 73520 (Oct. 25, 2016).

[9] 49 U.S.C. 32902(k)(2).

potential environmental impacts of the CAFE standards and alternatives and HDPUV FE standards and alternatives under NEPA. NHTSA is establishing CAFE standards for MY 2027–2032 passenger cars and light trucks and FE standards for MY 2030–2035 HDPUVs.

CAFE No-Action and Action Alternatives

The CAFE No-Action Alternative assumes that the national CAFE and greenhouse gas (GHG) MY 2026 standards finalized in 2022 continue in perpetuity. The No-Action Alternative represents a lower bound of CAFE stringency that NHTSA can consider and provides an analytical baseline against which to compare the environmental impacts of the other alternatives presented in the EIS.

NHTSA has analyzed a range of CAFE action alternatives with fuel economy stringencies that increase annually, on average, 1 percent to 6 percent from the MY 2026 standards for passenger cars and increase, on average, 3 percent to 8 percent for light trucks. This range of the No-Action Alternative and action alternatives 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.

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

Alt. PC1LT3[10] 1 percent increase per year, year over year for MY 2027–2032 passenger cars, and 3 percent per year, year over year for MY 2027–2032 light trucks

Alt. PC2LT4 2 percent increase per year, year over year for MY 2027–2032 passenger cars, and 4 percent per year, year over year for MY 2027–2032 light trucks (Alternative PC2LT4 is NHTSA's Preferred Alternative)

Alt. PC3LT5 3 percent increase per year, year over year for MY 2027–2032 passenger cars, and 5 percent per year, year over year for MY 2027–2032 light trucks

Alt. PC6LT8 6 percent increase per year, year over year for MY 2027–2032 passenger cars, and 8 percent per year, year over year for MY 2027–2032 light trucks

Table S-1 shows the estimated average required fleet-wide fuel economy forecasts by model year for each alternative.

[10] The abbreviation PC1LT3 is meant to reflect a 1 percent increase for passenger cars and a 3 percent increase for light trucks, including SUVs. The abbreviation for each CAFE action alternative uses the same naming convention.

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	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
2027	46.72	47.87	48.39	48.92	50.47
2028	46.68	49.08	50.12	51.17	54.50
2029	46.66	50.32	51.88	53.54	58.91
2030	46.68	51.62	53.78	56.07	63.70
2031	46.73	52.96	55.73	58.72	68.88
2032	46.74	54.30	57.74	61.48	74.45

Notes:
mpg = miles per gallon

The range of alternatives under consideration encompasses a spectrum of possible standards that NHTSA could select based on how it weighs EPCA's four statutory factors. These alternatives reflect differences in the degree of technology adoption across the fleet, costs to manufacturers and consumers, and conservation of oil and related reductions in GHG emissions. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the projected environmental effects of points that fall between the individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers the ability to select from a wide range of alternatives that begin with the No-Action Alternative and that increase up to 6 percent for passenger cars and up to 8 percent for light trucks. Within this range, stringencies could remain the same or differ year to year between and among regulatory classes.

As noted in the preamble to the proposed rule, NHTSA has tentatively determined that Alternative PC2LT4 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 has tentatively determined that Alternative PC2LT4 is maximum feasible for MYs 2027–2032 and is the Preferred Alternative.

HDPUV No-Action and Action Alternatives

The HDPUV No-Action Alternative assumes that the MY 2027 HDPUV FE standards finalized in the Phase 2 program continue in perpetuity. The No-Action Alternative represents a lower bound of fuel efficiency stringency that NHTSA can consider and provides an analytical baseline against which to compare the environmental impacts of the other alternatives presented in the EIS.

NHTSA has analyzed a range of HDPUV FE action alternatives with FE stringencies that increase annually, on average, 4 percent to 14 percent from the MY 2027 HDPUV FE standards finalized in the Phase 2 program. This range of No-Action Alternative and action alternatives encompass a spectrum of possible standards that, based on the different ways the agency could weigh EISA's requirements, encompass the maximum feasible improvement of FE stringency.

Throughout this EIS, potential impacts are shown for three HDPUV FE standard action alternatives that illustrate the following range of estimated average annual percentage increases in fuel efficiency for HDPUVs.

Alt. HDPUV4[11] 4 percent increase per year, year over year for MY 2030–2035 HDPUVs

Alt. HDPUV10 10 percent increase per year, year over year for MY 2030–2035 HDPUVs (Alternative HDPUV10 is NHTSA's Preferred Alternative)

Alt. HDPUV14 14 percent increase per year, year over year for MY 2030–2035 HDPUVs

Table S-2 shows the estimated average required fleet-wide fuel efficiency forecasts by model year for each alternative.

Table S-2. Projected Average Required Fleet-Wide Fuel Efficiency (gallons per 100 miles) for Heavy-Duty Pickup Trucks and Vans by Model Year and Alternative

Model Year	No-Action	HDPUV4	HDPUV10	HDPUV14
2030	4.93	4.54	3.99	3.64
2031	5.01	4.43	3.64	3.14
2032	5.01	4.25	3.28	2.70
2033	4.96	4.05	2.92	2.30
2034	4.96	3.88	2.63	1.98
2035	4.96	3.73	2.37	1.70

NHTSA reasonably believes the maximum feasible improvement falls within the range of alternatives presented in this EIS. This range encompasses a spectrum of possible standards that NHTSA could select that would satisfy EISA's requirements of increasing the fuel efficiency of HDPUVs. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the environmental impacts of points that fall between those individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers with the ability to select from a wide range of potential alternatives that begin with the No-Action Alternative and that increase up to 14 percent for HDPUVs. Within this range, stringency could remain the same or differ year to year.

As noted in the preamble to the proposed rule, NHTSA has tentatively determined that Alternative HDPUV10 is appropriate, cost-effective, and technologically feasible. NHTSA has tentatively determined that Alternative HDPUV10 is maximum feasible for MYs 2030–2035 and is the Preferred Alternative.

Environmental Consequences

This section describes how the CAFE and HDPUV FE standard No-Action Alternatives and action alternatives could affect energy use, air quality, and climate, as reported in Chapter 3, *Energy*; Chapter 4, *Air Quality*; and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, of this EIS, respectively. Air quality and climate impacts are reported for the entire light-duty (LD) vehicle fleet (passenger cars and light trucks combined) and the entire HDPUV fleet; results are reported separately for passenger cars and light trucks in Appendix A, *Modeling Results Reported Separately by Vehicle Class*. No quantifiable, alternative-specific impacts were identified for the other resource areas discussed in Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*, Chapter 7, *Environmental Justice*, and

[11] The abbreviation HDPUV4 is meant to reflect a 4 percent increase for HDPUVs. The abbreviation for each HDPUV action alternative uses the same naming convention.

Chapter 8, *Historic and Cultural Resources;* however, these resource areas are summarized at a high level here and not included in the detailed discussion of impacts below.

Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials,* describes the life-cycle environmental implications related to the vehicle cycle phase considering the materials and technologies (e.g., batteries) that NHTSA forecasts vehicle manufacturers might use to comply with the CAFE and HDPUV FE standards. The chapter discusses the impacts related to raw material extraction for materials used for vehicle manufacture, material processing for materials used for vehicle manufacture, component manufacture and vehicle assembly, and vehicle end of life (i.e., disposal and recycling). It also discusses potential opportunities for reductions in environmental impacts in the production and end-of-life vehicle life-cycle phases. NHTSA concludes that manufacturers can choose how to respond to the proposed standards and, depending on vehicle manufacturers' responses in using the various materials or technologies, impacts would vary. As discussed in Chapter 6, Section 6.1, *Introduction,* NHTSA does not know how manufacturers will rely on the different materials or technologies assessed in Chapter 6 and fuel sources assessed in Chapter 3, *Energy*, and as a result, cannot quantitatively distinguish between action alternatives. Chapter 6 further concludes that the magnitude of life-cycle GHG impacts associated with materials and technologies is small in comparison with the emissions reductions from avoided fuel consumption during vehicle use.

Chapter 7, *Environmental Justice,* qualitatively describes potential disproportionate impacts on low-income and minority populations. NHTSA has determined that the Proposed Action and alternatives would not result in disproportionately high and adverse human health or environmental effects on minority or low-income populations. The proposed rule would set 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 disproportionately high and adverse. Indeed, the reduction of air pollutants and GHGs could result in improvements in air quality, decreases in total health effects, and a reduction in the number and severity of outbreaks of vector-borne illnesses for minority and low-income communities.

Chapter 8, *Historic and Cultural Resources*, qualitatively describes potential impacts on historic and cultural resources. The Proposed Action and alternatives would not result in significant impacts on historic and cultural resources. 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 or sacred site or object. Metals critical to energy transition from gas-powered vehicles to electric vehicles (EVs) including copper, nickel, cobalt, and lithium may be located within or near areas of cultural and environmental importance to Native Americans. To the extent that other Federal agencies are involved in permitting mining actions, those agencies would be required to follow laws and procedures outlined in Chapter 8, Section 8.1, *Affected Environment*, which requires steps for Native American voices and perspectives to be solicited and considered during decision-making and planning for mining projects.

Direct, Indirect, and Cumulative Impacts

The potential impacts on energy use, air quality, and climate include *direct*, *indirect*, and *cumulative impacts.*[12] Direct impacts occur at the same time and place as the action. Indirect impacts occur later in time and/or are farther removed in distance. Cumulative impacts are the incremental direct and indirect impacts resulting from the action added to those of other past, present, and reasonably foreseeable future actions.

To derive the direct and indirect impacts of the action alternatives, NHTSA compares each CAFE and HDPUV FE action alternative to the relevant No-Action Alternative, which reflects baseline trends that would be expected in the absence of any regulatory action by NHTSA as discussed above. Because EPCA, as amended by EISA, requires NHTSA to set CAFE standards and FE standards for each model year, environmental impacts would also depend on future standards established by NHTSA but cannot be quantified at this time.

Cumulative impacts are effects on the environment that result from the incremental effects of the action when added to the effects of other past, present, and reasonably foreseeable 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. The other actions that contribute to cumulative impacts can vary by resource and are noted accordingly 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.

Four CAFE and HDPUV FE alternative combinations were considered for the cumulative impacts analysis: CAFE No-Action Alternative and HDPUV No-Action Alternative (No-Action Alternatives), Alternatives PC1LT3 and HDPUV4 (the lowest stringency CAFE and HDPUV FE alternatives), Alternatives PC2LT4 and HDPUV10 (the Preferred CAFE and HDPUV FE alternatives), and Alternatives PC6LT8 and HDPUV14 (the highest stringency CAFE and HDPUV FE alternatives). The specific combinations were chosen to present the full range of cumulative impacts of the two sets of standards that NHTSA is proposing in this rulemaking. The impacts of CAFE and HDPUV FE standards are integrated for the cumulative impacts analysis as their enforcement periods would concurrently intersect, resulting in a cumulative effect.

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 from the increase in imports, largely for use in the transportation sector.

[12] 40 CFR 1508.1(g).

Petroleum is by far the largest source of energy used in the transportation sector, and transportation accounts for the largest share of total U.S. petroleum consumption. In 2021, the transportation sector accounted for 78.8 percent of total U.S. petroleum consumption. In 2050, transportation is expected to account for 79.1 percent of total U.S. petroleum consumption.[13]

With transportation expected to account for 79.1 percent of total petroleum consumption, U.S. net petroleum imports in 2050 are expected to result primarily from fuel consumption by LD and HD vehicles. The United States became a net energy exporter in 2019[14] for the first time in 67 years because improvements in vehicle fuel economy, combined with increases in U.S. petroleum production, have substantially reduced U.S. oil imports, resulting in declining net petroleum imports.

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

Other sources of energy used in the transportation sector include electricity, diesel and biofuels, natural gas, and hydrogen.

- **Electricity.** Electricity currently makes up 0.2 percent of LD vehicle and commercial light truck fuel use, but the CAFE Model projects this proportion to increase to 33.9 percent across all LD vehicles by 2050, representing the largest share of fuel consumption outside of gasoline. For HDPUVs, electricity currently makes up 0.1 percent of fuel use and is projected to increase to 25.5 percent by 2050.
- **Diesel.** Diesel currently makes up 0.5 percent of fuel consumption for LD vehicles and commercial light trucks and the CAFE Model projects this proportion to decrease to 0.1 percent by 2050. For HDPUVs, diesel makes up 44.3 percent of current fuel consumption but is expected to decrease to 5 percent by 2050.
- **Natural gas.** Natural gas currently makes up 0.02 percent of fuel consumption for LD vehicles and commercial light trucks. For HDPUVs, natural gas accounts for less than 3 percent of fuel use. Natural gas as a transportation fuel is expected to grow 4.7 percent by 2050.
- **Hydrogen.** LD fuel cell vehicle hydrogen consumption is less than 0.01 percent of total LD and HDPUV fuel consumption. According to AEO (2022), hydrogen is projected from 2022 to grow 9.6 percent as a transportation fuel by 2050 (EIA 2022a).

Direct and Indirect Impacts

To calculate the impacts on fuel use for each action alternative, NHTSA subtracted projected fuel consumption under the relevant No-Action Alternative from the level under each action alternative. As the alternatives increase in stringency, total fuel consumption decreases. Table S-3 and Table S-4 show total 2022 to 2050 fuel consumption for each alternative and the direct and indirect fuel use impacts for each action alternative compared with the relevant No-Action Alternative through 2050. NHTSA used

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

[14] https://www.eia.gov/energyexplained/us-energy-facts/imports-and-exports.php.

2050 as the end year for its analysis because it is the year by which nearly the entire U.S. vehicle fleet will be composed of MY 2027–2032 or later LD vehicles and MY 2030–2035 HDPUV vehicles. These tables report total 2022 to 2050 fuel consumption in gasoline gallon equivalents (GGE) for diesel, gasoline, electricity, hydrogen, and biofuel for cars, light trucks, and HDPUVs. Gasoline is expected to account for 65.9 percent of energy consumption by passenger cars, light trucks, and HDPUVs in 2050.

Table S-3. Fuel Consumption and Decrease in Fuel Consumption by CAFE Standards Alternative (billion gasoline gallon equivalent total for calendar years 2022–2050)

	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Fuel Consumption					
Cars	804	797	796	793	767
Light trucks	1,957	1,947	1,932	1,895	1,782
All light-duty vehicles	2,761	2,744	2,727	2,688	2,548
Decrease in Fuel Use Compared to the No-Action Alternative					
Cars		-7 (-1%)	-8 (-1%)	-11 (-1%)	-37 (-5%)
Light trucks		-9 (0%)	-25 (-1%)	-62 (-3%)	-175 (-9%)
All light-duty vehicles		-17 (-1%)	-34 (-1%)	-73 (-3%)	-212 (-8%)

Note:
CAFE = Corporate Average Fuel Economy

Total LD vehicle fuel consumption from 2022 to 2050 under the CAFE No-Action Alternative is projected to be 2,761 billion GGE. LD vehicle fuel consumption from 2022 to 2050 under the Proposed Action and alternatives is projected to range from 2,744 billion GGE under Alternative PC1LT3 to 2,548 billion GGE under Alternative PC6LT8. All of the action alternatives would decrease fuel consumption compared to the No-Action Alternative, with fuel consumption decreases that range from 17 billion GGE under Alternative PC1LT3 to 212 billion GGE under Alternative PC6LT8.

Table S-4. Fuel Consumption and Decrease in Fuel Consumption by HDPUV FE Standards Alternative (billion gasoline gallon equivalent total for calendar years 2022–2050)

	No-Action	HDPUV4	HDPUV10	HDPUV14
Fuel Consumption				
HD Pickup Trucks and Vans	412.2	412.1	410.3	403.3
Decrease in Fuel Use Compared to the No-Action Alternative				
HD Pickup Trucks and Vans		-0.1 (0%)	-1.9 (0%)	-8.9 (-2%)

Notes:
FE = fuel efficiency; HD = heavy-duty; HDPUV = heavy-duty pickup trucks and vans

Total HDPUV fuel consumption from 2022 to 2050 under the HDPUV No-Action Alternative is projected to be 412.2 billion GGE. HDPUV fuel consumption from 2022 to 2050 under the action alternatives is projected to range from 412.1 billion GGE under Alternative HDPUV4 to 403.3 billion GGE under Alternative HDPUV14. All of the action alternatives would decrease fuel consumption compared to the No-Action Alternative, with decreases ranging from 0.1 billion GGE under Alternative HDPUV4 to 8.9 billion GGE under Alternative HDPUV14.

Cumulative Impacts

Changes in passenger travel, oil and gas exploration, global EV market projections, and EV 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 plug-in electric vehicles (PEV) technologies and manufacturing in response to government mandates (including foreign PEV quotas) may affect market trends and energy use.

Changing CAFE and HDPUV FE standards are expected to reduce gasoline and diesel fuel use in the transportation sector, but are not expected to have any discernable effect on oil and gas consumption by other sectors of the U.S. economy because petroleum products account for a very small share of energy use in other sectors. Depending on how manufacturers respond to CAFE standards and HDPUV FE standards, cumulative effects could occur in other energy source sectors, such as the electricity sector. For example, the timing of EV charging can affect the profitability of renewable energy sources: daytime charging favors solar, while nighttime charging benefits wind energy. Additionally, increased electricity demand could lead to higher prices, fuel switching in other sectors, increased natural gas usage and emissions, and reduced operations in refineries and biofuel production.

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 (CAA) 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, 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 CAA 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. As noted in Chapter 4, *Air Quality*, in 2021, on-road mobile sources were responsible for emitting 15.1 million tons[15] per year of CO (30 percent of total U.S. emissions), 79,000 tons per year (2 percent) of PM2.5, and 206,000 tons per year (1 percent) of PM10. In 2023, passenger cars and light trucks are estimated to contribute 86 percent of U.S. highway emissions of CO, 57 percent of highway emissions of PM2.5, and 65 percent of highway emissions of PM10. In 2023, HDPUVs are estimated to contribute 11 percent of highway emissions of CO, 8 percent of highway emissions of PM2.5, and 8 percent of highway emissions of PM10. Almost all of the PM in motor vehicle exhaust is PM2.5; therefore, this analysis focuses on PM2.5 rather than PM10. In 2021, on-road mobile sources also emitted 1.0 million tons per year (8 percent of total U.S. emissions) of VOCs and 2.2 million tons per year (29 percent) of NO_X, which are chemical precursors of ozone. In 2023, passenger cars and light trucks are estimated to emit 81 percent of U.S. highway emissions of VOCs and 49 percent of NO_X, and HDPUVs are estimated to contribute 11 percent of U.S. highway emissions of VOCs and 9 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 are important because they contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 1 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

NHTSA uses the CAFE Compliance and Effects Modeling System (the CAFE Model) to estimate manufacturers' potential responses to new CAFE, CO_2, and HDPUV FE standards and to estimate various impacts of those responses. DOT's Volpe National Transportation Systems Center develops, maintains, and applies the model for NHTSA. The basic design of the CAFE Model is as follows: the system first estimates how vehicle manufacturers might respond to a given regulatory scenario, and from that potential compliance solution, the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. NHTSA also uses EPA's Motor Vehicle Emissions Simulator (MOVES) model to estimate "downstream" (tailpipe exhaust) emission factors, and uses Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model to estimate emissions rates from fuel production and distribution processes ("upstream emissions").

To analyze air quality and human health impacts, NHTSA used the CAFE Model to calculate the emissions of criteria pollutants and MSATs from passenger cars, light trucks, and HDPUVs 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

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

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 EIS provides findings for air quality impacts for 2035 and 2050. In 2035, emissions of NO_X, PM2.5, and SO_2 increase, and emissions of CO and VOCs decrease, under all CAFE standard action alternatives compared to the CAFE No-Action Alternative. In 2050, emissions of NO_X and SO_2 increase under some CAFE standard action alternatives and decrease under others, while emissions of PM2.5, CO, and VOCs decrease under all CAFE standard action alternatives, compared to the CAFE No-Action Alternative. In 2035, emissions of NO_X, PM2.5, and SO_2 increase under the HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, while emissions of CO and VOCs decrease. In 2050, emissions of NO_X and SO_2 increase, and emissions of CO, PM2.5, and VOCs decrease, under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative.

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 PEVs after 2035); the relative proportions of gasoline, diesel, and other fuels in total fuel consumption changes; 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 Section II of the proposed rule preamble, Chapter 2 of the Technical Support Document, and Chapter 4 of the Preliminary Regulatory Impact Analysis issued concurrently with the EIS, 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,[16] then emissions would be lower; if NHTSA has underestimated the rebound effect, then emissions would be higher. In addition, in 2035 and 2050, the CAFE standard action alternatives would result in decreased incidence (or no substantial increased incidence) of PM2.5-related adverse health impacts, and the HDPUV FE standard action alternatives would result in unchanged or decreased incidence of those impacts. Decreases in adverse health outcomes include decreased incidences of premature mortality, acute bronchitis, respiratory emergency room visits, and work-loss days, due to decreases in downstream emissions particularly for PM2.5.

<u>Direct and Indirect Impacts</u>

Criteria Pollutants

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

- In 2035, emissions of NO_X, PM2.5, and SO_2 do not increase substantially under any of the CAFE standard action alternatives. Further, modeled increases were very small relative to reductions from the historical levels represented in the current CAFE standard. Relative to the No-Action Alternative, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 get larger from

[16] The increase in vehicle use that results from improved fuel economy.

Alternative PC1LT3 through Alternative PC6LT8 (the most stringent alternative in terms of estimated required miles per gallon). For CO and VOCs, the emissions decreases in 2035 get larger from Alternative PC1LT3 through Alternative PC6LT8 relative to the No-Action Alternative.

- In 2050, emissions of NO_X and SO_2 marginally increase under some CAFE standard action alternatives and decrease under others, compared to the CAFE No-Action Alternative. Further, any modeled increases were very small relative to reductions from the historical levels represented in the current CAFE standard. NO_X emissions decrease under Alternatives PC1LT3 and PC2LT4 but increase under Alternatives PC3LT5 and PC6LT8, compared to the No-Action Alternative. SO_2 emissions decrease under Alternative PC1LT3 but increase under Alternatives PC2LT4 through PC6LT8, and the increases get larger from Alternative PC2LT4 through Alternative PC6LT8. PM2.5 emissions in 2050 decrease under all action alternatives, but the decrease under Alternative PC3LT5 is less than the decrease under Alternative PC2LT4. As in 2035, emissions in 2050 of CO and VOCs decrease under the action alternatives compared to the No-Action Alternative. The CO and VOC emissions decreases get larger from Alternative PC1LT3 through Alternative PC6LT8.
- Under each CAFE standard action alternative compared to the CAFE 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 16.8 percent under Alternative PC6LT8 in 2035 compared to the No-Action Alternative. The largest relative decreases in emissions would occur for CO, for which emissions would decrease by as much as 27.8 percent under Alternative PC6LT8 in 2050 compared to the No-Action Alternative. Percentage increases and decreases in emissions of NO_X, PM2.5, and VOCs would be less, as small as less than 1 percent. 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.
- In 2035, emissions of NO_X, PM2.5, and SO_2 marginally increase under the HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, while emissions of CO and VOCs decrease. Further, any modeled increases were very small relative to reductions from the historical levels represented in the current HDPUV FE standard. Relative to the No-Action Alternative, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 get larger from Alternative HDPUV4 through Alternative HDPUV14 (the most stringent alternative in terms of the estimated required fuel consumption [gallons of fuel per 100 ton-mile]). For CO and VOCs, the emissions decreases in 2035 get larger from Alternative HDPUV4 through Alternative HDPUV14 relative to the No-Action Alternative.
- In 2050, emissions of NO_X and SO_2 marginally increase under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, and the increases get larger from Alternative HDPUV4 through Alternative HDPUV14. Further, any modeled increases were very small relative to reductions from the historical levels represented in the current HDPUV FE standard. Emissions of CO, PM2.5, and VOCs decrease under all action alternatives compared to the No-Action Alternative, and the decreases get larger from Alternative HDPUV4 through Alternative HDPUV14.
- Under each HDPUV FE standard action alternative compared to the HDPUV No-Action Alternative, the largest relative increases in emissions among the criteria pollutants would occur for SO_2, for which emissions would increase by as much as 4.2 percent under Alternative HDPUV14 in 2050 compared to the No-Action Alternative. The largest relative decreases in emissions would occur for CO and VOCs, for which emissions would decrease by as much as 5.7 percent under Alternative HDPUV14 in 2050 compared to the No-Action Alternative. Percentage increases and reductions in emissions of NO_X and PM2.5 would be less, as small as less than 1 percent. 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.

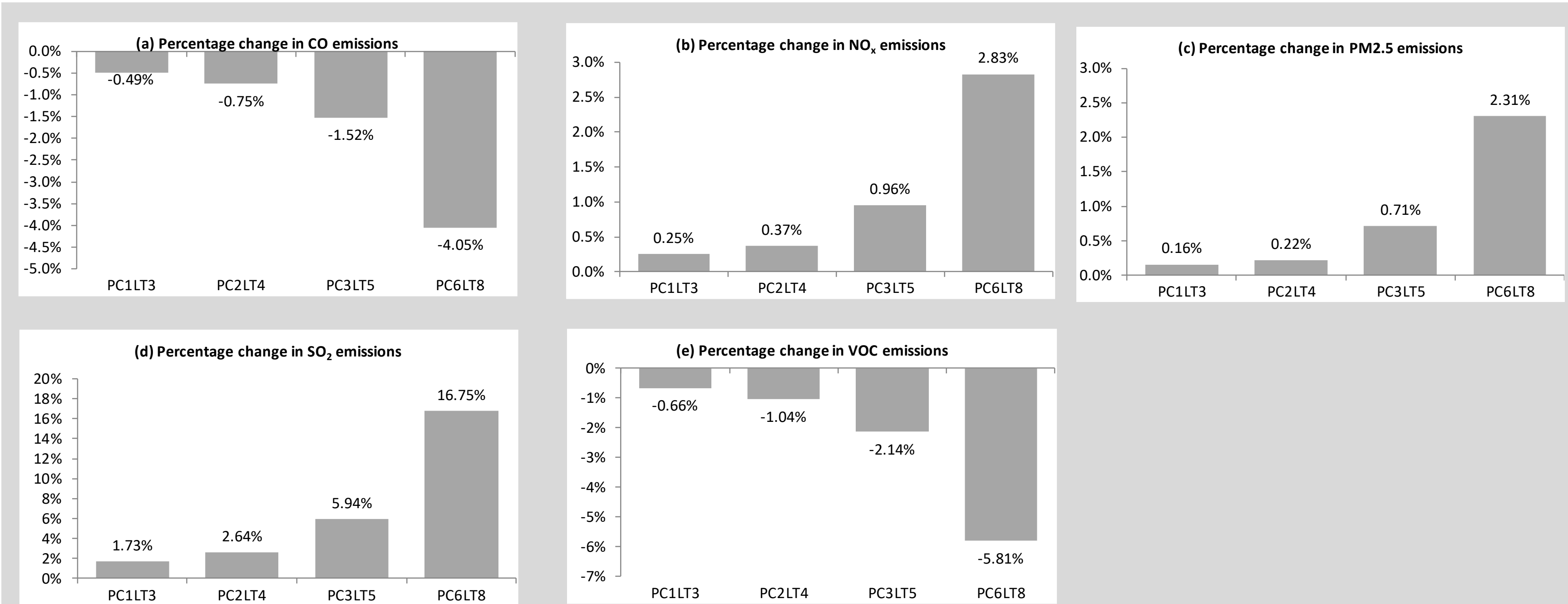
Toxic Air Pollutants

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

- Toxic air pollutant emissions across the CAFE standard action alternatives show decreases in 2035 and 2050 relative to the CAFE No-Action Alternative. The decreases get larger from Alternative PC1LT3 through Alternative PC6LT8.
- The largest relative decreases in national emissions of toxic air pollutants among the CAFE standard action alternatives, compared to the CAFE No-Action Alternative, generally would occur for acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, for which emissions would decrease by as much as 36 percent under Alternative PC6LT8 in 2050. Percentage decreases in emissions of benzene and DPM would be less, in some cases less than 1 percent. 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.
- Toxic air pollutant emissions across the HDPUV FE standard action alternatives remain the same or decrease in 2035 and 2050 relative to the HDPUV No-Action Alternative. The decreases get larger from Alternative HDPUV4 through Alternative HDPUV14.
- The largest relative decreases in national emissions of toxic air pollutants among the HDPUV FE standard action alternatives, compared to the HDPUV No-Action Alternative, generally would occur for acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde, for which emissions would decrease by as much as 7 percent under Alternative HDPUV14 in 2050. Percentage decreases in emissions of DPM would be less, in some cases less than 1 percent. 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.

Changes in criteria pollutant emissions in 2035 are shown by alternative in Figure S-1 for CAFE standard action alternatives and in Figure S-2 for HDPUV FE standard action alternatives. Changes in toxic air pollutant emissions in 2035 are shown by alternative in Figure S-3 for CAFE standard action alternatives and in Figure S-4 for HDPUV FE standard action alternatives.

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



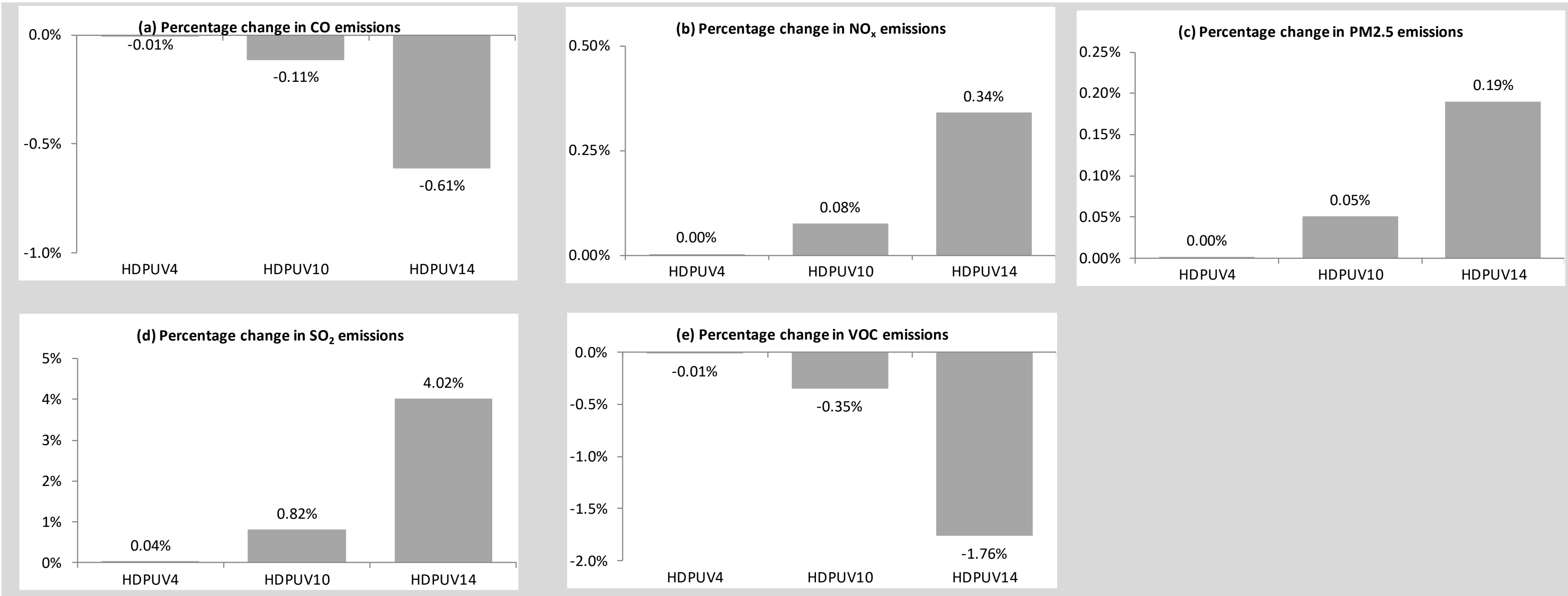
Notes:

The vertical (percentage) scale differs by pollutant.

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

CAFE = Corporate Average Fuel Economy; 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 Criteria Pollutant Emissions from U.S. HDPUVs for 2035 by HDPUV FE Standard Alternative Compared to the HDPUV No-Action Alternative, Direct and Indirect Impacts



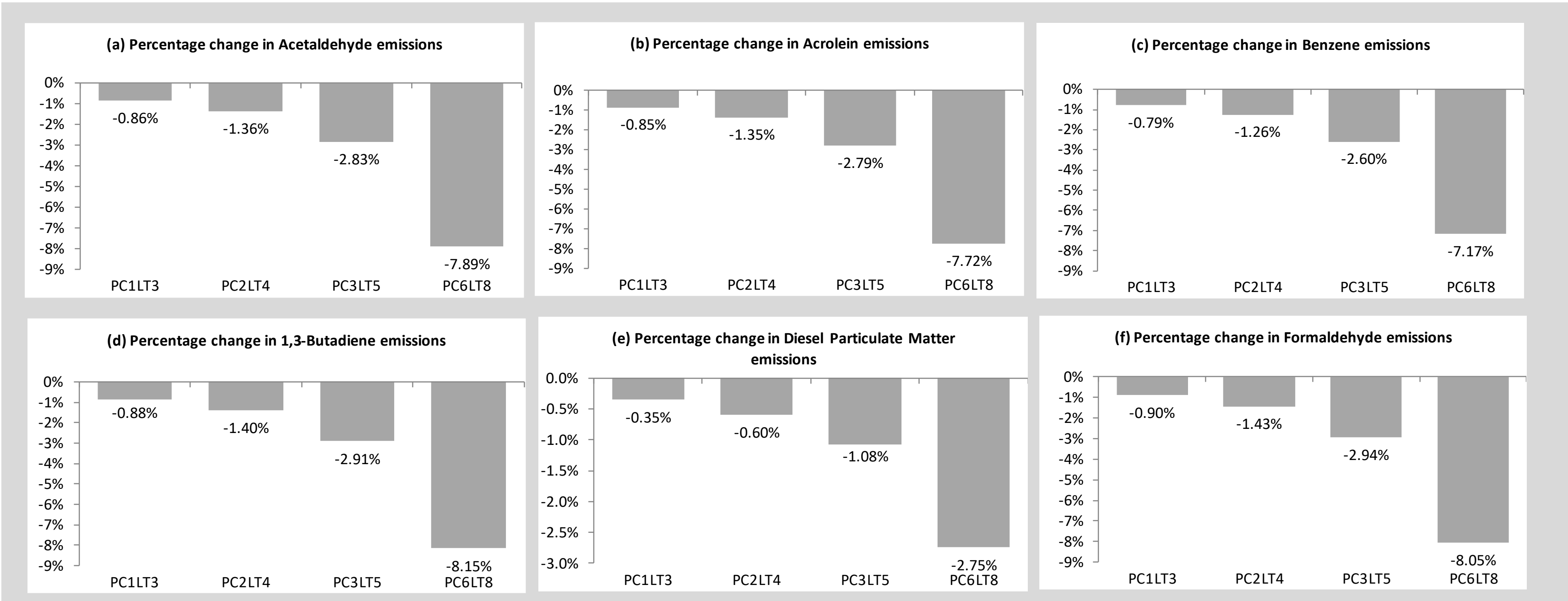
Notes:

The vertical (percentage) scale differs by pollutant.

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

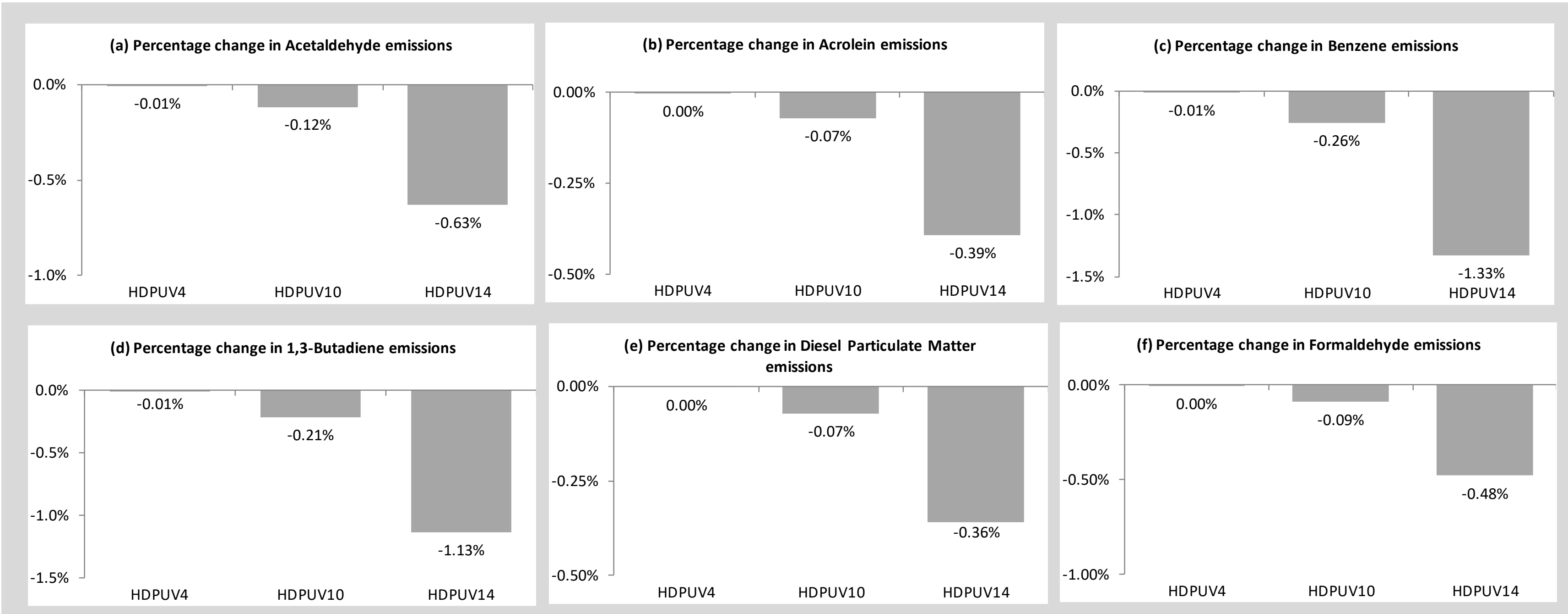
CO = carbon monoxide; FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans; NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns or less in diameter; SO_2 = sulfur dioxide; VOC = volatile organic compounds

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



Notes:
The vertical (percentage) scale differs by pollutant.
Negative values indicate emissions decreases; positive values are emissions increases.
CAFE = Corporate Average Fuel Economy

Figure S-4. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HDPUVs for 2035 by HDPUV FE Standard Alternative Compared to the HDPUV No-Action Alternative, Direct and Indirect Impacts



Notes:

The vertical (percentage) scale differs by pollutant.

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

FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans

Health Impacts

The air quality analysis identified the following health impacts.

- Adverse health impacts (mortality, acute bronchitis, respiratory emergency room visits, and other health effects) from criteria pollution emissions are projected to decrease nationwide in 2035 and 2050 under all CAFE standard action alternatives, relative to the CAFE No-Action Alternative, due to decreases in downstream emissions, particularly of PM2.5. The improvements to health impacts (or decreases in health incidences) would get larger from Alternative PC1LT3 to Alternative PC6LT8 in 2035 and 2050. These decreases reflect the generally increasing stringency of the action alternatives as they become implemented.
- Adverse health impacts from criteria pollutant emissions are projected to remain the same or decrease nationwide in 2035 and 2050 under all HDPUV FE standard action alternatives, relative to the HDPUV No-Action Alternative, due to decreases in downstream emissions, particularly of PM2.5.
- As mentioned above, changes in assumptions about modeled technology adoption; the relative proportions of gasoline, diesel, and other fuels in total fuel consumption changes; and changes in VMT from the rebound effect would alter these health impact results. However, NHTSA believes that these assumptions are reasonable.

Cumulative Impacts

Criteria Pollutants

The air quality analysis identified the following cumulative impacts on criteria air pollutants from the CAFE and HDPUV FE alternative combinations.

- In 2035, emissions of NO_X, PM2.5, and SO_2 marginally increase under the CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives, while emissions of CO and VOCs decrease. Further, any modeled increases were very small relative to reductions from the historical levels represented in the current CAFE and HDPUV FE standards. Relative to the No-Action Alternatives, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14 (the combination of the most stringent CAFE and HDPUV FE standard alternatives). For CO and VOCs, the emissions decreases in 2035 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14, relative to the No-Action Alternatives.
- In 2050, emissions of NO_X decrease under Alternatives PC1LT3 and HDPUV4 and Alternatives PC2LT4 and HDPUV10 but marginally increase under Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives. Further, any modeled increases were very small relative to reductions from the historical levels represented in the current CAFE and HDPUV FE standards. Emissions of SO_2 decrease under Alternatives PC1LT3 and HDPUV4 but increase under Alternatives PC2LT4 and HDPUV10 and Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives. Emissions of CO, PM2.5, and VOCs decrease under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives, and the decreases get larger from Alternatives PC1LT3 and HDPUV4 through Alternatives PC6LT8 and HDPUV14 for CO and VOCs, while the decreases for PM2.5 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives.

- Under each CAFE and HDPUV FE alternative combination compared to the No-Action Alternatives, the largest relative increases in emissions among the criteria pollutants would occur for SO_2, for which emissions would increase by as much as 15.2 percent under Alternatives PC6LT8 and HDPUV14 in 2035, compared to the No-Action Alternatives. The largest relative decreases in emissions would occur for CO, for which emissions would decrease by as much as 25.2 percent under Alternatives PC6LT8 and HDPUV14 in 2050, compared to the No-Action Alternatives. Percentage increases and decreases in emissions of NO_X and PM2.5 would be less, as small as less than 1 percent. 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.

Toxic Air Pollutants

The air quality analysis identified the following cumulative impacts on toxic air pollutants from the CAFE and HDPUV FE alternative combinations.

- Toxic air pollutant emissions across the CAFE and HDPUV FE alternative combinations remain the same or decrease in 2035 and 2050, relative to the No-Action Alternatives. The decreases in 2035 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10 and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14; the decreases in 2050 get larger from Alternatives PC1LT3 and HDPUV4 through Alternatives PC6LT8 and HDPUV14.
- The largest relative decreases in emissions generally would occur for acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde, for which emissions would decrease by as much as 29 percent under Alternatives PC6LT8 and HDPUV14 in 2050, compared to the No-Action Alternatives. Percentage decreases in emissions of DPM would be less, as small as less than 1 percent.

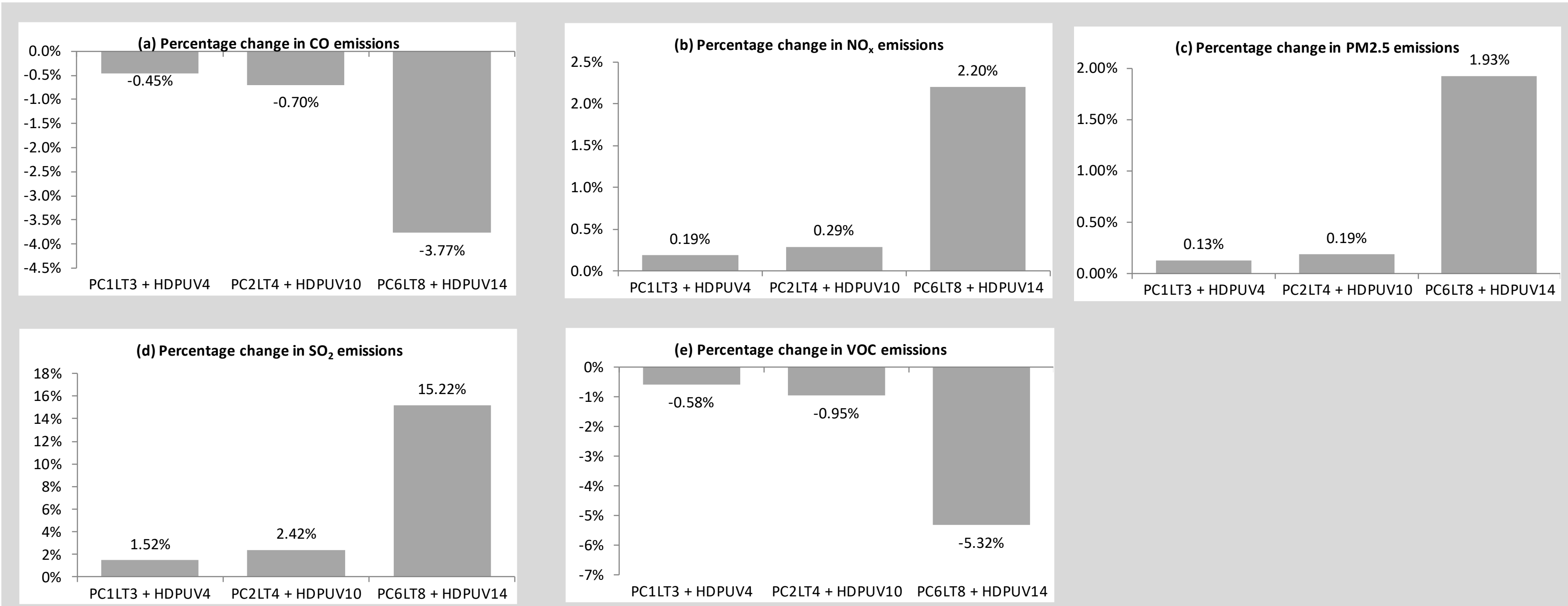
Changes in criteria pollutant emissions in 2035 are shown by alternative in Figure S-5, and changes in toxic air pollutant emissions in 2035 are shown by alternative in Figure S-6, for CAFE and HDPUV FE alternative combinations.

Health Impacts

The air quality analysis identified the following cumulative health impacts from the CAFE and HDPUV FE alternative combinations.

- Adverse health impacts (mortality, acute bronchitis, respiratory emergency room visits, and other health effects) from criteria pollutant emissions would remain the same or decrease nationwide in 2035 and 2050 under all CAFE and HDPUV FE alternative combinations, relative to the No-Action Alternatives, due to decreases in downstream emissions, particularly of PM2.5. The improvements to health impacts (or decreases in health incidences) in 2035 would get smaller or stay the same from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10 and then get larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14. In 2050, the improvements would get larger from Alternatives PC1LT3 and HDPUV4 to Alternatives PC6LT8 and HDPUV14. These decreases reflect the generally increasing stringency of the CAFE and HDPUV FE standard action alternatives as they become implemented.
- As mentioned above, changes in assumptions about modeled technology adoption; the relative proportions of gasoline, diesel, and other fuels in total fuel consumption changes; and changes in VMT from the rebound effect would alter these health impact results; however, NHTSA believes that these assumptions are reasonable.

Figure S-5. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs for 2035 by CAFE and HDPUV FE Alternative Combination Compared to the No-Action Alternatives, Cumulative Impacts



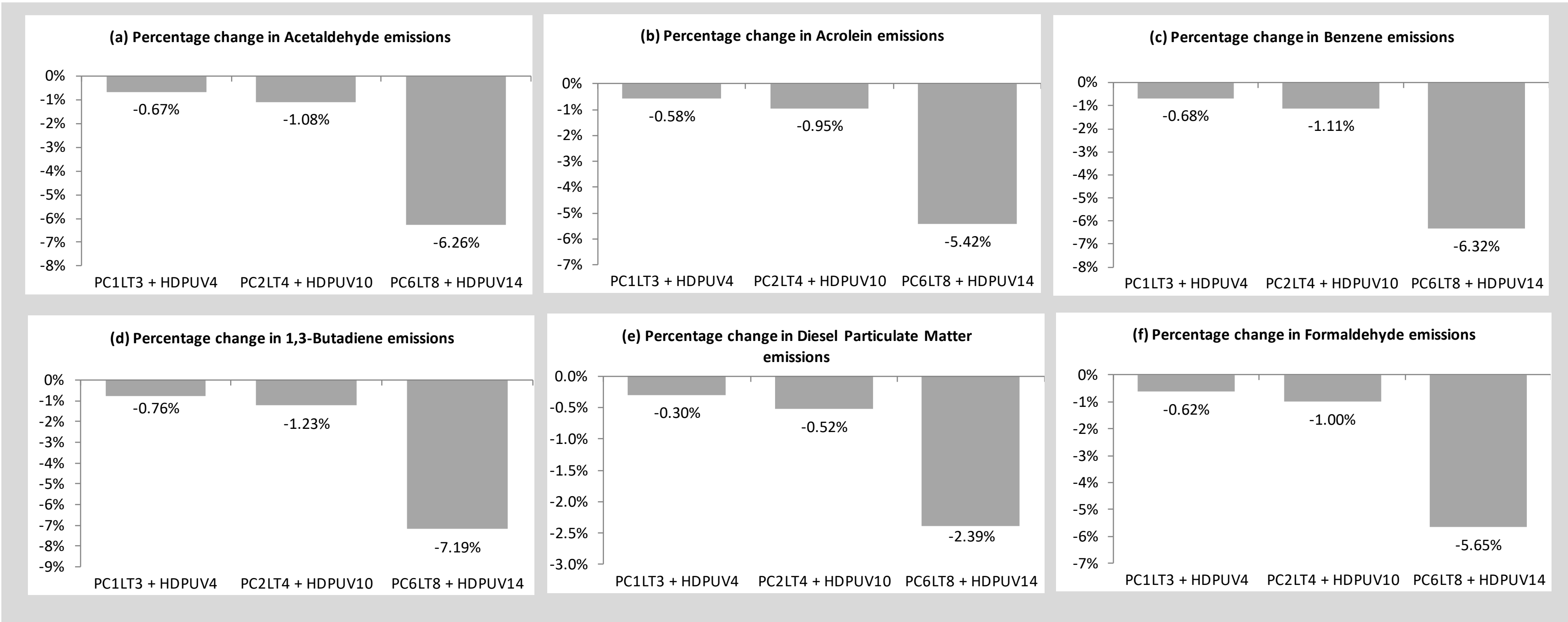
Notes:

The vertical (percentage) scale differs by pollutant.

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

CAFE = Corporate Average Fuel Economy; CO = carbon monoxide; FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans; 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-6. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs for 2035 by CAFE and HDPUV FE Alternative Combination Compared to the No-Action Alternatives, Cumulative Impacts



Notes:
The vertical (percentage) scale differs by pollutant.
Negative values indicate emissions decreases; positive values are emissions increases.
CAFE = Corporate Average Fuel Economy; FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans

Greenhouse Gas Emissions and Climate Change

This section describes how the Proposed Action and alternatives could affect the anticipated pace and extent of future changes in global climate. In this EIS, the discussion of direct and indirect impacts of climate change focuses on impacts associated with decreases in GHG emissions from the Proposed Action and alternatives as compared to projected GHG emissions under the relevant 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 reradiating much of it back to Earth's surface, 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 as primarily responsible for increasing the concentrations of GHGs in the atmosphere, and this buildup of GHGs is changing the Earth's energy balance. According to the Intergovernmental Panel on Climate Change (IPCC), the warming experienced over the past century is due to a combination of natural climate forcers (e.g., natural GHGs, solar activity), as well as human-made climate forcers (IPCC 2021a).

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.

IPCC, the U.S. Global Change Research Program (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 EIS 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, methane (CH_4), and nitrous oxide (N_2O) account for approximately 98 percent of global annual anthropogenic GHG emissions (World Resources Institute [WRI] 2023). 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.

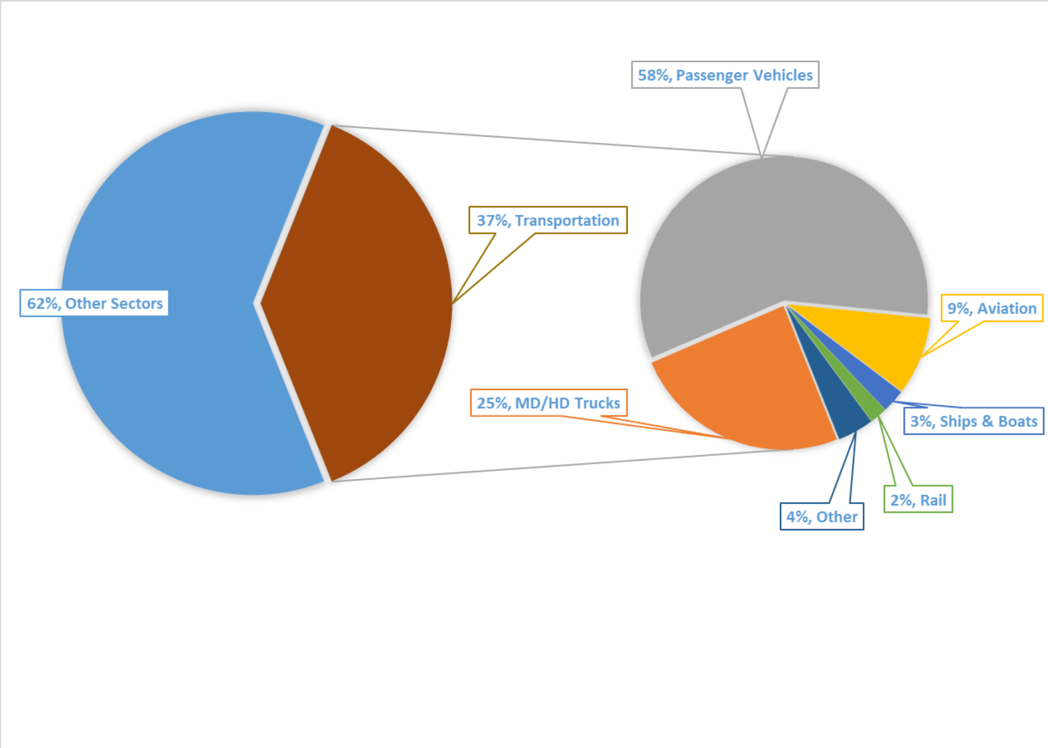
In 2019, the United States was the second largest emitter of GHGs, accounting for approximately 13 percent of total global emissions, excluding emissions and sinks from land-use change (WRI 2023).[17] EPA's National Greenhouse Gas Inventory for 1990 to 2021 indicates that, in 2021, the U.S. transportation sector was the single leading source of CO_2 emissions from fossil fuels, contributing over one-third of total U.S. CO_2 emissions from fossil fuels, with passenger cars and light trucks accounting for 58 percent of total U.S. CO_2 emissions from transportation (EPA 2023a). From 1990 to 2021, CO_2 emissions from passenger cars and light trucks increased by 12 percent, which is attributed to a 44.4 percent increase in VMT by LD motor vehicles (passenger cars and light trucks) driven by population increase, economic growth, and low fuel prices (EPA 2023a).

The coronavirus disease of 2019 (COVID-19) pandemic resulted in a 9 percent decrease in gross U.S. GHG emissions from 2019 to 2020, with contributions by sector remaining relatively consistent (EPA 2023a). Travel restrictions and behavior across the country resulted in decreased VMT by personal vehicles and lightweight trucks by 11 percent from 2019 to 2020 (EPA 2023a). However, due to the increased demand for e-commerce goods, VMT for HD vehicles increased from 2019 to 2020 (DOT 2022). Recent data show that this decrease in overall transportation emissions was temporary. Indicators of emissions such as VMT have significantly increased since the end of 2020 as travel restrictions eased and economic activity increased (Liu et al. 2020). VMT increased by 11 percent from 2020 to 2021 (DOT 2021a), despite shifts in travel and behavior compared to before the pandemic (e.g., increases in Americans working from home or hybrid working). Furthermore, between 2020 and 2021, CO_2 emissions from passenger cars and light trucks increased 10 percent; CO_2 emissions from transportation increased 11 percent (EPA 2023a).

Figure S-7 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.

[17] These numbers are based on global and U.S. estimates for 2019, the most recent year for which a global estimate is available. Excluding emissions and sinks from land-use change and forestry.

Figure S-7. Contribution of Transportation to U.S. Carbon Dioxide Emissions by Mode (2021)



Source: EPA 2023a
MD/HD = Medium-Duty and Heavy-Duty

Key Findings for Climate

The Proposed Action and alternatives would decrease both U.S. passenger car and light truck and HDPUV fuel consumption and CO_2 emissions compared with the relevant No-Action Alternative, reducing the anticipated increases in global CO_2 concentrations, temperature, precipitation, sea level, and ocean acidification that would otherwise occur.

Estimates of GHG emissions and decreases are presented for each of the action alternatives for both CAFE standards and HDPUV FE standards. 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 Shared Socioeconomic Pathway (SSP) 3-7.0 scenario to represent the reference case emissions scenarios. SSP3-7.0 is a high emissions scenario that assumes no additional global cooperation on mitigation efforts resulting in limited mitigation of GHG emissions. NHTSA selected the SSP3-7.0 scenario for its incorporation of a comprehensive suite of GHG and pollutant gas emissions, including carbonaceous aerosols and a global context of emissions with a full suite of GHGs and ozone precursors. This scenario yields a radiative forcing of approximately 7.0 watts per square meter in the year 2100. More information on global emissions scenarios used in this analysis can be found in Appendix E, *Greenhouse Gas Emissions and Climate Change*.

Greenhouse Gas Emissions

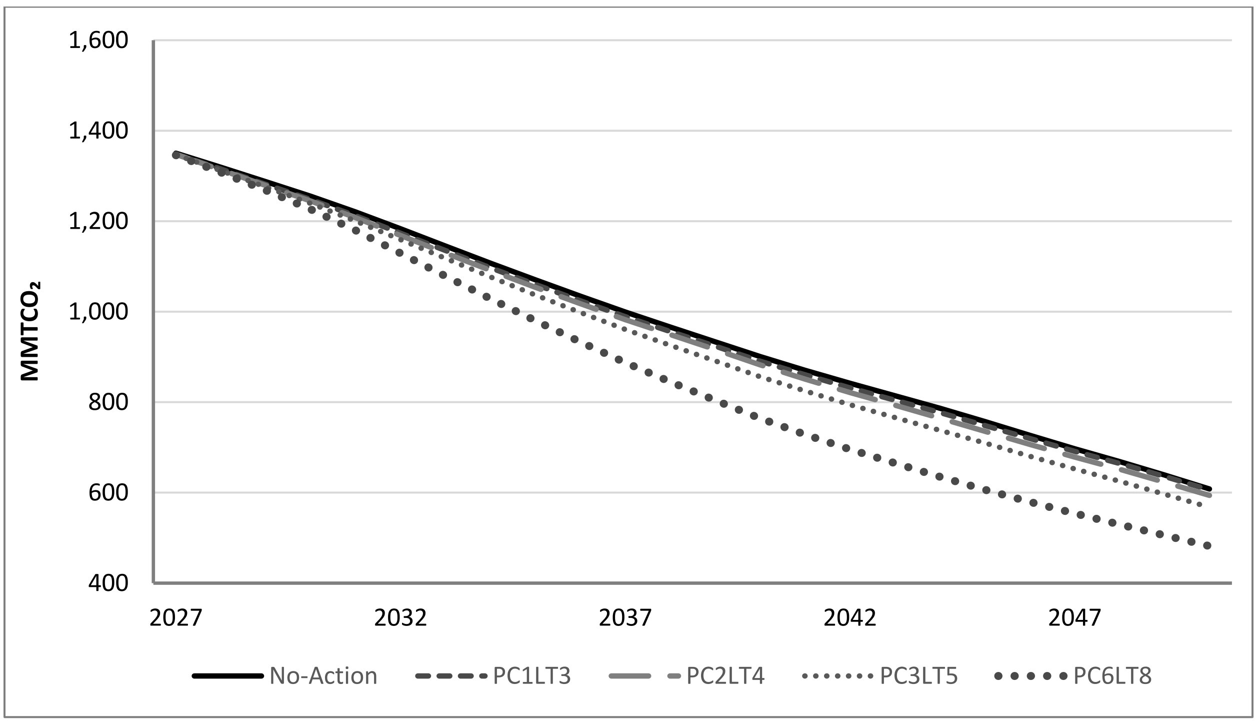
The alternatives would have the following impacts related to GHG emissions.

- Figure S-8 shows projected annual CO_2 emissions from passenger cars and light trucks under all CAFE standard action alternatives. Passenger cars and light trucks are projected to emit 52,800 million metric tons of carbon dioxide ($MMTCO_2$) from 2027 through 2100 under the CAFE No-Action Alternative. Alternative PC1LT3 and Alternative PC3LT5 would decrease these emissions by less than 1 and 5 percent, respectively, through 2100. Alternative PC2LT4, the preferred alternative, would decrease these emissions by 2 percent through 2100. Alternative PC6LT8 would decrease these emissions by 16 percent through 2100. Emissions would be highest under the No-Action Alternative, and emissions reductions would increase from Alternative PC1LT3 to Alternative PC6LT8. All CO_2 emissions estimates associated with the CAFE standard action alternatives include upstream emissions.
- Figure S-9 shows projected annual CO_2 emissions from HDPUV under all HDPUV FE standard action alternatives. HDPUVs are projected to emit 9,800 $MMTCO_2$ from 2027 through 2100 under the HDPUV No-Action Alternative. The action alternatives would decrease these emissions by a range of less than 0.1 percent under HDPUV4 to 4 percent under HDPUV14 through 2100. Alternative HDPUV10, the preferred alternative, would decrease these emissions by 1 percent over the same period. All CO_2 emissions estimates associated with the HDPUV FE standard action alternatives include upstream emissions.
- Compared with total projected CO_2 emissions of 559 $MMTCO_2$ from all passenger cars and light trucks under the CAFE No-Action Alternative in the year 2100, the CAFE standard action alternatives are expected to reduce CO_2 emissions from passenger cars and light trucks in the year 2100 less than 1 percent under Alternative PC1LT3, 7 percent under Alternative PC3LT5, and 21 percent under Alternative PC6LT8. Under Alternative PC2LT4, the 2100 total projected CO_2 emissions for all passenger cars and light trucks are 546 $MMTCO_2$, reflecting a 2 percent decrease.
- Compared with total projected CO_2 emissions of 115 $MMTCO_2$ from all HDPUVs under the HDPUV No-Action Alternative in the year 2100, the HDPUV FE standard action alternatives are expected to decrease CO_2 emissions from HDPUVs in the year 2100 by a range of less than 1 percent under Alternative HDPUV4 to 5 percent under Alternative HDPUV14. Under Alternative HDPUV10, the 2100 total projected CO_2 emissions for all HDPUVs are 113 $MMTCO_2$, reflecting a 2 percent decrease.
- Compared to SSP3-7.0 total global CO_2 emissions projection of 4,991,547 $MMTCO_2$ under the CAFE No-Action Alternative from 2027 through 2100, the CAFE standard action alternatives are expected to reduce global CO_2 by 0.01 percent under Alternative PC1LT3, 0.02 percent under Alternative PC2LT4, 0.06 percent under Alternative PC3LT5, and 0.17 percent under Alternative PC6LT8 by 2100.
- Compared to SSP3-7.0 total global CO_2 emissions projection of 4,991,547 $MMTCO_2$ under the HDPUV No-Action Alternative from 2027 through 2100, the HDPUV action alternatives are expected to

reduce global CO_2 by less than 0.01 percent under Alternatives HDPUV4 and HDPUV10, and 0.01 percent under Alternative HDPUV14 by 2100.

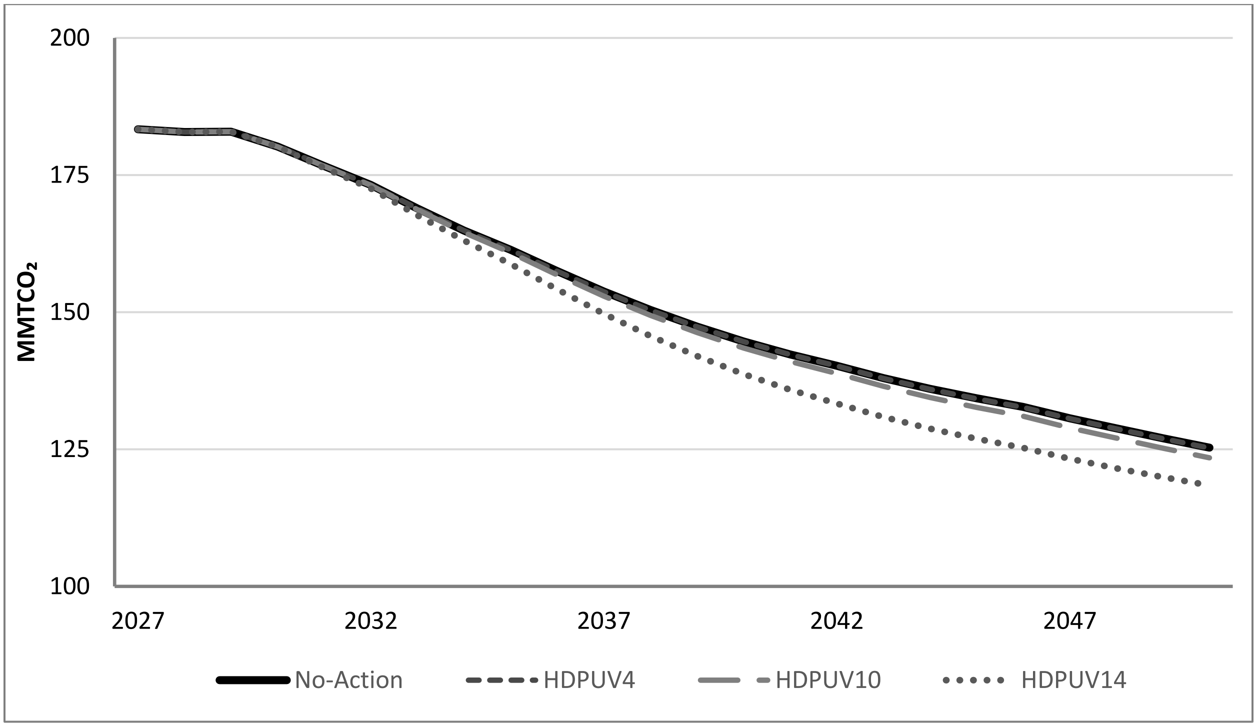
- The emissions reductions from all passenger cars and light trucks in 2035 compared with emissions under the CAFE No-Action Alternative are approximately equivalent to the annual emissions from 2,481,083 vehicles under Alternative PC1LT3, 4,006,611 vehicles under Alternative PC2LT4, 8,125,856 vehicles under Alternative PC3LT5, and 21,921,146 vehicles under Alternative PC6LT8. (A total of 260,514,221 passenger cars and light trucks are projected to be on the road in 2035 under the No-Action Alternative.)
- The emissions reductions from HDPUVs in 2035 compared with emissions under the HDPUV No-Action Alternative are approximately equivalent to the annual emissions from 2,325 vehicles under Alternative HDPUV4, 59,962 vehicles under Alternative HDPUV10, and 297,812 vehicles under Alternative HDPUV14. (A total of 18,607,101 HDPUVs are projected to be on the road in 2035 under the No-Action Alternative.)

Figure S-8. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from CAFE Standards for All U.S. Passenger Cars and Light Trucks by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Figure S-9. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from HDPUV FE Standards for All HDPUVs by Alternative



FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans; $MMTCO_2$ = million metric tons of carbon dioxide

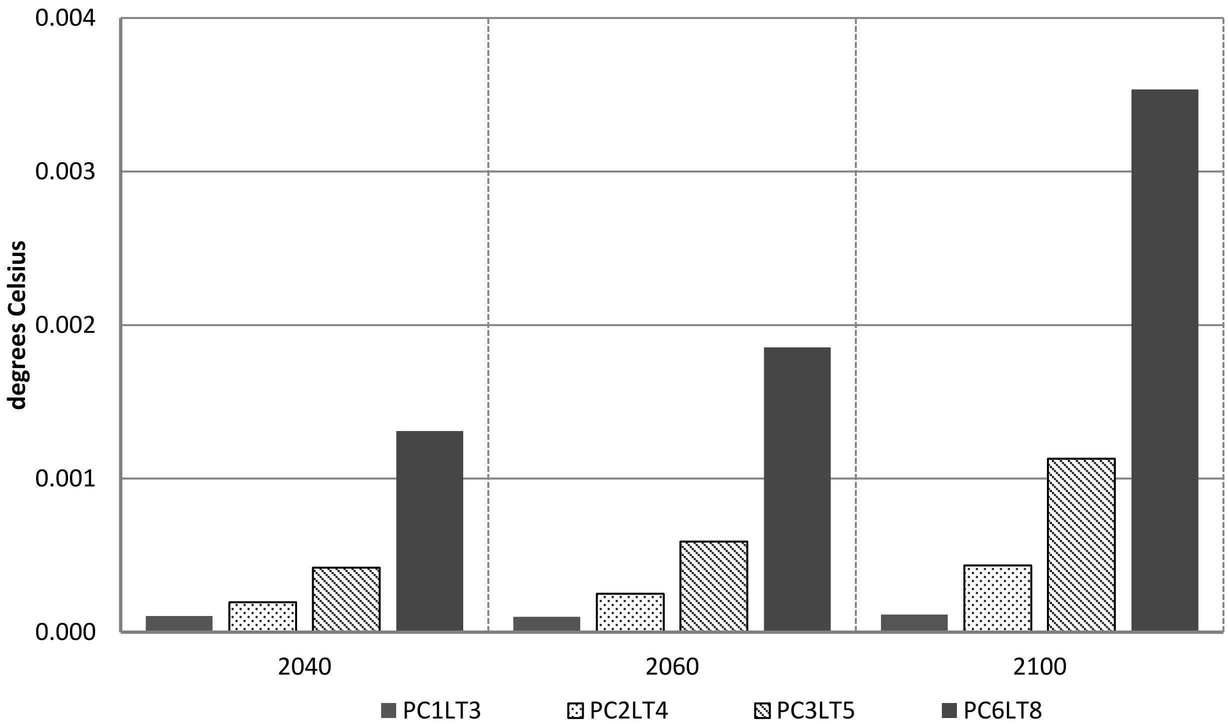
Climate Change Indicators

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 are estimated to be 838.31 parts per million (ppm) under the CAFE No-Action Alternative. CO_2 concentrations under the CAFE standard action alternatives could reach 837.48 ppm under Alternative PC6LT8, indicating a maximum atmospheric CO_2 decrease of approximately 0.83 ppm compared to the No-Action Alternative. Atmospheric CO_2 concentrations under Alternative PC1LT3 would decrease by 0.03 ppm compared with the No-Action Alternative.
- Under the HDPUV FE standard action alternatives CO_2 concentrations in the atmosphere could decrease to 838.27 ppm under Alternative HDPUV14, indicating a maximum atmospheric CO_2 decrease of approximately 0.04 ppm compared to the HDPUV No-Action Alternative. Atmospheric CO_2 concentration under Alternative HDPUV4 would decrease by less than 0.01 ppm compared with the No-Action Alternative.
- Global mean surface temperature is projected to increase by approximately 4.34 degrees Celsius (°C) (7.81 degrees Fahrenheit [°F]) under the CAFE No-Action Alternative by 2100. The most stringent CAFE standard action alternative (Alternative PC6LT8) would decrease this projected temperature rise by 0.004°C (0.007°F), while Alternative PC1LT3 would decrease projected temperature rise by less than 0.001°C (0.002°F). Figure S-10 shows the increase in projected global mean surface temperature under each action alternative compared with temperatures under the CAFE No-Action Alternative.

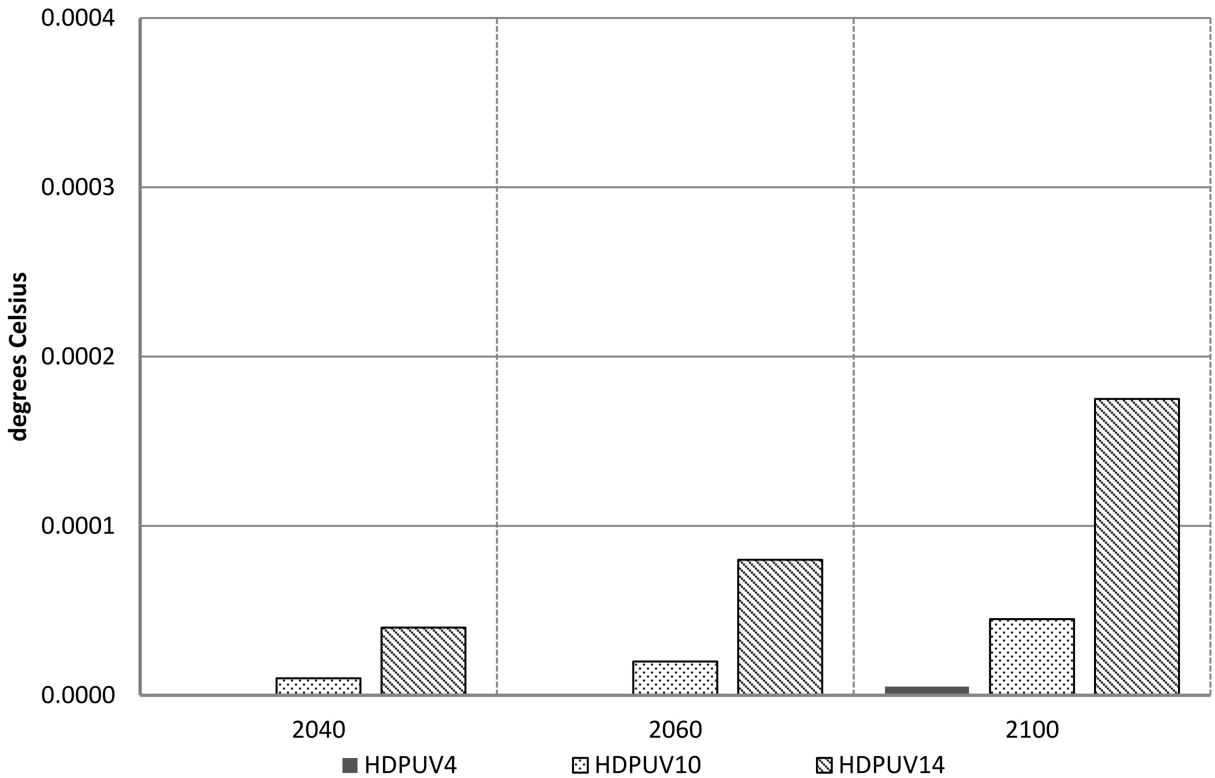
- Global mean surface temperature is projected to increase by approximately 4.34°C (7.81°F) under the HDPUV No-Action Alternative by 2100. The range of temperature increases under the HDPUV FE standard action alternatives would decrease this projected temperature rise by a range of less than 0.0001°C (0.0002°F) under Alternative HDPUV4 to 0.0002°C (0.003°F) under Alternative HDPUV14. Figure S-11 shows the increase in projected global mean surface temperature under each HDPUV action alternative compared with temperatures under the No-Action Alternative.
- Projected sea-level rise in 2100 ranges from a high of 83.24 centimeters (32.77 inches) under the CAFE No-Action Alternative to a low of 83.16 centimeters (32.74 inches) under Alternative PC6LT8. Alternative PC6LT8 would result in a decrease in sea-level rise equal to 0.08 centimeter (0.03 inch) by 2100 compared with the level projected under the No-Action Alternative. Alternative PC1LT3 would result in a decrease of less than 0.01 centimeter (0.004 inch) compared with the No-Action Alternative.
- Under the HDPUV FE standard action alternatives, projected sea-level rise in 2100 under the SSP3-7.0 scenario varies less than 0.01 centimeter (0.004 inch) from a high of 83.24 centimeters (32.77 inches) under the HDPUV No-Action Alternative.
- Global mean precipitation is anticipated to increase by 7.42 percent by 2100 under the CAFE No-Action Alternative. Under the CAFE standard action alternatives, this increase in precipitation would be reduced by 0.00 to 0.01 percent.
- Global mean precipitation is anticipated to increase by 7.42 percent by 2100 under the HDPUV No-Action Alternative. HDPUV FE standard action alternatives would see a reduction in precipitation in the range of 0.00 to 0.01 percent.
- Ocean pH in 2100 is anticipated to be 8.1937 under Alternative PC6LT8, about 0.0004 more than the CAFE No-Action Alternative. Under Alternative PC1LT3, ocean pH in 2100 would be 8.1933, or less than 0.0001 more than the CAFE No-Action Alternative.
- For HDPUV FE standard action alternatives, ocean pH in 2100 is anticipated to be 8.1933 under Alternative HDPUV14, or less than 0.0001 more than the HDPUV No-Action Alternative.

Figure S-10. CAFE Standards Reductions in Global Mean Surface Temperature Compared to the CAFE No-Action Alternative



CAFE = Corporate Average Fuel Economy

Figure S-11. HDPUV FE Standards Reductions in Global Mean Surface Temperature Compared to the HDPUV No-Action Alternative



FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans

Cumulative Impacts

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 is SSP2-4.5, which is an intermediate global emissions scenario. It 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 2027 to 2100 under the CAFE and HDPUV FE alternative combinations and other reasonably foreseeable future actions compared with the No-Action Alternatives range from 300 $MMTCO_2$ under Alternatives PC1LT3 and HDPUV4 to 9,000 $MMTCO_2$ under Alternatives PC6LT8 and HDPUV14. The Proposed Action and alternatives would decrease total vehicle emissions by between 0.5 percent under Alternatives PC1LT3 and HDPUV4 and 14 percent under Alternatives PC6LT8 and HDPUV14 by 2100.

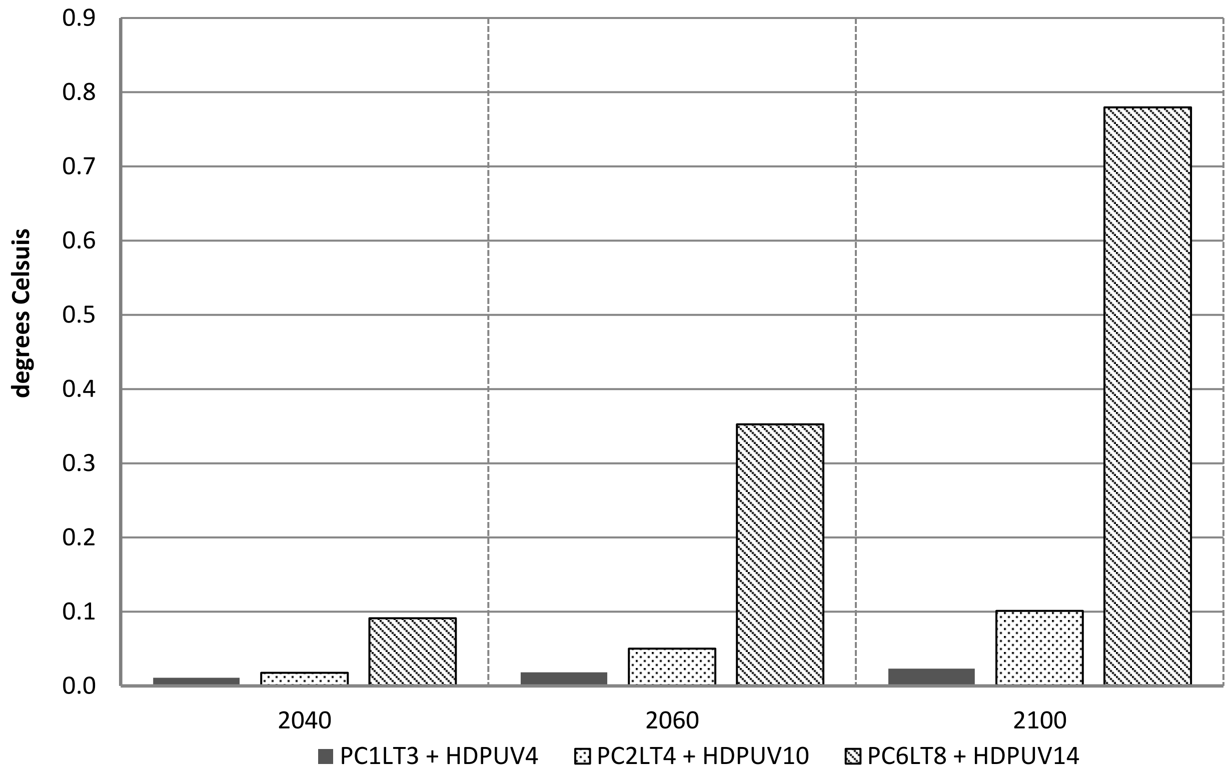
- Compared with projected total global CO_2 emissions of 2,484,191 $MMTCO_2$ from all sources from 2027 to 2100 using the moderate climate scenario, the incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.01 percent under Alternatives PC1LT3 and HDPUV4 and 0.36 percent under Alternatives PC6LT8 and HDPUV14 by 2100.

Climate Change Indicators

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

- Estimated atmospheric CO_2 concentrations in 2100 range from 587.78 ppm under the No-Action Alternatives to 587.00 ppm under Alternatives PC6LT8 and HDPUV14 (the combination of the most stringent CAFE and HDPUV FE standard alternatives). This is a decrease of 0.78 ppm compared with the No-Action Alternatives.
- Global mean surface temperature decreases for the CAFE and HDPUV FE alternative combinations compared with the No-Action Alternatives in 2100 range from a low of less than 0.001°C (0.002°F) under Alternatives PC1LT3 and HDPUV4 to a high of 0.004°C (0.007°F) under Alternatives PC6LT8 and HDPUV14. Figure S-12 illustrates the reductions in the rate at which global mean temperature would increase under each CAFE and HDPUV FE alternative combination compared with the No-Action Alternatives.
- Global mean precipitation is anticipated to increase 6.11 percent under the No-Action Alternatives, with the CAFE and HDPUV FE alternative combinations reducing this effect up to 0.01 percent.
- Projected sea-level rise in 2100 ranges from a high of 67.12 centimeters (26.42 inches) under the No-Action Alternatives to a low of 67.03 centimeters (26.39 inches) under Alternatives PC6LT8 and HDPUV14, indicating a maximum decrease in projected sea-level rise of 0.08 centimeter (0.03 inch) by 2100.
- Ocean pH in 2100 is anticipated to be 8.3333 under Alternatives PC6LT8 and HDPUV14, about 0.005 less than the No-Action Alternatives.

Figure S-12. Reductions in Global Mean Surface Temperature Compared with the No-Action Alternatives, Combined Impacts



Health, Societal, and Environmental Impacts of Climate Change

The Proposed Action and alternatives for both CAFE and HDPUV FE standards would reduce the impacts of climate change that would otherwise occur under the No-Action Alternatives. The largest magnitude of changes in climate effects would be produced by the most stringent action alternatives combination, which are Alternatives PC6LT8 and HDPUV14. Using the three-degree sensitivity analysis, by the year 2100 the following would result.

- A 0.78 ppm lower concentration of CO_2.
- A four-thousandths-of-a-degree increase in the rate of temperature rise.
- A small percentage change in the rate of precipitation increase.
- Between 0.10 and 0.11 centimeter (0.04 inch) decrease in projected sea-level rise.
- An increase of 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 and 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, in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, NHTSA provides a qualitative discussion of projected impacts by presenting the findings of peer-reviewed panel reports including those from the 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 Alternatives, they would not entirely prevent climate change and associated impacts. It is difficult to attribute any particular impact to emissions resulting from this rulemaking; however, NHTSA's assumption is that overall impacts are likely to be beneficial due to the reduced emissions resulting from the action alternatives. A detailed discussion of sectoral and regional impacts of climate change is provided in Chapter 5, Section 5.4.3, *Health, Societal, and Environmental Impacts of Climate Change*.

Comparison of Alternatives

Direct and Indirect Impacts

Table S-5 summarizes the direct and indirect effects of the CAFE standard action alternatives on each resource. Table S-6 summarizes the direct and indirect effects of the HDPUV FE standard action alternatives on each resource.

Cumulative Impacts

Table S-7 summarizes the cumulative impacts of the CAFE and HDPUV FE standard action alternatives on energy, air quality, and climate, as presented in Chapter 3, Section 3.3.2, *Cumulative Impacts,* Chapter 4, Section 4.2.2, *Cumulative Impacts,* and Chapter 5, Section 5.4.2*, Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*. These cumulative impacts are presented as the impacts of three specific combinations of CAFE standard and HDPUV FE standard action alternatives, which represent the full range of cumulative impacts of the two sets of standards that NHTSA is proposing in its rulemaking.

Table S-5. Direct and Indirect Impacts of CAFE Standards

No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Energy: Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2022–2050 (billion gasoline gallon equivalent)				
2,761	2,744	2,727	2,688	2,548
Energy: Combined U.S. Passenger Car and Light Truck Decrease in Fuel Consumption for 2022–2050 (billion gallons)				
--	-17	-34	-73	-212
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)				
--	Decrease: CO (-28,695) and VOCs (-4,593). Increase: NO_X (713), PM2.5 (35), and SO_2 (1,477).	Decrease: CO (-43,800) and VOCs (-7,203), emissions smaller than Alt. PC1LT3. Increase: NO_X (1,039), PM2.5 (48), and SO_2 (2,256), emissions larger than Alt. PC1LT3.	Decrease: CO (-88,750) and VOCs (-14,878), emissions smaller than Alts. PC1LT3 and PC2LT4. Increase: NO_X (2,701), PM2.5 (156), and SO_2 (5,087), emissions larger than Alts. PC1LT3 and PC2LT4.	Decrease: CO (-236,876) and VOCs (-40,350), emissions smaller than Alts. PC1LT3, PC2LT4, and PC3LT5. Increase: NO_X (8,009), PM2.5 (505), and SO_2 (14,338), emissions larger than Alts. PC1LT3, PC2LT4, and PC3LT5.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)				
--	Decrease: Acetaldehyde (-16), acrolein (-1), benzene (-58), 1,3-butadiene (-6), DPM (-121), and formaldehyde (-13). Increase: None.	Decrease: Acetaldehyde (-25), acrolein (-2), benzene (-91), 1,3-butadiene (-10), DPM (-207), and formaldehyde (-21), emissions smaller than Alt. PC1LT3. Increase: None.	Decrease: Acetaldehyde (-52), acrolein (-3), benzene (-189), 1,3-butadiene (-22), DPM (-373), and formaldehyde (-44), emissions smaller than Alts. PC1LT3 and PC2LT4. Increase: None.	Decrease: Acetaldehyde (-146), acrolein (-10), benzene (-520), 1,3-butadiene (-60), DPM (-951), and formaldehyde (-120), emissions smaller than Alts. PC1LT3, PC2LT4, and PC3LT5. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035 (Krewski et al. 2009)				
--	Premature mortality: -4 cases Work loss: -902 days	Premature mortality: -7 cases Work loss: -1,507 days	Premature mortality: -10 cases Work loss: -2,719 days	Premature mortality: -27 cases Work loss: -7,400 days
Climate: Total Carbon Dioxide Emissions from U.S. Passenger Cars and Light Trucks for 2027–2100 ($MMTCO_2$)				
52,800	52,500	51,700	50,000	44,200
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)				
838.31	838.29	838.21	838.04	837.48

No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Climate: Increase in Global Mean Surface Temperature by 2100 in °C (°F)				
4.340°C (7.812°F)	4.339°C (7.810°F)	4.339°C (7.810°F)	4.338°C (7.808°F)	4.336°C (7.805°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)				
83.24 (32.77)	83.24 (32.77)	83.23 (32.77)	83.22 (32.76)	83.16 (32.74)
Climate: Global Mean Precipitation Increase by 2100				
7.42%	7.42%	7.42%	7.42%	7.41%
Climate: Ocean Acidification in 2100 (pH)				
8.1933	8.1933	8.1933	8.1934	8.1937

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; CAFE = Corporate Average Fuel Economy; CO = carbon monoxide; DPM = diesel particulate matter; ppm = parts per million; $MMTCO_2$ = 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 S-6. Direct and Indirect Impacts of HDPUV FE Standards

No-Action	HDPUV4	HDPUV10	HDPUV14
Energy: HDPUV Fuel Consumption for 2022–2050 (billion gasoline gallon equivalent)			
412.2	412.1	410.3	403.3
Energy: HDPUV Decrease in Fuel Consumption for 2022–2050 (billion gallons)			
--	-0.1	-1.9	-8.9
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)			
--	No change: PM2.5 (0). Decrease: CO (-28) and VOCs (-14). Increase: NO_X (3) and SO_2 (4).	Decrease: CO (-587) and VOCs (-331), emissions smaller than Alt. HDPUV4. Increase: NO_X (72), PM2.5 (2), and SO_2 (95), emissions larger than Alt. HDPUV4.	Decrease: CO (-3,181) and VOCs (-1,674), emissions smaller than Alts. HDPUV4 and HDPUV10. Increase: NO_X (324), PM2.5 (9), and SO_2 (469), emissions larger than Alts. HDPUV4 and HDPUV10.

No-Action	HDPUV4	HDPUV10	HDPUV14
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)			
--	No change: Acetaldehyde (0), acrolein (0), benzene (0), 1,3-butadiene (0), DPM (0), and formaldehyde (0). Decrease: None. Increase: None.	No change: Acrolein (0) and 1,3-butadiene (0). Decrease: Acetaldehyde (-1), benzene (-3), DPM (-4), and formaldehyde (-1), emissions smaller than Alt. HDPUV4. Increase: None.	No change: Acrolein (0). Decrease: Acetaldehyde (-3), benzene (-16), 1,3-butadiene (-1), DPM (-21), and formaldehyde (-3), emissions smaller than Alts. HDPUV4 and HDPUV10. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035			
--	Premature mortality: No change Work loss: -1 day	Premature mortality: No change Work loss: -22 days	Premature mortality: No change Work loss: -141 days
Climate: Total Carbon Dioxide Emissions from All HDPUVs for 2027–2100 ($MMTCO_2$)			
9,800	9,800	9,600	9,300
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
838.31	838.31	838.30	838.27
Climate: Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
4.340°C (7.812°F)	4.340°C (7.812°F)	4.339°C (7.810°F)	4.339°C (7.810°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
83.24 (32.77)	83.24 (32.77)	83.24 (32.77)	83.24 (32.77)
Climate: Global Mean Precipitation Increase by 2100			
7.42%	7.42%	7.42%	7.42%
Climate: Ocean Acidification in 2100 (pH)			
8.1933	8.1933	8.1933	8.1933

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; CAFE = Corporate Average Fuel Economy; CO = carbon monoxide; DPM = diesel particulate matter; ppm = parts per million; FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans; $MMTCO_2$ = 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 S-7. Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards

No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Energy: Fuel Consumption of LD Vehicles and HDPUVs (billion gasoline gallon equivalent total for calendar years 2022–2050)			
3,173	3,156	3,138	2,952
Energy: Decrease in Fuel Consumption of LD Vehicles and HDPUVs (billion gasoline gallon equivalent total for calendar years 2022–2050)			
--	-17	-36	-221
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)			
--	Decrease: CO (-28,722) and VOCs (-4,607). Increase: NO_X (716), PM2.5 (35), and SO_2 (1,481).	Decrease: CO (-44,388) and VOCs (-7,535), emissions smaller than Alt. PC1LT3 + HDPUV4. Increase: NO_X (1,111), PM2.5 (51), and SO_2 (2,352), emissions larger than Alt. PC1LT3 + HDPUV4.	Decrease: CO (-240,057) and VOCs (-42,025), emissions smaller than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10. Increase: NO_X (8,334), PM2.5 (514), and SO_2 (14,807), emissions larger than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)			
--	Decrease: Acetaldehyde (-16), acrolein (-1), benzene (-58), 1,3-butadiene (-7), DPM (-121), and formaldehyde (-14). Increase: None.	Decrease: Acetaldehyde (-26), acrolein (-2), benzene (-94), 1,3-butadiene (-11), DPM (-211), and formaldehyde (-22), emissions smaller than Alt. PC1LT3 + HDPUV4. Increase: None.	Decrease: Acetaldehyde (-149), acrolein (-10), benzene (-536), 1,3-butadiene (-62), DPM (-972), and formaldehyde (-124), emissions smaller than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035			
--	Premature mortality: -4 cases Work loss: -903 days	Premature mortality: -7 cases Work loss: -1,529 days	Premature mortality: -28 cases Work loss: -7,541 days
Climate: Total Carbon Dioxide Emissions from All LD Vehicles and HDPUVs for 2027–2100 ($MMTCO_2$)[a]			
62,500	62,200	61,300	53,500
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
587.78	587.76	587.68	587.00
Climate: Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
2.826°C (5.087°F)	2.826°C (5.087°F)	2.826°C (5.087°F)	2.822°C (5.080°F)

No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
67.12 (26.43)	67.11 (26.42)	67.11 (26.42)	67.03 (26.39)
Climate: Global Mean Precipitation Increase by 2100			
6.11%	6.10%	6.10%	6.10%
Climate: Ocean pH in 2100			
8.3328	8.3328	8.3329	8.3333

Notes:
[a] Total greenhouse gas emissions from the combined impacts of all LD vehicles and HDPUVs are the same as the additive sum presented 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 an intermediate global emissions scenario (SSP2-4.5) as opposed to the high emissions scenario (SSP3-7.0) used in the direct and indirect effects analysis. NHTSA chose the SSP2-4.5 scenario as plausible global emissions baseline for the cumulative analysis because this scenario is more aligned with reasonably foreseeable global actions that will result in a moderate level of emissions reductions (although it does not explicitly include any particular policy or program).
°C = degrees Celsius; °F = degrees Fahrenheit; CAFE = Corporate Average Fuel Economy; CO = carbon monoxide; DPM = diesel particulate matter; EV = electric vehicle; FE = fuel efficiency; HDPUV = heavy-duty pickup trucks and vans; $MMTCO_2$ = 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

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 (GVWR) of less than 8,500 pounds, and medium-duty passenger vehicles with a GVWR of less than 10,000 pounds.[4]

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

[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 (LD) vehicles. The terms *passenger automobile, light truck,* and *medium duty passenger vehicle* are defined in 49 CFR Part 523.

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

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

[7] 49 U.S.C. 32902(k)(2).

[8] *Id*.

[9] *Id*.

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

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,[12] MY 2012–2016 passenger cars and light trucks,[13] MY 2017 and beyond passenger cars and light trucks,[14] MY 2021–2026 passenger cars and light trucks,[15] and most recently MY 2024–2026 passenger cars and light trucks.[16] NHTSA also established, pursuant to EISA, fuel efficiency (FE) standards for medium- and heavy-duty vehicles for MYs 2014–2018 (HD Fuel Efficiency Improvement Program Phase 1)[17] and MYs 2018–2027 (HD Fuel Efficiency Improvement Program Phase 2).[18] NHTSA has issued its LD fuel economy and medium- and heavy-duty FE standards in close coordination with the U.S. Environmental Protection Agency (EPA), because EPA also sets standards that affect the same vehicles.[19]

In the Phase 1 and Phase 2 HD Fuel Efficiency Improvement Program rules, NHTSA's fuel consumption standards and EPA's GHG emissions standards were tailored to each of the three current regulatory categories of HD vehicles: (1) combination tractors; (2) heavy-duty pickup trucks and vans (HDPUVs); and (3) vocational vehicles, as well as gasoline and diesel heavy-duty engines. EPA's hydrofluorocarbon emissions standards that currently apply to air conditioning systems in tractors and HDPUVs were also applied to vocational vehicles.

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[10] In accordance with the decision in *Truck Trailer Manufacturers Association, Inc. v. EPA*, 17 F.4th 1198 (D.C. Cir. 2021), NHTSA is no longer including trailer standards in its HD Fuel Efficiency Improvement Program Phase 2 regulations.

[11] 49 U.S.C. 32902(k)(3).

[12] 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]).

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

[14] 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).

[15] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Final Rule, 87 FR 25710 (May 2, 2022); 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").

[16] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Final Rule, 87 FR 25710 (May 2, 2022).

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

[18] 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).

[19] Although the agencies' programs and standards are closely coordinated, they are separate. NHTSA issues CAFE and FE standards pursuant to its statutory authority under EPCA, as amended by EISA. EPA sets national GHG 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 light truck fleet fuel economy pursuant to EPCA (49 U.S.C. 32904(c)).

To inform its development of the new CAFE and HDPUV FE standards and pursuant to the National Environmental Policy Act (NEPA),[20] NHTSA prepared this Environmental Impact Statement (EIS) to evaluate the potential environmental impacts of a reasonable range of alternatives the agency is considering for MY 2027–2032 CAFE standards and a reasonable range of alternatives NHTSA is considering for MY 2030–2035 HDPUV FE standards. 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).[21] This EIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of alternatives for both CAFE and FE standards, including a No-Action Alternative and a Preferred Alternative, pursuant to Council on Environmental Quality (CEQ) NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations.[22] This EIS analyzes direct, indirect, and cumulative impacts, and discusses impacts in proportion to their significance.

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] Because NHTSA's Proposed Action is a notice of proposed rulemaking (NPRM) consisting of two distinct proposals (CAFE standards and HDPUV FE standards), the agency's purpose of and need for the rulemaking are the statutory authority and directives in EPCA, as amended by EISA, for NHTSA to set CAFE standards and HDPUV FE standards. The following sections discuss EPCA's and EISA's requirements for setting CAFE standards for passenger cars and light trucks and FE standards for HDPUVs.

1.2.1 CAFE Standards for Passenger Cars and Light Trucks

The first purpose of the rulemaking is to set MY 2027–2032 CAFE standards. Because in any single rulemaking under EPCA, standards must be established for not more than 5 model years, NHTSA intends to announce expected (or augural) CAFE standards for MY 2032 (see Section 1.3, *CAFE and FE Standards Rulemaking Process*, for additional information on augural standards). In accordance with EPCA/EISA, NHTSA will establish CAFE standards that 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

[20] 42 U.S.C. 4321–4347.

[21] 42 U.S.C. 4332.

[22] The CEQ NEPA implementing regulations are codified at 40 CFR Parts 1500–1508; 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.

[23] *See* 40 CFR 1502.13.

[24] 49 U.S.C. 32902(a).

need of the United States to conserve energy."[25] NHTSA construes these statutory factors as including environmental and safety considerations.[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 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]

1.2.2 FE Standards for HDPUVs

In accordance with EPCA/EISA, the second purpose of this rulemaking is to set MY 2030–2035 HDPUV FE standards that are "designed to achieve the maximum feasible improvement."[30] These new FE standards will build on the success of the Phase 1 and Phase 2 HD Fuel Efficiency Improvement Programs in furtherance of EPCA's goals of energy independence and security, as well as improving environmental outcomes and national security.

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[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] For environmental considerations, *see Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, 1325 n. 12 (D.C. Cir. 1986); *Public Citizen* v. *NHTSA,* 848 F.2d 256, 262-3 n. 27 (D.C. Cir. 1988) (noting that "NHTSA has itself interpreted the factors it must consider in setting CAFE standards as including environmental effects"); *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1196 (9th Cir. 2008); 40 CFR 1500.6. For safety considerations, *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)).

[27] *See* proposed rule preamble, Section V.A.5.a(4).

[28] 49 U.S.C. 32902(b)(1)-(2).

[29] 49 U.S.C. 32902(b)(3)(A).

[30] 49 U.S.C. 32902(k)(2).

When establishing standards to improve the fuel efficiency of HD vehicles, EISA requires that NHTSA "adopt and implement appropriate test methods, measurement metrics, fuel economy standards,[31] and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for [HD vehicles]."[32] Congress also directed that the standards adopted under the program, pursuant to EISA, must provide no fewer than 4 model years of regulatory lead time and 3 model years of regulatory stability.[33] In considering these various requirements, NHTSA will also account for relevant environmental and safety considerations.

1.3 CAFE and FE Standards 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.[34]

NHTSA is proposing a rule to set CAFE standards for LD vehicles for MYs 2027–2031. NHTSA is also proposing to issue augural MY 2032 CAFE standards, meaning that they represent NHTSA's current best estimate, based on the information available to the agency today, of what levels of stringency might be maximum feasible in MY 2032. See the preamble to the NPRM (Section V.A) for more information. The MY 2032 CAFE standards will not be finalized in the rulemaking analyzed by this EIS due to the statutory requirement that NHTSA set average fuel economy standards not more than 5 model years at a time. The MY 2032 CAFE standards will be set in a subsequent, *de novo* notice-and-comment rulemaking conducted in full compliance with 49 U.S.C. 32902 and other applicable law. Additionally, NHTSA's proposed rule would set FE standards for MY 2030–2035 HDPUVs. Furthermore, in conjunction with NHTSA's Proposed Action, EPA proposed GHG emissions standards under Section 202(a) of the Clean Air Act (CAA) for MY 2027–2032 LD vehicles and HDPUVs.[35] This EIS 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 components of NHTSA's Proposed Action. Section 1.3.2, *Greenhouse Gas Standards for Light- and Medium-Duty Vehicles (U.S. Environmental Protection Agency)*, summarizes EPA's coordinated GHG emissions standards.

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[31] In the Phase 1 HD Fuel Efficiency Improvement Program rulemaking, NHTSA, aided by the National Academies of Sciences report, assessed potential metrics for evaluating fuel efficiency. NHTSA found that fuel economy would not be an appropriate metric for HD vehicles. Instead, NHTSA chose a metric that considers the amount of fuel consumed when moving a ton of freight (i.e., performing work). As explained in the Phase 2 HD Fuel Efficiency Improvement Program Final Rule, this metric, delegated by Congress to NHTSA to formulate, is not precluded by the text of the statute. The agency concluded that it is a reasonable way by which to measure fuel efficiency for a program designed to reduce fuel consumption. Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2; Final Rule, 81 FR 73478, 73520 (Oct. 25, 2016).

[32] 49 U.S.C. 32902(k)(2).

[33] 49 U.S.C. 32902(k)(3).

[34] 49 U.S.C. 32902(b)(2)(A) requires a combined fuel economy average for MY 2020 of at least 35 miles per gallon.

[35] Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles; Proposed Rule, 88 FR 29184 (May 5, 2023).

1.3.1 Proposed Action

For this EIS, NHTSA's Proposed Action is to promulgate a rulemaking setting CAFE standards (final standards for MY 2027–2031 LD vehicles, augural standards for MY 2032 LD vehicles) and MY 2030–2035 FE standards for HDPUVs, in accordance with EPCA, as amended by EISA. As part of the current rulemaking, NHTSA is considering a range of alternatives for MY 2027–2032 CAFE standards and a range of alternatives for MY 2030–2035 HDPUV FE standards. The two sets of standards that constitute NHTSA's Proposed Action and alternatives considered for each set of standards in this EIS are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*.

1.3.1.1 CAFE Standards

Level of CAFE Standards

NHTSA is proposing to promulgate CAFE standards for passenger cars and light trucks under the agency's statutory authority. All CAFE alternatives under consideration by NHTSA would set CAFE standards for MYs 2027–2031 and establish augural CAFE standards for MY 2032. All CAFE standard action alternatives would be more stringent than the CAFE No-Action Alternative. More specifically, NHTSA considers three CAFE standard action alternatives where passenger car and light truck stringencies increase at different rates, with light truck stringencies increasing at a higher rate than passenger car stringencies (see Chapter 2, Section 2.2.2.1, *CAFE Standard Action Alternatives*). Under NHTSA's CAFE action alternatives, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would range from 47.0 to 50.5 miles per gallon (mpg) in MY 2027 and 54.3 to 74.5 mpg in MY 2032. This compares to estimated average required fuel economy levels of 46.7 mpg in MY 2027 through MY 2032, respectively, under the CAFE No-Action Alternative. Under NHTSA's Preferred Alternative for CAFE standards, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would be 48.4 mpg in MY 2027 and 57.7 mpg in MY 2032. Because the CAFE 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 CAFE 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.

Form of CAFE Standards

Since the reformed CAFE program for light trucks for MYs 2008–2011,[36] NHTSA has set CAFE 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.[37] Since then, NHTSA and EPA have used an attribute standard when setting CAFE and GHG standards for LD vehicles.[38] In this rulemaking for MYs 2027–

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

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

[38] *See* Chapter 2 of previous CAFE EISs (NHTSA 2010, 2012, 2020, 2022).

2032, NHTSA again proposes attribute-based standards based on vehicle footprint for passenger cars and light trucks.

Under an attribute-based standard, each vehicle model has a fuel economy performance target, the level of which depends on the vehicle's attribute. As in previous CAFE rulemakings, NHTSA proposes vehicle footprint as the attribute for CAFE standards. Vehicle footprint is one measure of vehicle size and is defined as a vehicle's wheelbase multiplied by the vehicle's track width. NHTSA believes that the footprint attribute is the most appropriate attribute on which to base CAFE standards under consideration, as discussed in Section II.B of the NPRM preamble.

Under the proposed rule, each manufacturer would have separate standards for passenger cars and for light trucks, based on the footprint target curves promulgated by the agency and the mix of vehicles that each manufacturer produces for sale in a given model year. Generally, larger vehicles (i.e., vehicles with larger footprints) would be subject to lower fuel economy targets than smaller vehicles 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[39] average (for CAFE, harmonic average[40]) of those targets. The manufacturer's ultimate compliance obligation is based on that average; no individual vehicle or nameplate is required to meet or exceed its specific performance target level, but the manufacturer's fleet (either domestic passenger car, import passenger car, or light truck) on average must meet or exceed the average required level for the entire fleet in order to comply. In other words, a manufacturer's individual CAFE standards for cars and trucks would be based on the target levels associated with the footprints of its particular mix of cars and trucks manufactured in that model year. Because of the curves that represent the CAFE standard for each model year, a manufacturer with a relatively high percentage of smaller vehicles would have a higher standard than a manufacturer with a relatively low percentage of smaller vehicles.

Therefore, although a manufacturer's fleet average standard could be estimated throughout the model year based on the projected production volume of its vehicle fleet, the standard with which the manufacturer must comply would be based on its final model year vehicle production. Compliance would be determined by comparing a manufacturer's harmonically averaged fleet fuel economy level in a model year with a required fuel economy level calculated using the manufacturer's actual production levels and the targets for each vehicle it produces.[41] 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 II.B of the NPRM preamble, NHTSA includes a full discussion of the equations and coefficients that define the passenger car and light truck curves established for each model year.

[39] Production for sale in the United States.

[40] 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.

[41] While manufacturers may use a variety of flexibility mechanisms to comply with CAFE standards, 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).

1.3.1.2 HDPUV FE Standards

HDPUVs are defined in 49 CFR 523.7. This category of vehicles includes pickup trucks and vans with a GVWR between 8,501 pounds and 14,000 pounds (also referred to in the industry as Class 2b through 3 vehicles) and anything that manufacturers choose to certify under § 523.7. NHTSA sets standards for HDPUVs using an approach similar to that used to set CAFE standards.

Level of HDPUV FE Standards

The NPRM proposes new fuel consumption standards (specified as gallons per 100 miles) for HDPUVs that would be applied in largely the same manner as the standards set for these vehicle classes under the Phase 1 and Phase 2 HD Fuel Efficiency Improvement Program rules. All HDPUV FE standard alternatives under consideration by NHTSA would set HDPUV FE standards for MYs 2030–2035. All HDPUV FE standard action alternatives would be more stringent than the HDPUV No-Action Alternative. Under NHTSA's HDPUV FE action alternatives, the agency currently estimates that the combined average of manufacturers' required fuel consumption levels would be 4.54 to 3.64 gallons per 100 miles in MY 2030 and 3.73 to 1.70 gallons per 100 miles in MY 2035. This compares to estimated average required fuel consumption levels of 4.93 and 4.96 gallons per 100 miles in MY 2030 and MY 2035, respectively, under the HDPUV No-Action Alternative. Under NHTSA's Preferred Alternative for HDPUV FE standards, the agency currently estimates that the combined average of manufacturers' required fuel consumption levels would be 3.99 gallons per 100 miles in MY 2030 and 2.37 gallons per 100 miles in MY 2035.

Similar to CAFE standards, because the HDPUV FE standards are attribute-based and apply separately to each manufacturer, actual average required FE levels would 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 FE levels under each HDPUV regulatory alternative, any estimates of future sales are subject to considerable uncertainty. Therefore, the average future required FE under each regulatory alternative is also subject to considerable uncertainty.

Form of HDPUV FE Standards

As in the previous HD vehicle rulemakings, NHTSA is proposing to use work factor as the metric for setting HDPUV FE standards. The work factor attribute combines vehicle payload capacity and vehicle towing capacity, in pounds, with an additional fixed adjustment for four-wheel-drive vehicles. Fuel consumption targets would be determined for each vehicle with a unique work factor. These targets would then be production-weighted and summed to derive a manufacturer's annual fleet average standards. The NPRM proposes to establish separate curves for diesel and gasoline HDPUVs. See Section III.B.3 of the NPRM preamble for a complete discussion of the proposed HDPUV FE standards.

1.3.1.3 Program Flexibilities for Achieving Compliance

As with previous LD and HD vehicle rules, NHTSA is proposing CAFE and HDPUV FE standards that include a few changes to the program flexibilities for achieving compliance. The following flexibility provisions are discussed in Section VI of the NPRM preamble:

- Elimination of off-cycle and air conditioning efficiency fuel consumption improvement values for battery electric vehicles in the CAFE program starting in MY 2027.

- Elimination of the five-cycle and alternative approval pathways for the CAFE program starting in MY 2027.
- Elimination of the off-cycle credits for HDPUVs starting in MY 2030.

Other flexibilities that had been finalized in past rulemakings by NHTSA are not changing. Expiring flexibilities, such as incentives for full-size pickup trucks with strong hybrid technologies, will not be updated and will be allowed to sunset. NHTSA is not including any new flexibilities or incentives in this NPRM.

1.3.1.4 Compliance

CAFE Standards

The MY 2017 and beyond final rule, which was issued in 2012, established detailed and comprehensive regulatory provisions for compliance and enforcement under the CAFE and CO_2 emissions standards programs. In the SAFE Vehicles Final Rule, NHTSA and EPA made minor modifications to these provisions, as they would apply for model years beyond MY 2020. These changes are described in Section IX of the SAFE Vehicles Final Rule preamble. NHTSA's current compliance and enforcement program is described in Section VII of the MY 2024–2026 CAFE Final Rule.[42] NHTSA is proposing the following minor change to the CAFE standards compliance and enforcement provisions, which is described in detail in Section VI of the NPRM preamble.

- Requirement to respond to requests for information regarding off-cycle requests within 60 days for LD vehicles for MYs 2025 and 2026.

NHTSA makes its ultimate determination of a manufacturer's CAFE compliance obligation based on official reported and verified CAFE data received from EPA.[43] 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 600.512-12. EPA test procedures are contained in 40 CFR Part 600 and 40 CFR Part 86.

HDPUV FE Standards

For HDPUVs, vehicle testing is conducted on chassis dynamometers using the drive cycles from the EPA Federal Test Procedure (FTP) (or "city" test) and Highway Fuel Economy Test (HFET or "highway" test). The FTP and HFET results are weighted by 55 percent and 45 percent, respectively, and then harmonically averaged to calculate a combined cycle result. The 55/45 cycle weightings are the same as for the LD vehicle CAFE program because NHTSA and EPA believe the real-world driving patterns for HDPUVs are similar to those of LD trucks except that HDPUVs are typically operated at higher loads than LD trucks. NHTSA is proposing to continue to determine compliance with HDPUV FE standards through a fleet averaging process similar to the process used in determining passenger car and light truck compliance with CAFE standards. NHTSA is proposing minor changes to the FE standards compliance and enforcement provisions, which are described in detail in Section VI.C of the NPRM preamble.

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[42] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Final Rule, 87 FR 25710, 26025 (May 2, 2022).

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

1.3.2 Greenhouse Gas Standards for Light- and Medium-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*,[44] a case involving a 2003 EPA order denying a petition for rulemaking to regulate GHG emissions from motor vehicles under CAA Section 202(a).[45] 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 GHGs 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."[46] 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.[47]

Accordingly, the NHTSA and EPA joint final rulemakings for MY 2012–2016, MY 2017 and beyond, and MY 2021–2026 passenger cars and light trucks (SAFE Vehicles Final Rule), as well as EPA's most recent LD GHG standards rulemaking, are part of EPA's response to the U.S. Supreme Court decision.[48] 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 SAFE Vehicles Final Rule were closely coordinated despite being issued as separate regulatory actions. The CAFE and CO_2 standards for MY 2026 represented roughly equivalent levels of stringency and serve as a coordinated starting point for the agencies' proposed CAFE, HDPUV FE, and GHG standards for this current rulemaking effort. Similar to recent NHTSA CAFE standard and EPA GHG standard rulemakings, the current NHTSA and EPA proposals remain closely coordinated.

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[44] 549 U.S. 497 (2007).

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

[46] 549 U.S. at 531-32. For more information on *Massachusetts v. Environmental Protection Agency,* see Regulating Greenhouse Gas Emissions under the Clean Air Act; Advance Notice of Proposed Rulemaking, 73 FR 44354 at 44397 (July 30, 2008). 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.

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

[48] Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards; Final Rule, 86 FR 74434 (Dec. 30, 2021). SAFE Vehicles Final Rule, *supra* note 15. Light-Duty Vehicle 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).

1.4 Cooperating Agencies

Section 1501.8 of the CEQ NEPA implementing regulations emphasizes agency cooperation early in the NEPA process and authorizes a lead agency (in this case, NHTSA) to request the assistance of other agencies that have either jurisdiction by law or special expertise regarding issues considered in an EIS.[49] NHTSA invited EPA and the U.S. Department of Energy (DOE) to become cooperating agencies with NHTSA in the development of this EIS. Additionally, EISA directs that NHTSA's HD rulemaking must be conducted in consultation with EPA and the Department of Energy.[50] EPA and DOE accepted NHTSA's invitation and agreed to become cooperating agencies.[51] EPA and DOE personnel were asked to review and comment on this EIS prior to publication.

1.5 Public Review and Comment

On August 16, 2022, NHTSA published a notice of intent to prepare an EIS to analyze the potential environmental impacts of CAFE standards for MY 2027 and beyond passenger cars and light trucks and FE standards for MY 2029 and beyond HDPUVs.[52] The notice described the statutory requirements for the standards, provided information about the NEPA process, and initiated the scoping process by requesting public input on the scope of the environmental analysis.[53] Another key purpose of scoping is to "deemphasize insignificant issues, narrowing the scope of the [EIS] process accordingly."[54] NHTSA invited the public to submit scoping comments on the notice on or before September 15, 2022, by posting to the NHTSA EIS docket (Docket No. NHTSA-2022-0075).

Consistent with NEPA and its implementing regulations, NHTSA provided direct notice of the availability of the agency's published scoping notice to likely interested individuals and stakeholders. Specifically, NHTSA mailed a notification of the scoping notice to Governors of every state and U.S. territory and Native American tribes and tribal organizations. In addition, NHTSA sent email notification of the availability of the scoping notice to other potential stakeholders, including:

- 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.
- Organizations representing state and local governments.

[49] 40 CFR 1501.8.

[50] 49 U.S.C. 32902(k)(2).

[51] 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 GHG emissions standards for LD 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.

[52] Notice of Intent To Prepare an Environmental Impact Statement for Model Years 2027 and Beyond Corporate Average Fuel Economy Standards and Model Years 2029 and Beyond Heavy-Duty Pickup Trucks and Vans Vehicle Fuel Efficiency Improvement Program Standards, 87 FR 50386 (Aug. 16, 2022). NHTSA's Notice of Intent included MY 2029, however in accordance with 49 U.S.C. 32902(k)(3)(B), NHTSA must provide 3 years of regulatory stability for new HDPUV standards. Because MY 2027 is the last finalized HDPUV standard, NHTSA will begin setting HDPUV standards in MY 2030.

[53] Scoping, as defined under NEPA, is an early and open process to determine the scope of issues for analysis in an EIS, including identifying the significant issues and eliminating from further study nonsignificant issues. 40 CFR 1501.9.

[54] 40 CFR 1500.4(i).

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

NHTSA received 20 public comments on the notice of intent.[55] Scoping comments were received from four original equipment manufacturers (Cummins Inc.; Rivian Automotive, LLC; Hyundai Motor America; and Tesla, Inc.) and four trade associations (American Petroleum Institute, Growth Energy, Zero Emission Transportation Association, and The Aluminum Association). In addition, NHTSA received scoping comments from two advocacy organizations: Environmental Law & Policy Center and Sierra Club and Earthjustice (joint comment letter). Scoping comments were also received from state and local governments and Native American tribes: Pennsylvania Department of Transportation, State of Missouri Office of Administration, Office of the Oakland City Attorney, Mille Lacs Band of Ojibwe, and Southern Ute Indian Tribe. Finally, NHTSA received five scoping comments from private citizens. Appendix B, *Scoping Comments*, includes summaries of all scoping comments received by issue topic. This summary includes identification of all alternatives, information, and analyses submitted by public commenters during the scoping process, as required by 40 CFR 1502.17. NHTSA requests comments and feedback on the agency's summary of scoping comments presented in Appendix B, *Scoping Comments*.[56] All comments received are available at http://www.regulations.gov, Docket No. NHTSA-2022-0075.

Commenters went beyond the traditional scoping inquiry related to the nature and content of the environmental analysis. For example, some commenters made suggestions relating to various components of the CAFE and HDPUV FE standards (e.g., attribute-based curves, inclusion of a backstop, compliance flexibilities). Other commenters addressed the technological and economic assumptions included in NHTSA's CAFE Model. Comments of this nature are more directly relevant to the NHTSA rulemaking than they are to determining the scope of the environmental analysis, identifying impacts that should be analyzed in depth, or identifying impacts that require less detailed consideration. NHTSA has evaluated these comments in preparing the NPRM and will consider them in light of all other substantive comments received before making a final decision and issuing a final rule. Although NHTSA acknowledges areas of overlap with other aspects of the rulemaking, the comments summarized in Appendix B focus more specifically on the EIS scoping process.

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

This EIS is being issued for public review and comment concurrently with the NPRM to establish passenger car and light truck CAFE standards and HDPUV FE standards. NHTSA invites comments on this EIS, including the alternatives evaluated and methodologies used for analysis. Specifically, NHTSA solicits comments on the range of alternatives considered for CAFE standards and HDPUV FE standards, including intended model years and stringencies. Individuals may submit their written comments on the EIS, identified by docket number NHTSA-2022-0075, by any of the following methods:

- **Federal eRulemaking Portal***:* Go to http://www.regulations.gov. Follow the online instructions for submitting comments.

[55] The full comment letters can be found at www.regulations.gov under the search term *NHTSA-2022-0075*, which corresponds to the docket number for this EIS. All comments will be displayed in the search results.

[56] 40 CFR 1502.17(a)(2).

- **Mail:** Docket Management Facility: U.S. Department of Transportation, 1200 New Jersey Avenue SE, West Building Ground Floor, Room W12-140, Washington, DC 20590-0001.
- **Hand Delivery or Courier:** West Building Ground Floor, Room W12-140, 1200 New Jersey Avenue SE, between 9 a.m. and 5 p.m. ET, Monday through Friday, except Federal holidays. To be sure someone is there to help you, please call (202) 366-9826 before coming.
- **Fax:** (202) 493-2251.

Regardless of how you submit your comments, you must include Docket No. NHTSA-2022-0075 on your comments. All comments received, including any personal information provided, will be posted without change to http://www.regulations.gov, as described in the system of records notice (DOT/ALL-14 FDMS), which can be reviewed at https://www.transportation.gov/privacy. Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comments, if submitted on behalf of an association, business, labor union, etc.). You may call the Docket Management Facility at (202) 366-9826.

EPA will publish a Notice of Availability of this EIS in the *Federal Register*. That notice will include a deadline by which comments on this EIS must be received. The deadline for receiving comments will also be posted on NHTSA's website. A public hearing will be held during the public comment period; details regarding and a date for the public hearing will be released on NHTSA's website.

NHTSA will simultaneously issue the Final EIS and Record of Decision (i.e., the final rule), pursuant to 49 U.S.C. 304a(b) and DOT's *Final Guidance on the Use of Combined Final Environmental Impact Statements/Records of Decision and Errata Sheets in National Environmental Policy Act Reviews* (DOT 2019a)[57] unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.

[57] Available at: https://www.transportation.gov/sites/dot.gov/files/docs/mission/transportation-policy/permittingcenter/337371/feis-rod-guidance-final-04302019.pdf.

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 a range of reasonable alternatives that meet the purpose and need for the proposed action.[1] An agency must explore and evaluate all reasonable alternatives, including the alternative of taking no action.[2] For alternatives that an agency eliminates from detailed study, the agency must "briefly discuss the reasons for their elimination."[3] The purpose of and need for the agency's action (Chapter 1, *Purpose and Need for the Action*) provide the foundation for determining the range of reasonable alternatives to be considered in its NEPA analysis.[4]

This chapter describes the Proposed Action and alternatives, explains the methods and assumptions applied in the analysis of environmental impacts, describes the resource areas dismissed from further consideration, 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 Dismissed from Further Consideration in this EIS and EIS Organization*
- Section 2.5, Resource Areas Affected and Types of Emissions

2.2 Proposed Action and Alternatives

NHTSA's action is a rulemaking to set CAFE standards for MY 2027–2032[5] passenger cars and light trucks (also referred to as the light-duty [LD] vehicle fleet) and fuel efficiency (FE) standards for MY 2030–2035 heavy-duty pickup trucks and vans (HDPUVs) in accordance with the Energy Policy and Conservation Act of 1975 (EPCA),[6] as amended by the Energy Independence and Security Act of 2007 (EISA).[7] The MY 2032 standards proposed for passenger cars and light trucks are "augural," in that they fall beyond the statutory 5-model-year period set out in 49 U.S.C. 32902, and thus represent what the agency *would* propose, based on current information, but NHTSA would not be finalizing those standards as part of this rulemaking effort. However, NHTSA includes the proposed MY 2032 augural standards as part of the analysis of environmental impacts considered in this EIS.

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[1] 40 CFR 1502.14; 40 CFR 1508.1(z).

[2] 40 CFR 1502.14(c).

[3] 40 CFR 1502.14(a).

[4] 40 CFR 1502.13. See City of Carmel-By-The-Sea v. U.S. Dept. of Transp., 123 F.3d 1142, 1155 (9th Cir. 1997); City of Alexandria v. Slater, 198 F.3d 862, 867-69 (D.C. Cir. 1999), cert. denied sub nom., 531 U.S. 820 (2000).

[5] Because in any single rulemaking under the Energy Policy and Conservation Act of 1975 (EPCA), CAFE standards may be established for not more than 5 model years, NHTSA intends to issue conditional (or augural) CAFE standards for MY 2032. The CAFE standards for MY 2032 will be determined with finality in a subsequent, *de novo* notice-and-comment rulemaking conducted in full compliance with 49 U.S.C. 32902 and other applicable law.

[6] 42 U.S.C. 6201 et seq.

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

For the purpose of this analysis, the impacts of the proposed CAFE standards and alternatives are measured relative to a CAFE No-Action Alternative, which assumes that the national CAFE and greenhouse gas (GHG) MY 2026 standards[8] finalized in 2022 continue in perpetuity, as well as including the zero-emission vehicle (ZEV) mandates issued by California and other *Section 177* states (see Section 2.2.1.1, *CAFE No-Action Alternative*, for a full description of the CAFE No-Action Alternative). In developing the CAFE standards and alternatives, NHTSA considered the four EPCA statutory factors that guide the agency's determination of maximum feasible standards: technological feasibility, economic practicability, the effect of other motor vehicle standards of the government on fuel economy, and the need of the United States to conserve energy.[9] In addition, NHTSA considered relevant safety and environmental factors.[10] As discussed further in Section I of the preamble to the proposed rule, NHTSA's review of its CAFE standards 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, and also comports with the President's direction in Executive Order 14037.[11] During the process of developing the CAFE and HDPUV FE standards, NHTSA consulted with EPA and the U.S. Department of Energy (DOE) regarding a variety of matters, as required by EPCA.[12]

Similarly, the impacts of the HDPUV FE standards and alternatives are measured relative to an HDPUV No-Action Alternative, which assumes that the MY 2027 HDPUV FE standards finalized jointly by EPA and NHTSA in the Heavy-Duty (HD) Fuel Efficiency Improvement Program Phase 2[13] continue in perpetuity. In developing the HDPUV FE standards and alternatives, NHTSA considered the three EISA requirements that (1) the program must be "designed to achieve the maximum feasible improvement"; (2) the various required aspects of the program must be appropriate, cost-effective, and technologically feasible for [HD vehicles]; and (3) the standards adopted under the program must not provide less than 4 model years of lead time and 3 model years of regulatory stability.[14] In considering these various requirements, NHTSA also accounted for relevant environmental and safety considerations.

Consistent with CEQ NEPA implementing regulations, this EIS compares a reasonable range of CAFE standard action alternatives to the CAFE No-Action Alternative and a reasonable range of HDPUV FE standard action alternatives to the HDPUV No-Action Alternative (Section 2.2.1, *No-Action Alternatives*)

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[8] NHTSA has issued its LD fuel economy and medium- and heavy-duty FE standards in close coordination with EPA's setting of national GHG vehicle emissions standards because both standards affect the same vehicles. Although the agencies' programs and standards are closely coordinated, they are separate. NHTSA issues CAFE and FE standards pursuant to its statutory authority under EPCA, as amended by EISA. EPA sets national GHG emissions standards under Section 202(a) of the Clean Air Act (42 U.S.C. 7521(a)). In addition, EPA has the responsibility to measure passenger car and light truck fleet fuel economy pursuant to EPCA (49 U.S.C. 32904(c)).

[9] 49 U.S.C. 32902(f).

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

[11] Strengthening American Leadership in Clean Cars and Trucks; Presidential Document, 86 FR 43583 (Aug. 10, 2021).

[12] 49 U.S.C. 32902(i).

[13] 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).

[14] 49 U.S.C. 32902(k)(2) and (3).

and identifies the agency's preferred alternatives.[15] NHTSA has recommended Alternative PC2LT4 (Preferred Alternative for CAFE standards), which means that passenger car (PC) stringency increases at a rate of 2 percent per year (2) and light truck (LT) stringency increases at a rate of 4 percent per year (4), as the CAFE program Preferred Alternative. NHTSA has recommended Alternative HDPUV10 (Preferred Alternative for HDPUV FE standards), which means that HDPUV stringency increases at a rate of 10 percent per year, as the FE program Preferred Alternative. The different action alternatives are defined in terms of percent-increases in stringency from year to year, but they differ slightly between passenger cars and light trucks on the one hand, and HDPUVs on the other. For passenger cars and light trucks, readers should recognize that those year-over-year changes in stringency are not measured in terms of mile per gallon differences (as in, 1 percent more stringent than 30 miles per gallon [mpg] in 1 year equals 30.3 mpg in the following year), but rather in terms of shifts in the footprint functions that form the basis of the actual CAFE standards (as in, on a gallon per mile basis, the CAFE standards change by a given percentage from one model year to the next).

Because NHTSA intends to set standards for passenger cars, light trucks, and HDPUVs,[16] and because evaluating the environmental impacts of this rule requires consideration of the impacts of the standards for all three vehicle classes, the main analyses of direct and indirect effects of the Proposed Action and alternatives presented in this EIS reflect: (1) the environmental impacts associated with the proposed CAFE standards for LD vehicles, and (2) the environmental impacts associated with the proposed HDPUV FE standards. The analyses of cumulative impacts of the Proposed Action and alternatives presented in this EIS reflect the cumulative or combined impact of the two sets of standards that are being proposed by NHTSA in its proposed rule. Appendix A, *Modeling Results Reported Separately by Vehicle Class*, shows separate results for passenger cars and light trucks under each CAFE standard alternative, results for HDPUVs under each HDPUV FE standard alternative, and cumulative impacts climate modeling results separately for LD vehicles and HDPUVs for each CAFE and HDPUV FE alternative.

The CAFE standard action alternatives considered in this EIS are attribute-based standards based on vehicle footprint.[17] Footprint is the rectangular area measured from where the four tires hit the ground. 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

[15] 40 CFR 1502.14(d).

[16] 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. Separately, and in accordance with EPCA, as amended by EISA, NHTSA is required to set FE standards for HDPUVs in each model year that are "designed to achieve the maximum feasible improvement" (49 U.S.C. 32902(k)(2)).

[17] The different action alternatives are defined in terms of percent-increases in stringency from year to year, but they differ slightly between passenger cars and light trucks on the one hand, and HDPUVs on the other. For passenger cars and light trucks, readers should recognize that year-over-year changes in stringency are not measured in terms of mpg differences (as in, 1 percent more stringent than 30 mpg in 1 year equals 30.3 mpg in the following year), but rather in terms of shifts in the footprint functions that form the basis of the actual CAFE standards (as in, on a gallon-per-mile basis, the CAFE standards change by a given percentage from one model year to the next). In other words, the footprint-based standard curves increase for each alternative based on percent increases in fuel efficiency (gallons per mile), and not fuel economy (mpg).

of the model year would therefore be based on the production-weighted average target and performance of each model in its fleet. The HDPUV FE standard action alternatives considered in this EIS are attribute-based standards based on work factor. The work factor attribute combines vehicle payload capacity and vehicle towing capacity, in pounds, with an additional fixed adjustment for four-wheel-drive vehicles. Fuel consumption targets would be determined for each vehicle with a unique work factor. These targets would then be production-weighted and summed to derive a manufacturer's annual fleet average standards. The notice of proposed rulemaking (NPRM) proposes to establish separate curves for diesel and gasoline HDPUVs. As discussed in Chapter 1, Section 1.6, *Next Steps in the National Environmental Policy Act and Joint Rulemaking Process*, NHTSA invites comments on the alternatives considered in this EIS.

2.2.1 No-Action Alternatives

The CAFE and HDPUV No-Action Alternatives represent a lower bound of CAFE and HDPUV FE stringency that NHTSA can consider and provide an analytical baseline against which to compare the environmental impacts of the CAFE and HDPUV FE standard action alternatives, respectively, presented in the EIS.[18] 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 CAFE and HDPUV FE standard action alternatives are calculated in relation to the baseline of the relevant No-Action Alternative.

2.2.1.1 CAFE No-Action Alternative

The CAFE No-Action Alternative assumes that the MY 2026 CAFE standards finalized in 2022[19] continue in perpetuity.[20] In addition, the No-Action Alternative assumes that manufacturers would comply with ZEV mandates issued by California and other *Section 177* states.[21] The No-Action Alternative also assumes that manufacturers would make production decisions in response to estimated market demand for fuel economy or fuel efficiency, considering estimated fuel prices; estimated product development cadence; estimated availability, applicability, cost, and effectiveness of fuel-saving technologies; and

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[18] 40 CFR 1502.2(e), 1502.14(c) (2020). 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).

[19] Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks; Final Rule, 87 FR 25710 (May 2, 2022). Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards; Final Rule, 86 FR 74434 (Dec. 30, 2021).

[20] In the last CAFE analysis, the No-Action Alternative also included five manufacturers' voluntary agreements with the State of California to achieve more stringent GHG standards through MY 2026. The stringency in the California Framework Agreement standards were superseded with EPA's revised GHG rule. Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards; Final Rule, 86 FR 74434 (Dec. 30, 2021).

[21] Section 177 of the Clean Air Act allows states to adopt motor vehicle emissions standards California has put in place. 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 California Air Resources Board, *States that have Adopted California's Vehicle Standards under Section 177 of the Federal Clean Air Act*, https://ww2.arb.ca.gov/resources/documents/states-have-adopted-californias-vehicle-standards-under-section-177-federal. Accessed: Mar. 25, 2023.

available tax credits. The No-Action Alternative further assumes the applicability of recently passed tax credits for battery-based vehicle technologies, which improve the attractiveness of those technologies to consumers.

Table 2.2.1-1 shows the estimated average required fleet-wide fuel economy NHTSA forecasts under the CAFE No-Action Alternative for LD vehicles. The values reported in that table do not apply strictly to manufacturers in those model years. 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 2027–2032 CAFE standards) to the market forecast defining the estimated future fleets of new passenger cars and light trucks across all manufacturers. The fuel economy numbers presented here do not include a fuel economy adjustment factor to account for real-world driving conditions (see Section 2.2.4, *Gap between Compliance Fuel Economy and Real-World Fuel Economy*, for more discussion about the difference between adjusted and unadjusted 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 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Passenger cars	58.8	58.8	58.8	58.8	58.8	58.8
Light trucks	42.6	42.6	42.6	42.6	42.6	42.6
Combined cars and trucks	46.7	46.7	46.7	46.7	46.7	46.7

mpg = miles per gallon

2.2.1.2 HDPUV No-Action Alternative

The HDPUV No-Action Alternative assumes that the MY 2027 HDPUV FE standards finalized in the Phase 2 program[22] continue in perpetuity. The No-Action Alternative also takes into account the California Air Resources Board's (CARB's) Advanced Clean Trucks (ACT) program, set to begin in MY 2024; the ACT program stipulates that manufacturers must electrify specified percentages of their HD fleets in order to continue selling HD vehicles in California and other states that have formally adopted the program. The No-Action Alternative also assumes that manufacturers would make production decisions in response to estimated market demand for fuel economy or fuel efficiency, considering estimated fuel prices; estimated product development cadence; estimated availability, applicability, cost, and effectiveness of fuel-saving technologies; and available tax credits. The No-Action Alternative further assumes the applicability of recently passed tax credits for battery-based vehicle technologies, which improve the attractiveness of those technologies to consumers.

Table 2.2.1-2 shows the estimated average required fleet-wide fuel consumption standards NHTSA forecasts under the HDPUV No-Action Alternative. The values reported in that table do not apply strictly to manufacturers in those model years. The values in Table 2.2.1-2 reflect NHTSA's estimate based on application of the mathematical function defining the alternative (i.e., the curves that define the MY 2030–2035 FE standards) to the market forecast defining the estimated future fleets of new HDPUVs across all manufacturers. The fuel efficiency numbers presented here do not include a fuel efficiency adjustment factor to account for real-world driving conditions (see Section 2.2.4, *Gap between*

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

Compliance Fuel Economy and Real-World Fuel Economy, for more discussion about the difference between adjusted and unadjusted fuel economy [mpg] and fuel efficiency [gallons per 100 miles] values).

Table 2.2.1-2. No-Action Alternative: Estimated Average Required U.S. Heavy-Duty Pickup Trucks and Vans Fleet-Wide Fuel Efficiency (gallons per 100 miles) by Model Year

	MY 2030	MY 2031	MY 2032	MY 2033	MY 2034	MY 2035
Heavy-Duty Pickup Trucks and Vans	4.93	5.01	5.01	4.96	4.96	4.96

2.2.2 Action Alternatives

2.2.2.1 CAFE Standard Action Alternatives

In addition to the CAFE No-Action Alternative, NHTSA analyzed a range of CAFE standard action alternatives with fuel economy stringencies that increase, on average, between 1 percent and 6 percent annually from the MY 2026 standards for passenger cars and increase, on average, between 3 percent and 8 percent for light trucks. Under each action alternative, EPA GHG emissions standards and manufacturers' compliance with state 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 2032 CAFE standards for each alternative would continue indefinitely.[23] 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 the CAFE standard No-Action Alternative and action alternatives under consideration.[24]

Throughout this EIS, estimated impacts are shown for the No-Action Alternative and four CAFE standard action alternatives that illustrate the following range of estimated average annual percentage increases in fuel economy for both passenger cars and light trucks:

Alt. PC1LT3 — 1 percent increase per year, year over year for MY 2027–2032 passenger cars, and 3 percent per year, year over year for MY 2027–2032 light trucks

Alt. PC2LT4 — 2 percent increase per year, year over year for MY 2027–2032 passenger cars, and 4 percent per year, year over year for MY 2027–2032 light trucks (Alternative PC2LT4 is NHTSA's Preferred Alternative for CAFE standards)

Alt. PC3LT5 — 3 percent increase per year, year over year for MY 2027–2032 passenger cars, and 5 percent per year, year over year for MY 2027–2032 light trucks

[23] All CAFE standard action alternatives assume the MY 2032 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 EIS would also depend on future standards established by NHTSA, but cannot be quantified at this time.

[24] For a full discussion of the agency's balancing of the statutory factors related to maximum feasible standards, consult the proposed rule. NHTSA balances the statutory factors in Section V.A of the proposed rule preamble.

Alt. PC6LT8 6 percent increase per year, year over year for MY 2027–2032 passenger cars, and 8 percent per year, year over year for MY 2027–2032 light trucks

The range of alternatives under consideration encompasses a spectrum of possible standards that NHTSA could select based on how it weighs EPCA's four statutory factors. These alternatives reflect differences in the degree of technology adoption across the fleet, costs to manufacturers and consumers, and conservation of oil and related reductions in GHG emissions. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the projected environmental effects of points that fall between the individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers the ability to select from a wide range of alternatives that begin with the No-Action Alternative and that increase up to 6 percent for passenger cars and up to 8 percent for light trucks. Within this range, stringencies could remain the same or differ year to year between and among regulatory classes.

Tables for each of the CAFE standard action alternatives show estimated average required fuel economy levels reflecting application of the mathematical functions defining the alternatives to the market forecast defining the estimated future fleets of new passenger cars and light trucks across all manufacturers. The actual standards under the alternatives are footprint-based and each manufacturer would have a CAFE standard that is unique to each of its fleets, depending on the footprints and production volumes of the vehicle models produced by that manufacturer. The required fuel economy values projected for each action alternative do not include a fuel economy adjustment factor to account for real-world driving conditions. (See Section 2.2.4, *Gap between Compliance Fuel Economy and Real-World Fuel Economy,* for more discussion about the difference between adjusted and unadjusted economy.)

This EIS 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 EIS 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 proposed rule, NHTSA has tentatively determined that Alternative PC2LT4 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 has tentatively determined that Alternative PC2LT4 is maximum feasible for MYs 2027–2032 and is the Preferred Alternative.

Alternative PC1LT3: 1 percent increase per year for MY 2027–2032 passenger cars and 3 percent increase per year for MY 2027–2032 light trucks

Alternative PC1LT3 would require a 1 percent annual fleet-wide increase in fuel economy for passenger cars and a 3 percent annual fleet-wide increase in fuel economy for light trucks for MYs 2027–2032. Table 2.2.2-1 lists the estimated average required fleet-wide fuel economy under Alternative PC1LT3, as estimated in the analysis performed for this EIS.[25]

[25] The analysis performed for the EIS 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 EIS and

Table 2.2.2-1. Alternative PC1LT3: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Passenger cars	59.4	60.0	60.6	61.2	61.8	62.4
Light trucks	43.9	45.3	46.7	48.1	49.6	51.2
Combined cars and trucks	47.9	49.1	50.3	51.6	53.0	54.3

mpg = miles per gallon

Alternative PC2LT4 (Preferred Alternative): 2 percent increase per year for MY 2027–2032 passenger cars and 4 percent increase per year for MY 2027–2032 light trucks

Alternative PC2LT4 would require a 2 percent annual fleet-wide increase in fuel economy for passenger cars and a 4 percent annual fleet-wide increase in fuel economy for light trucks for MYs 2027–2032. Table 2.2.2-2 lists the estimated average required fleet-wide fuel economy under Alternative PC2LT4.

Table 2.2.2-2. Alternative PC2LT4: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Passenger cars	60.0	61.2	62.5	63.7	65.1	66.4
Light trucks	44.4	46.2	48.2	50.2	52.2	54.4
Combined cars and trucks	48.4	50.1	51.9	53.8	55.7	57.7

mpg = miles per gallon

Alternative PC3LT5: 3 percent increase per year for MY 2027–2032 passenger cars and 5 percent increase per year for MY 2027–2032 light trucks

Alternative PC3LT5 would require a 3 percent annual fleet-wide increase in fuel economy for passenger cars and a 5 percent annual fleet-wide increase in fuel economy for light trucks for MYs 2027–2032. Table 2.2.2-3 lists the estimated average required fleet-wide fuel economy under Alternative PC3LT5.

Table 2.2.2-3. Alternative PC3LT5: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Passenger cars	60.6	62.5	64.4	66.4	68.5	70.6
Light trucks	44.9	47.2	49.7	52.3	55.1	58.0
Combined cars and trucks	48.9	51.2	53.5	56.1	58.7	61.5

mpg = miles per gallon

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.

Alternative PC6LT8: 6 percent increase per year for MY 2027–2032 passenger cars and 8 percent increase per year for MY 2027–2032 light trucks

Alternative PC6LT8 would require a 6 percent annual fleet-wide increase in fuel economy for passenger cars and an 8 percent annual fleet-wide increase in fuel economy for light trucks for MYs 2027–2032. Table 2.2.2-4 lists the estimated average required fleet-wide fuel economy under Alternative PC6LT8.

Table 2.2.2-4. Alternative PC6LT8: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032
Passenger cars	62.5	66.5	70.8	75.3	80.1	85.2
Light trucks	46.3	50.3	54.7	59.5	64.6	70.3
Combined cars and trucks	50.5	54.5	58.9	63.7	68.9	74.4

mpg = miles per gallon

2.2.2.2 HDPUV FE Standard Action Alternatives

In addition to the HDPUV No-Action Alternative, NHTSA analyzed a range of HDPUV FE standard action alternatives with FE stringencies that increase, on average, between about 4 percent and 14 percent annually from the MY 2029 HDPUV FE fuel consumption standards finalized in the Phase 2 program. Under each action alternative, CARB's ACT program is treated in the same manner as under the No-Action Alternative.

For purposes of its analysis, NHTSA assumes that the MY 2035 HDPUV FE standards for each alternative would continue indefinitely.[26] The agency believes that, based on the different ways the agency could weigh EISA's requirements, the maximum feasible improvement of FE stringency falls within the range of alternatives under consideration.[27]

Throughout this EIS, estimated impacts are shown for three HDPUV FE standard action alternatives that illustrate the following range of estimated average annual percentage increases in fuel efficiency for HDPUVs:

Alt. HDPUV4 4 percent increase per year, year over year for MY 2030–2035 HDPUVs

Alt. HDPUV10 10 percent increase per year, year over year for MY 2030–2035 HDPUVs (Alternative HDPUV10 is NHTSA's Preferred Alternative for HDPUV FE standards)

Alt. HDPUV14 14 percent increase per year, year over year for MY 2030–2035 HDPUVs

NHTSA reasonably believes the maximum feasible improvement falls within the range of alternatives presented in this EIS. This range encompasses a spectrum of possible standards that NHTSA could select

[26] All HDPUV FE standard action alternatives assume the MY 2035 standards would continue indefinitely. Because EPCA, as amended by EISA, requires NHTSA to set FE standards for each model year, environmental impacts reported in this EIS would also depend on future standards established by NHTSA, but cannot be quantified at this time.

[27] For a full discussion of the agency's balancing of EISA's requirements, consult the proposed rule. NHTSA balances the requirements in Section V.A of the proposed rule preamble.

that would satisfy EISA's requirements of increasing the fuel efficiency of HDPUVs. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the environmental impacts of points that fall between those individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers with the ability to select from a wide range of potential alternatives that begin with the No-Action Alternative and that increase up to 14 percent for HDPUVs. Within this range, stringency could remain the same or differ year to year.

Tables for each of the HDPUV FE standard action alternatives show estimated average required fuel consumption levels reflecting application of the mathematical functions defining the alternatives to the market forecast defining the estimated future fleets of new HDPUVs across all manufacturers. The actual standards under the alternatives are attribute-based and each manufacturer would have a FE standard that is unique to each of its fleets, depending on the work factor and production volumes of the vehicle models produced by that manufacturer. The required fuel consumption values projected for each action alternative do not include a fuel efficiency adjustment factor to account for real-world driving conditions. (See Section 2.2.4, *Gap between Compliance Fuel Economy and Real-World Fuel Economy,* for more discussion about the difference between adjusted and unadjusted fuel economy.) New fuel consumption standards for HDPUVs are specified as gallons per 100 miles.

As noted in the preamble to the proposed rule, NHTSA has tentatively determined that Alternative HDPUV10 is appropriate, cost-effective, and technologically feasible. NHTSA has tentatively determined that Alternative HDPUV10 is maximum feasible for MYs 2030–2035 and is the Preferred Alternative.

Alternative HDPUV4: 4 percent increase per year for MY 2030–2035 heavy-duty pickup trucks and vans

Alternative HDPUV4 would require a 4 percent annual fleet-wide increase in fuel efficiency for HDPUVs for MYs 2030–2035. Table 2.2.2-5 lists the estimated average required fleet-wide fuel efficiency under Alternative HDPUV4.

Table 2.2.2-5. Alternative HDPUV4: Estimated Average Required U.S. Heavy-Duty Pickup Trucks and Vans Fleet-Wide Fuel Efficiency (gallons per 100 miles) by Model Year[a]

	MY 2030	MY 2031	MY 2032	MY 2033	MY 2034	MY 2035
Heavy-Duty Pickup Trucks and Vans	4.54	4.43	4.25	4.05	3.88	3.73

Notes:
[a] = HDPUV fleet required and achieved fuel economy and fuel consumption values are provided in the Preliminary Regulatory Impact Analysis.

Alternative HDPUV10 (Preferred Alternative): 10 percent increase per year for MY 2030–2035 heavy-duty pickup trucks and vans

Alternative HDPUV10 would require a 10 percent annual fleet-wide increase in fuel efficiency for HDPUVs for MYs 2030–2035. Table 2.2.2-6 lists the estimated average required fleet-wide fuel efficiency under Alternative HDPUV10.

Table 2.2.2-6. Alternative HDPUV10: Estimated Average Required U.S. Heavy-Duty Pickup Trucks and Vans Fleet-Wide Fuel Efficiency (gallons per 100 miles) by Model Year [a]

	MY 2030	MY 2031	MY 2032	MY 2033	MY 2034	MY 2035
Heavy-Duty Pickup Trucks and Vans	3.99	3.64	3.28	2.92	2.63	2.37

Notes:
[a] HDPUV fleet required and achieved fuel economy and fuel consumption values are provided in the Preliminary Regulatory Impact Analysis.

Alternative HDPUV14: 14 percent increase per year for MY 2030–2035 heavy-duty pickup trucks and vans

Alternative HDPUV14 would require a 14 percent annual fleet-wide increase in fuel efficiency for HDPUVs for MYs 2030–2035. Table 2.2.2-7 lists the estimated average required fleet-wide fuel efficiency under Alternative HDPUV14.

Table 2.2.2-7. Alternative HDPUV14: Estimated Average Required U.S. Heavy-Duty Pickup Trucks and Vans Fleet-Wide Fuel Efficiency (gallons per 100 miles) by Model Year [a]

	MY 2030	MY 2031	MY 2032	MY 2033	MY 2034	MY 2035
Heavy-Duty Pickup Trucks and Vans	3.64	3.14	2.70	2.30	1.98	1.70

Notes:
[a] HDPUV fleet required and achieved fuel economy and fuel consumption values are provided in the Preliminary Regulatory Impact Analysis.

2.2.3 U.S. Environmental Protection Agency's Greenhouse Gas Standards

As explained in Chapter 1, Section 1.3.2, *Greenhouse Gas Standards for Light- and Medium-Duty Vehicles (U.S. Environmental Protection Agency)*, NHTSA has issued its LD fuel economy and medium- and heavy-duty FE standards in close coordination with EPA's setting of national GHG vehicle emissions standards since EPA first began setting these standards in 2012. EPA is in the process of amending its GHG emissions standards under Section 202(a) of the Clean Air Act for MYs 2027–2032.[28] Table 2.2.3-1 and Table 2.2.3-2 list EPA's estimates of its projected overall fleet-wide CO_2 emissions compliance targets under its revised standards.

Table 2.2.3-1. Proposed U.S. Passenger Car and Light-Truck Fleet-Wide Carbon Dioxide Emissions Compliance Targets under EPA's Greenhouse Gas Standards (grams/mile)

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032 [a]
Passenger cars	134	116	99	91	82	73
Light trucks	163	142	120	110	100	89
Combined cars and trucks [b]	152	131	111	102	93	82

Notes:
[a] Applies to MY 2032 and later.
[b] The combined cars and trucks carbon dioxide targets are a function of assumed car/truck shares.

[28] Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles; Proposed Rule, 88 FR 29184 (May 5, 2023).

Table 2.2.3-2. Proposed HDPUV Fleet-Wide Carbon Dioxide Emissions Compliance Targets under EPA's Greenhouse Gas Standards (grams/mile)

	MY 2027	MY 2028	MY 2029	MY 2030	MY 2031	MY 2032 [a]
Vans	393	379	345	309	276	243
Pickup Trucks	462	452	413	374	331	292
Combined vans and pickup trucks [b]	438	427	389	352	312	275

Notes:
[a] Applies to MY 2032 and later.
[b] The combined vans and pickup trucks carbon dioxide targets are a function of assumed vans/pickup truck shares.

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

Real-world fuel economy levels achieved by LD vehicles in on-road driving are lower than the corresponding levels measured under the laboratory-like test conditions used to determine CAFE compliance. This difference 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; also, 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.[29]

For HDPUVs, vehicle testing is conducted on chassis dynamometers using the drive cycles from the EPA Federal Test Procedure (city test) and Highway Fuel Economy Test (highway test). The Federal Test Procedure and Highway Fuel Economy Test results are weighted by 55 percent and 45 percent, respectively, and then harmonically averaged to calculate a combined cycle result. The 55/45 cycle weightings are the same as for the LD CAFE program because NHTSA and EPA believe the real-world driving patterns for HDPUVs are similar to those of light trucks except that HDPUVs are typically operated at higher loads than light trucks. Compliance with fuel consumption standards for HDPUVs will continue to be determined through a fleet averaging process similar to the process used in determining passenger car and light truck compliance with CAFE standards. NHTSA is proposing minor changes to the FE standards compliance and enforcement provisions, which are described in detail in Section VI.C of the NPRM preamble.

For more discussion of the on-road fuel economy gap (the difference between adjusted and unadjusted mpg), see Chapter 2.3.7 of the Technical Support Document (TSD).

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

2.3 Standard-Setting and EIS Methods and Assumptions

Each of the CAFE and HDPUV FE standard action alternatives considered in the EIS represents a different manner in which NHTSA could conceivably balance its statutory factors and considerations in setting the CAFE standards and HDPUV FE standards. For example, the most stringent CAFE standard action alternative in terms of required mpg (Alternative PC6LT8) would involve a 6 percent per year average annual fleet-wide increase in fuel efficiency for passenger cars and an 8 percent per year average annual fleet-wide increase in fuel efficiency for light trucks for MYs 2027–2032;[30] the most stringent HDPUV FE standard action alternative in terms of required fuel consumption (gallons per 100 miles) would involve a 14 percent per year average annual fleet-wide increase in fuel efficiency for HDPUVs for MYs 2030–2035. In contrast, the least stringent CAFE standard action alternative (Alternative PC1LT3) would require a 1 percent per year average annual fleet-wide increase in fuel efficiency for passenger cars and a 3 percent per year average annual fleet-wide increase in fuel efficiency for light trucks for MYs 2027–2032; the least stringent HDPUV FE standard action alternative would require a 4 percent per year average annual fleet-wide increase in fuel efficiency for HDPUVs for MYs 2030–2035.

NHTSA has assessed the effectiveness and costs of technologies as well as market forecasts and economic assumptions for both fuel economy and FE standards, as described in the TSD. NHTSA uses a modeling system to assess the technologies that manufacturers could apply to their fleet to comply with each CAFE and HDPUV FE standard action 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.[31] The CAFE Model developed by the Volpe National Transportation Systems Center (Volpe)[32] 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 or HDPUV FE 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 2022 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 improving technology, and the standards being considered, in ways estimated to be optimal when also accounting for many real-world constraints faced by automobile manufacturers.

[30] As discussed in Chapter 1, *Purpose and Need for the Action*, and Section 2.1, *Introduction*, the MY 2032 CAFE standard is an augural standard and would not be required; rather, it is proposed by NHTSA.

[31] Many of the technologies that vehicle manufacturers use to improve fuel economy and fuel efficiency on LD and HDPUV vehicles are similar, and the CAFE Model is (and has also historically been) equipped to analyze the impacts of different levels of stringency for both types of vehicles.

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

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 GHGs, fatalities resulting from highway vehicle crashes, incidents of health impacts resulting from air pollution, and overall social costs and benefits.

For this EIS, NHTSA used the CAFE Model to estimate annual fuel consumption for each calendar year from 2022, the most recent year for which the new vehicle market was observed, through 2050, when almost all passenger cars, light trucks, and HDPUVs in use would have been manufactured and sold during or after NHTSA's standard-setting model years proposed in this action.

2.3.1.1 CAFE Model Inputs

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

- Availability, applicability, effectiveness, and cost of fuel-saving technologies.
- Several time series that describe the macroeconomic context in which the standards are implemented, including real gross domestic product (GDP), real disposable personal income, U.S. population and number of households, and consumer confidence.
- Economic factors, including mileage accumulation patterns, future fuel prices, the rebound effect (the increase in vehicle use that can result from improved fuel economy), and emission factors and the costs of emissions (or benefits of emissions reductions).
- Fuel characteristics and vehicular emissions rates.
- Information about the historic vehicle population produced between MY 1975 and MY 2021.
- Projections of future annual production volumes for passenger cars, light trucks, and HDPUVs.
- 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.[33]
- Coefficients defining the shape and level of fuel efficiency and CO_2 work factor-based curves, which combine vehicle payload capacity and vehicle towing capacity, in pounds, with an additional fixed adjustment for four-wheel-drive vehicles. Fuel consumption targets would be determined for each HDPUV with a unique work factor.[34]
- Projections of vehicle model/configurations that could foreseeably be replaced with vehicles qualifying for credit toward ZEV mandates.

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 or HDPUV FE standards to be examined for each fleet, for each model year. The model then estimates the costs associated with this additional technology utilization and accompanying changes in travel demand, fuel consumption, fuel outlays, emissions, and economic externalities related to petroleum consumption and other factors.

For more information about the CAFE Model and its inputs, see the TSD and Preliminary Regulatory Impact Analysis (PRIA). Model documentation, publicly available in the rulemaking docket and on

[33] Applicable only to the CAFE standards.

[34] Applicable only to the HDPUV FE standards.

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 and HDPUV FE standards, the CAFE Model alone does not determine the CAFE or HDPUV FE standards NHTSA proposes or promulgates as final regulations. NHTSA considers the results of analyses using the CAFE Model and external analyses, including this EIS and the analyses cited herein. 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 improve their fuel economy (or fuel efficiency, in the case of HDPUVs). 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 LD vehicle and HDPUV analysis fleets 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 forecasts used in this EIS 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, light trucks, and HDPUVs. The CAFE Model considers technologies in four broad categories: engine, transmission, vehicle, and electrification and hybrid technologies, subject to the different regulatory scenarios.[35] More information about the technology assumptions used in this EIS can be found in Chapter 3 of the TSD and Section II.C and Section II.D of the proposed rule preamble. Table 2.3.1-1 lists the types of technologies considered in this analysis for improving fuel economy.

[35] As discussed in the NPRM preamble, NHTSA's "standard setting" constraints mean that the CAFE Model does not apply certain electrification technologies, nor does it allow manufacturers to use credits, during standard setting years. For this EIS analysis, NHTSA does not apply these constraints (Section 2.3.2, *Constrained versus Unconstrained CAFE Model Analysis*).

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 LD Fuel Economy or HDPUV Fuel Efficiency

Fleet	Engine Technologies	Transmission Technologies	Vehicle Technologies	Electrification and Hybrid Technologies
LD	• Variable valve lift technology • Stoichiometric gasoline direct-injection technology • Cylinder deactivation technology • Advanced cylinder deactivation technology • Turbocharged and downsized engines • High compression ratio engines • Variable compression ratio engines • Variable turbo geometry • Advanced diesel engines	• Six- and eight-speed automatic transmissions • Advanced eight-, nine-, and ten-speed automatic transmissions • Six- and eight-speed dual clutch transmissions • Continuously variable transmissions • Advanced continuously variable transmissions	• Low-rolling-resistance tires (three levels) • Aerodynamic drag reduction (four levels) • Mass reduction (five levels)	• 12-volt stop-start technology • 48-volt belt integrated starter generator technology • Strong hybrid electric vehicles (power split and P2) • Plug-in hybrid electric vehicles (20-mile and 50-mile range) • Battery electric vehicles (150-mile, 250-mile, 300-mile, and 400-mile range) • Fuel cell vehicles
HDPUV	• Stoichiometric gasoline direct-injection technology • Cylinder deactivation technology • Turbocharged and downsized engines • Advanced diesel engines	• Six- and eight-speed automatic transmissions • Advanced nine- and ten-speed automatic transmissions	• Low-rolling-resistance tires (two levels) • Aerodynamic drag reduction (two levels) • Mass reduction (two levels)	• 12-volt stop-start technology • 48-volt belt integrated starter generator technology • Strong hybrid electric vehicles (P2) • Plug-in hybrid electric vehicles (50-mile range) • Battery electric vehicles (150- and 250-mile range for vans, 250- and 300-mile range for pickups)

Economic Assumptions

NHTSA's analysis of the energy savings, changes in emissions, and environmental impacts likely to result from the CAFE and HDPUV FE standard 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, light trucks, and HDPUVs 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, light trucks, and HDPUVs 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 (for CAFE and HDPUV FE standards).
- 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 may result from increases in fuel economy (CAFE standards) or fuel efficiency (HDPUV FE standards).[36]
- The costs of increased congestion and noise caused by added passenger car, light truck, and HDPUV use.
- The costs of LD vehicle and HDPUV 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, light trucks, and HDPUVs typically remain in use for many years, so even though NHTSA is proposing to set CAFE standards through MY 2031 and proposing augural CAFE standards through MY 2032 (passenger cars and light trucks) and issuing FE standards through MY 2035 (HDPUVs), 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

[36] In addition to less frequent refueling, the CAFE Model also estimates less frequent recharging for battery electric vehicles.

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 GDP growth rate. For example, the increase in the price of new vehicles as a result of manufacturers' compliance actions can result in increased demand for used vehicles, extending the expected age and lifetime vehicle miles 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 efficiency, although at the same time that additional mobility creates benefits for drivers and their passengers. When CAFE and HDPUV FE standards are increased, total passenger car, light truck, and HDPUV VMT will increase slightly because of the rebound effect, and tailpipe emissions on a per-mile basis will increase proportionally to the marginal increases in VMT. Conversely, when the cost of fuel consumed per mile driven increases (as a result of higher fuel prices), vehicle use decreases.

In this EIS, the rebound effect for LD vehicles and HDPUVs 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; NHTSA's analysis of the LD fleet holds this underlying VMT constant across regulatory alternatives. Thus, each alternative evaluated would reflect changes in emissions estimates based on the differences in the proposed levels of fuel economy under these CAFE standards (Section 2.5.1, *Downstream Emissions*).

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

In the NPRM, NHTSA is proposing CAFE standards for MYs 2027–2032[37] 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 average of those targets. NHTSA describes its methods for developing the coefficients defining the curves for the Proposed Action and alternatives in Chapter 1 of the TSD.

[37] As discussed in Chapter 1, *Purpose and Need for the Action*, and Section 2.1, *Introduction*, the MY 2032 CAFE standard is an augural standard and would not be required; rather, it is proposed by NHTSA.

Coefficients Defining the Shape and Level of FE Work Factor Attribute-Based Curves

In the NPRM, NHTSA is proposing HDPUV FE standards for MYs 2030–2035 expressed as a mathematical function that defines a fuel efficiency target for each vehicle model and, for each fleet, establishes a required FE level determined by computing the sales-weighted average of those targets. The NPRM also proposes to establish separate curves for diesel and gasoline HDPUVs. 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 for the CAFE program presented in Chapter 8 of the PRIA and in Section IV of the preamble to the proposed rule differ slightly from those presented in this EIS. EPCA and EISA require that the Secretary of Transportation 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.[38] NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "Federal agencies consider the environmental impacts of their actions in the decision-making process."[39] The EIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuel technologies in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives. These restrictions do not apply to considerations on setting HDPUV FE standards and, thus, the CAFE Model results presented in the PRIA, preamble, and this EIS for the HDPUV FE standards are identical.

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 (2022)		
National Energy Modeling System	• Inputs are default values for the AEO 2022 Reference Case[40]	• Projected fuel prices for all fuels • U.S. average electricity-generating mix for future years • Passenger car and light truck fleet share • Growth rates in HDPUV sales
IHS Markit (2022)		
IHS Markit Long-Term Macro Forecast	• Inputs are default values for the May 2022 baseline forecast	• U.S. population and household counts • Real GDP and disposable income

[38] 49 U.S.C. 32902(h).

[39] 40 CFR 1500.1(a).

[40] NHTSA used AEO 2022 Reference Case during EIS development due to the availability of the AEO data at the time of modeling. AEO 2023 was released in spring 2023 and used different emissions assumptions. NHTSA is considering the ability to update to AEO 2023 for the Final EIS.

Model Title	Model Inputs	Model Outputs Used in this Analysis
Argonne National Laboratory: GREET (2022 Version) Fuel-Cycle Model		
Greenhouse Gases and Regulated Emissions in Transportation	• Estimates for nationwide average electricity generating mix from NEMS forecasts in AEO 2022 • Emissions factors for petroleum extraction, transportation, and refining as well as finished gasoline and diesel transportation, storage, and distribution[41]	• 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 (2022)		
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 emissions factors (tailpipe and evaporative) for CAFE Model for cars, light trucks, and HDPUVs for two fuel types: gasoline and diesel
Volpe: CAFE Model (2023 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 emissions factors	• Costs associated with utilization of additional fuel-saving technologies • Changes in travel demand, fuel consumption, fuel outlays • Technology utilization scenarios • Estimated U.S. vehicle fleet 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 RCP radiative forcing targets	• Regional population estimates • Labor productivity growth • Energy demand • Agriculture, land cover, and land-use models • Atmospheric gas concentrations	• GCAMReference, GCAM6.0, and RCP4.5 global GHG emissions scenarios (baselines)
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 (low global GHG emissions scenario), SSP2-4.5 (intermediate global GHG emissions scenario, the reference scenario used in the cumulative impacts analysis), and SSP3-7.0 (high global GHG emissions scenario, the reference scenario used in the direct and indirect impacts analysis)

[41] Other inputs (e.g., for hydrogen and E85 emissions data) are based on default GREET 2018 data.

Model Title	Model Inputs	Model Outputs Used in this Analysis
Brookhaven National Laboratory and Oak Ridge National Laboratory: CO2SYS (v.2.3)		
CO_2 System Calculations Model	• Atmospheric gas concentrations from MAGICC model output • Natural sea water observations prepared at the Scripps Institution of Oceanography • Constants from the CO2SYS model	• Projected ocean pH in 2040, 2060, and 2100 under GHG emissions scenarios
National Center for Atmospheric Research: MAGICC7		
Model for the Assessment of Greenhouse Gas-Induced Climate Change	• Adjusted climate scenarios to reflect projected emissions from the U.S. LD vehicle fleet (CAFE standard action alternatives) or the U.S. HDPUV fleet (HDPUV FE standard action alternatives) from the relevant standard action alternatives.	• Projected global CO_2 concentrations, global mean surface temperature from 2027 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; HDPUVs = heavy-duty pickup trucks and vans; 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 EIS, NHTSA uses projections of energy prices, global petroleum demand, and supply derived from the 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). 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 EIS, NHTSA uses NEMS-based projections by citing directly to unmodified projections published by EIA as part of the AEO.

References to the AEO 2022 (and earlier AEOs) in this EIS 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 2022 in this EIS as it is widely used and publicly available. NHTSA used AEO 2022 during development of the Draft EIS due to the availability of the AEO data at the time of modeling. NHTSA is considering the ability to update to AEO 2023 for purposes of the Final EIS and final rule.

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 unreasonable or the means to obtain it are not known," the regulations require an agency to include the following elements in its NEPA document:[42]

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

In this EIS, NHTSA acknowledges incomplete, uncertain, or unavailable information where it is relevant to the agency's analysis of the potential environmental impacts of the Proposed Action and alternatives. For example, NHTSA recognizes that scientific information about the potential environmental impacts of changes in emissions of CO_2 and associated changes in temperature, including those expected to result from the proposed rule, is uncertain and incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change Sixth Assessment Report (2021a, 2021b) and the U.S. Global Change Research Program (GCRP) Fourth National Climate Assessment (GCRP 2017) as a recent "summary of existing credible scientific evidence that is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment."[43] Some discussions in this EIS, such as in Section 5.4.3, *Health, Societal, and Environmental Impacts of Climate Change*, address general potential effects of climate change, but these impacts are not attributable to any particular action, such as the Proposed Action and alternatives.

2.4 Resource Areas Dismissed from Further Consideration in this EIS and EIS Organization

In this EIS, NHTSA has not analyzed certain resource areas because the Proposed Action and alternatives would have negligible or no impact on these resource areas[44] or because they are discussed in other documents that are available for public review (e.g., 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 is not required for this rulemaking action to set CAFE and HDPUV FE standards. NHTSA has concluded that a Section 7(a)(2) consultation is not required because any potential for a specific impact on particular listed species and their habitats associated with emissions changes achieved by this rulemaking are too uncertain and remote to trigger the threshold for such a consultation. That

[42] 40 CFR 1502.21(c).

[43] 40 CFR 1502.21(c)(3).

[44] 40 CFR 1502.2(b).

conclusion, based on the discussion and analysis included in NHTSA's proposed rule preamble, applies here to the fuel consumption and GHG emissions reductions anticipated to occur under the Proposed Action and alternatives. The agency's discussion of its responsibilities under the ESA are addressed in the preamble to the proposed 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 Proposed Action and alternatives are not a transportation program or project requiring the use of Section 4(f) resources, a Section 4(f) evaluation has not been prepared.
- **Safety Impacts on Human Health.** In developing the proposed standards, NHTSA analyzed how future changes in fuel economy and fuel efficiency in the LD and HD sectors 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 to create estimates of how mass reduction would influence safety outcomes in a crash based on body style and size. 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 standards and HDPUV FE standards. Finally, NHTSA examined the impact on VMT due to changes in the cost of driving, also known as the rebound effect. These effects are discussed in both Section II.H.6 of the preamble to the proposed rule and Chapter 7.2.1 of the PRIA.
- **Noise.** 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 could result in decreased road noise compared to the No-Action Alternatives. The introduction of more hybrid and electric vehicles (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 2016a). NHTSA most recently analyzed the direct and indirect impacts of CAFE standards on noise in the MY 2024–2026 Final Supplemental EIS, Section 7.4, *Noise* (NHTSA 2022). Additionally, NHTSA has completed EISs since 2010 for setting standards, and all prior EISs have concluded that the proposed action of a rulemaking to set fuel economy or FE standards would not result in noise impacts. NHTSA analyzed noise impacts as part of this rulemaking and determined that there would be no changes to the prior effects analysis and no significant impact.

The affected environment and environmental consequences of the Proposed Action and alternatives on resources other than those listed above are described in Chapter 3, *Energy*, Chapter 4, *Air Quality*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*, Chapter 7, *Environmental Justice*, and Chapter 8, *Historic and Cultural Resources.* In prior EISs, NHTSA has provided an individual chapter on cumulative impacts; however, in this EIS, NHTSA has included cumulative impacts for resources within the individual resource chapter. NHTSA has made additional changes to prior EIS organization, such as including land use and hazardous materials and regulated waste, which are both discussed in Chapter 3, *Energy*, and Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*.

In addition, in prior EISs, environmental impacts related to the vehicle upstream fuel cycle impacts—raw material extraction, transportation, refining, and delivery (discussed in Section 2.5, *Resources Areas*

Affected and Types of Emissions)—were discussed in chapters related to both energy and the full vehicle life cycle. In this EIS, environmental impacts related to the upstream fuel cycle are discussed in Chapter 3, *Energy*, and Chapter 7, *Historical and Cultural Resources*. In this EIS, Chapter 6, *Life Cycle Assessment Implications of Vehicle Materials*, discusses only what is referred to commonly as the "vehicle cycle," which encompasses the raw material extraction, material processing, component manufacture and vehicle assembly, and vehicle end of life related to materials used to make vehicles.

2.5 Resource Areas Affected and Types of Emissions

The major resource areas affected by the Proposed Action and alternatives are energy, air quality, and climate. Chapter 3, *Energy*, describes the affected environment for energy and direct, indirect, and cumulative impacts of energy consumption under each alternative. Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, describe the affected environments and direct, indirect, and cumulative impacts for air quality and climate change, respectively. Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials,* describes the vehicle life-cycle impacts implications of differing assumptions relating to vehicle materials and technology. The Proposed Action and alternatives also would affect (although to a lesser degree than energy, air quality, and climate) environmental justice and historic and cultural resources. These resource areas are discussed in Chapter 7, *Environmental Justice*, and Chapter 8, *Historic and Cultural Resources*.

Emissions, including GHGs, criteria pollutants, and toxic air pollutants, are categorized for purposes of this analysis as either *downstream* or *upstream*. Downstream emissions are released from a vehicle while it is in operation, parked, or being refueled, and consist of tailpipe exhaust, evaporative emissions of volatile organic compounds from the vehicle's fuel storage and delivery system, and particulates generated by brake and tire wear. All downstream emissions estimates in the CAFE Model use emissions factors from EPA's Motor Vehicle Emission Simulator (MOVES3) model (EPA 2022a). Upstream emissions related to the Proposed Action and 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 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 GHGs, criteria air pollutants, and toxic air pollutants. Upstream emissions considered in this EIS 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 2.5.1, *Downstream Emissions*, and Section 2.5.2, *Upstream Emissions*, describe analytical methods and assumptions used in this EIS for emissions modeling, including the impact of the rebound effect. Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, discuss modeling issues related specifically to the air quality and climate change analyses, respectively.

2.5.1 Downstream Emissions

Downstream emissions are primarily from vehicle (tailpipe) exhaust. The basic method used to estimate tailpipe emissions entails multiplying the estimated vehicle activity, such as VMT or gallons of fuel consumed, by their estimated emissions rates per unit of activity of each pollutant. In this rulemaking, 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 emissions rates appropriate to each vehicle type, fuel used, model year, and age as of that future year.

The CAFE Model uses emissions factors developed by EPA using the MOVES3 model (EPA 2022a). MOVES incorporates EPA's updated estimates of real-world emissions from passenger cars, light trucks, and HDPUVs and accounts for emissions control requirements on exhaust emissions and evaporative emissions, including the Tier 2 Vehicle & Gasoline Sulfur Program (EPA 2011), the mobile source air toxics rule (EPA 2007), and the Tier 3 Motor Vehicle Emission and Fuel Standards Rule (EPA 2014a). The MOVES database includes national default distributions by vehicle type and age, activity level, regulatory class, fuel composition and supply, and other key parameters used to generate emissions estimates. MOVES defaults were used for all other parameters to estimate tailpipe and other components of downstream emissions under both the CAFE and HDPUV No-Action Alternatives.

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 efficiency 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 efficiency and emissions. Because the CAFE and HDPUV FE standards are not intended to dictate the design and technology choices manufacturers must make to comply, a manufacturer could employ technologies that increase fuel efficiency (and therefore reduce CO_2 and SO_2 emissions) while at the same time increasing emissions of certain criteria pollutants or toxic air pollutants, as long as the manufacturer's production still meets both the fuel economy and efficiency standards for LD vehicles and HDPUVs as well as prevailing EPA regulated pollutant standards. Depending on which strategies are pursued to meet the increased CAFE and HDPUV FE standards proposed, emissions of regulated and unregulated pollutants could increase or decrease.

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

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

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

Almost all of the carbon in fuels 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) and fuel efficiency (gallons per 100 miles). Therefore, tailpipe emissions factors for CO_2 and SO_2 vary by vehicle operating conditions and are dependent on the amount of fuel used per mile.

In contrast to CO_2 and SO_2, downstream emissions of the other criteria pollutants and toxic air pollutants are given in terms of grams emitted per mile. This term is used because the formation of these pollutants is affected by the continually varying conditions of engine and vehicle operation dictated by the amount of power required and by the type and efficiency of emissions controls with which a vehicle is equipped.[45] For other criteria pollutants and air toxics, MOVES calculates emissions 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 emissions 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 emissions factors that were representative of lifetime average emissions rates for vehicles meeting the Tier 3 emissions and fuel standards.[46] 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.[47] These

[45] 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 and HDPUV FE 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.

[46] 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 MY 2023 and beyond vehicles.

[47] 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. Therefore, the estimates of aggregate emissions reported for the CAFE and HDPUV FE No-Action Alternatives and the CAFE and HDPUV FE standard 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 relevant 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.

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.[48]

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,[49] 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 efficiency, causing tailpipe emissions of each air pollutant generated by vehicle use (rather than by fuel consumption) to increase in proportion to this increase in VMT. 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 efficiency, then the net result can be an increase in total downstream emissions. If the decreases are smaller from the VMT rebound effect, then the net result can be a decrease in total downstream emissions.

2.5.2 Upstream Emissions

NHTSA also estimated the impacts of the Proposed Action and 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 and fuel efficiency increases, NHTSA anticipates increases in upstream emissions from fuel production and distribution, because the total amount of fuel used by passenger cars, light trucks, and HDPUVs would increase. To the extent that any CAFE or HDPUV FE standard action alternative would be affected by the relevant No-Action Alternative projections of increased EV adoption and use, upstream emissions associated with charging EVs could increase. 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 Chapter 3, Section 3.2, *Affected Environment*, 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 CAFE or HDPUV FE standards. Changes in net emissions depend on the relative magnitudes of the increase in emissions from additional vehicle use due to the rebound effect and

[48] 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.

[49] These are 30 and 15 parts per million (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 SO_2 per gallon of diesel.

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 EIS, NHTSA used the NEMS AEO 2022 version to project the U.S. average electricity-generating fuel mix (e.g., coal, natural gas, petroleum) for the reference year 2022 and used the GREET model (2022 version) (ANL 2022) to estimate upstream emissions. The analysis assumed that the vehicles would be sold and operated (refueled or charged) during the 2022 to 2050 timeframe. The analysis presented throughout this EIS assumes that the future EV fleet would charge from a nationally representative grid mix. As with gasoline, diesel, and E85, emissions factors for electricity were calculated in 5-year increments from 2022 to 2050 in GREET to account for projected changes in the national grid mix. GREET also contains information on the energy intensities (amount of pollutant emitted per unit of electrical energy generated).

For the CAFE and HDPUV FE standard action alternatives in this EIS, NHTSA assumed that increased fuel economy and fuel efficiency affect upstream emissions by decreasing volumes of gasoline and diesel produced and consumed,[50] and by causing changes in emissions related to electricity generation in 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 emissions factors for individual phases of the fuel production and distribution process derived from GREET. The emissions 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 relevant No-Action Alternative.

[50] 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 CAFE and HDPUV FE standard action alternatives would be identical to those under the relevant No-Action Alternative.

CHAPTER 3 ENERGY

NHTSA's light-duty (LD) vehicle CAFE standards and heavy-duty pickup trucks and vans (HDPUV) fuel efficiency (FE) standards regulate vehicle fuel economy and fuel efficiency, considering "the need of the United States to conserve energy."[1] NHTSA has consistently interpreted "the need of the United States to conserve energy" to mean "the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum."[2] The *Annual Energy Outlook* (AEO) 2022 projects that transportation fuel will account for 79.1 percent of U.S. petroleum consumption in 2050 (Energy Information Administration [EIA] 2022a).[3] It is important for decisionmakers and the public to understand the environmental implications of petroleum, as discussed in Section 3.2.1, *Gasoline*, given the United States' large projected future need.

Although petroleum is overwhelmingly the primary source of energy for passenger cars and light trucks (i.e., LD vehicles), as well as HDPUVs, these vehicles can use other fuels (e.g., electricity, natural gas). In past EISs, NHTSA considered the affected environment for energy to encompass current and projected U.S. energy consumption and production across all fuels (i.e., petroleum, biofuel, natural gas, hydrogen, liquefied petroleum gas [LPG], and electricity) and sectors (i.e., transportation, industrial, residential, commercial, unspecified, and electricity generation). While changing CAFE standards is expected to reduce gasoline and diesel fuel use in the transportation sector, it is not expected to have any discernable effect on energy consumption by other sectors of the U.S. economy, because petroleum products account for a very small share of energy use in other sectors; see Section 3.3.2.2, *Other Past, Present, and Reasonably Foreseeable Future Actions*, for more details. In this EIS, NHTSA has expanded discussions of potential environmental impacts from transportation fuel use to provide a more targeted discussion of the potential energy impacts of changing CAFE standards, by including more information on upstream emissions from methane (CH_4) and emissions leaks, oil spills during transportation, and land-use impacts on greenhouse gas (GHG) emissions and biofuel production.

The following sections summarize the current and projected fuel use by the transportation sector, specifically LD vehicles and HDPUVs:

- Section 3.1, *Introduction*, discusses overall energy production and transportation fuel consumption to contextualize the energy impacts of the Proposed Action and alternatives, which are discussed in Section 3.3, *Environmental Consequences*.
- Section 3.2, *Affected Environment*, discusses by vehicle fuel type the physical environmental effects of the fuel production (i.e., the upstream impacts) and consumption (i.e., the downstream impacts). Air quality, climate, and other impacts are cross-referenced to other chapters in this EIS, where appropriate.
- Section 3.3, *Environmental Consequences*, discusses how the Proposed Action and alternatives would affect LD vehicle energy consumption, as projected by the CAFE Model.[4]

[1] 49 U.S.C. 32902(f).

[2] 42 FR 63184, 63188 (Dec. 15, 1977).

[3] This chapter uses 2050 as NHTSA's analysis year because it is sufficiently far in the future to have almost the entire LD vehicle fleet composed of MY 2027 and later vehicles.

[4] Note that the AEO and CAFE Model use different underlying assumptions but show similar resulting trends in projected energy use.

3.1 Introduction

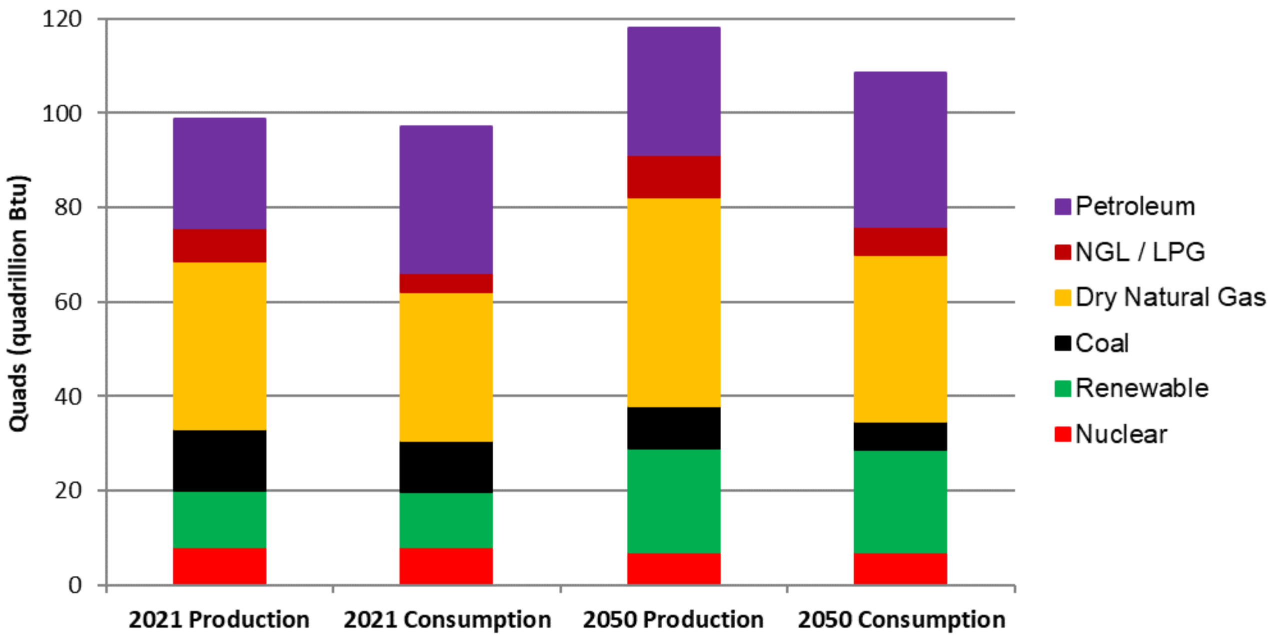
The AEO is a projection of U.S. domestic energy markets produced annually to 2050 by the U.S. Department of Energy's (DOE) EIA. The AEO 2022 projections presented throughout this chapter, referred to as the *reference case* projections, represent hypothetical scenarios based on policies in place at the time of the last AEO release (March 3, 2022), 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. NHTSA used AEO 2022 Reference Case during EIS development due to the availability of the AEO data at the time of modeling. AEO 2023 was released in spring 2023 and used different emissions assumptions. NHTSA will consider the feasibility of updating to AEO 2023 for the Final EIS. Unforeseen shifts and major events that have occurred since AEO 2022 publication are discussed in Section 3.3.2, *Cumulative Impacts*. Additionally, energy market projections are highly uncertain because it is difficult to predict changes in forces that shape these markets, such as changes in technology, demographics, and resources. To address uncertainties in future energy prices, economic conditions, technology costs, and oil and gas supply, EIA develops additional AEO side cases with low and high assumptions for each uncertainty category. The AEO side cases relevant to this Proposed Action are discussed briefly in Section 3.3.2, *Cumulative Impacts*.

Energy sources used across all sectors in the United States include nuclear power, coal, natural gas, crude oil (converted to petroleum products for consumption), and natural gas liquids (converted to LPG for consumption). These five energy sources accounted for 87.9 percent of U.S. energy consumption in 2021, whereas hydropower, biomass, solar, wind, and other renewable energy accounted for 12.1 percent of U.S. energy consumption in 2021 (EIA 2022a).

By 2050, the top five aforementioned energy sources are projected to account for 80.0 percent of U.S. energy consumption, a reduction of 7.9 percentage points from their previous share, while the share of energy from renewable sources is projected to rise to 20.0 percent (EIA 2022a). 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 2021 through 2050.[5] The change in U.S. energy production and consumption from 2021 through 2050 is shown in Figure 3.1-1.

[5] The United States' position as a net energy importer or exporter is one of several considerations on energy security and energy intensity that NHTSA's CAFE standards are intended to address. Improvements in vehicle fuel economy, combined with increases in U.S. petroleum production, have substantially reduced U.S. oil imports, resulting in declining net petroleum imports. These factors improve U.S. energy security by reducing total petroleum use and reducing dependence on oil imports. Readers may consult Chapter 6.2.4 of the Technical Support Document for a more detailed description of energy security considerations.

Figure 3.1-1. U.S. Energy Production and Consumption by Source in 2021 and 2050



Source: EIA 2022a
Btu = British thermal unit; NGL = natural gas liquid; LPG = liquefied petroleum gas

Section 3.2, *Affected Environment*, provides an additional discussion of these energy sources, to the extent that they contribute to the affected environment for transportation sector energy consumption.

Transportation sector fuel consumption accounts for 28 percent of total U.S. energy production and consumption (EIA 2022b). AEO 2022 projects transportation sector fuel consumption to increase from 26.4 quadrillion British thermal units (quads) in 2021 to 29.9 quads in 2050. In 2021, petroleum supplied 90.6 percent of transportation energy use, biofuel (mostly ethanol used in gasoline blending) 5.6 percent, natural gas 3.3 percent, LPG (propane) 0.03 percent, and electricity 0.5 percent. In 2050, AEO 2022 projects that petroleum is expected to supply 85.8 percent of transportation energy use, biofuel 6.1 percent, natural gas 3.8 percent, hydrogen 0.02 percent, LPG 0.06 percent, and electricity 4.2 percent.

In 2021, LD vehicles accounted for 54.2 percent of transportation energy consumption, commercial light trucks accounted for 3.4 percent, buses and freight trucks accounted for 21.8 percent, air travel accounted for 8.7 percent, and other transportation (e.g., boats, rail, pipeline) accounted for 11.9 percent. In 2050, LD vehicles are expected to account for 51.1 percent of transportation energy consumption, commercial light trucks 3.7 percent, buses and freight trucks 20.2 percent, air travel 14.5 percent, and other transportation 10.4 percent.[6] The projected decline in the percentage of

[6] The HDPUV category in the proposed rule, Section V.A.2, includes vehicles with gross weight ratings of 8,501 to 14,000 pounds. As the AEO 2022 does not contain information on HDPUVs specifically, but other subsets of heavy vehicles, statistics for commercial light trucks with gross vehicle weight ratings of 8,501 to 10,000 pounds were included instead, comprising step vans, utility vans, and full-sized pickup trucks.

transportation energy used by LD vehicles reflects the fuel economy improvements that are expected under the CAFE No-Action Alternative.[7]

In 2021, the transportation sector accounted for 78.8 percent of total U.S. petroleum consumption, and transportation is expected to account for 79.1 percent of U.S. petroleum use in 2050.[8] Between 2021 and 2050 transportation sector gasoline consumption is projected to increase by 3.6 percent, primarily due to a 30.9 percent projected increase in vehicle miles traveled (VMT) by LD vehicles. The CAFE Model shows that gasoline (including ethanol used in gasoline blending) accounted for 98.4 percent of LD vehicle fuel consumption in 2022, and is projected to account for 65.9 percent of consumption in 2050.[9] As illustrated in Table 3.1-1, the CAFE Model projects the gasoline share of LD vehicle fuel use to decline as a result of projected growth in electricity, from 0.2 percent of consumption in 2022 to 33.9 percent in 2050. As shown in Table 3.1-2, HDPUV diesel consumption is expected to fall significantly from 44.3 percent in 2022 to 5.0 percent in 2050, whereas electricity consumption is expected to increase from 0.1 percent in 2022 to 25.5 percent in 2050 and gasoline consumption is expected to increase from 55.0 percent to 69.3 percent over the same timeframe. Although energy shares are projected to shift across fuel types, total energy is projected to decrease over this period.

Table 3.1-1. Energy Consumption for LD Vehicles for 2022 and 2050

Fuel	2022 (%)	2050 (%)
Gasoline (including ethanol blending)	98.4	65.9
Electricity	0.2	33.9
Diesel	0.5	0.1
E85	0.9	0.1
Other fuels	<0.1	<0.1

Table 3.1-2. Energy Consumption for HDPUVs for 2022 and 2050

Fuel	2022 (%)	2050 (%)
Gasoline (including ethanol blending)	55.0	69.3
Electricity	0.1	25.5
Diesel	44.3	5.0
E85	0.6	0.2

AEO 2022 also projects a 21 percent increase from 2021 to 2050 in energy used by commercial light truck vehicles. Commercial light truck fuel consumption is projected to increase in overall share of total

[7] AEO 2023 was released on March 16, 2023, after primary development of this Draft EIS, which, therefore, uses AEO 2022. AEO 2023 considers the last final action on LD CAFE standards for MY 2024–2026 and accounts for Inflation Reduction Act.

[8] The docket for this EIS (NHTSA-2022-0075) will include an Excel workbook that shows how values reported in this chapter reflect separate AEO 2022 tables for energy supply and disposition, energy consumption by sector and source, and renewable consumption by sector and source (file name "Draft EIS Energy Figures based on 2022 AEO"). The data presented in this chapter include electricity losses 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 (e.g., coal, natural gas) used to deliver electricity for consumption.

[9] The CAFE Model projections here reflect the No-Action Alternative and differ from the AEO 2022 projections discussed above because the CAFE Model projections include reductions in energy consumption from NHTSA's latest proposed LD CAFE and HDPUV FE standards.

transportation energy consumption by 2040 due to an increase in commercial light truck vehicle fuel consumption and decrease in LD fuel consumption.

AEO 2022 also projects a 42.9 percent increase in VMT for commercial light trucks from 2021 to 2050. The large projected increase in HDPUV VMT results in a relatively small increase in HDPUV fuel use because there is a large projected increase in HDPUV stock fuel efficiency as older vehicles are replaced by vehicles that comply with Phase 1 and Phase 2 standards for HDPUV fuel efficiency.

3.2 Affected Environment

As discussed in previous EISs, the impact of CAFE and HDPUV FE standards on energy consumption across fuels and sectors is small. Therefore, for this EIS, NHTSA considered the physical effects of LD vehicle and HDPUV energy production (i.e., upstream) and consumption (i.e., downstream). As the scope and end points of each energy source's physical impacts differ, NHTSA's discussions in the following sections have been adapted to convey the affected environment specific to each fuel source. For Section 3.2.1, *Gasoline*, NHTSA largely examines the upstream impacts of gasoline's production, focusing on the environmental impacts of petroleum production, transportation, and refining as well as the effects from gasoline's transportation, storage, and distribution. For Section 3.2.2, *Electricity*, NHTSA discusses processes of electricity generation and regional distribution that contribute to its upstream impact as well as downstream impacts associated with electric fuel consumption. Similarly, the remaining sections on diesel and biofuels, natural gas, and hydrogen elaborate on each fuel source's affected environment in the context of its processes and impacts. Additionally, discussions of impacts formerly in the Final Supplemental EIS, Chapter 7, *Other Impacts* (NHTSA 2022), such as land use, oil exploration and extraction, spills, biofuel production, and hazardous waste production from energy-related processes, are incorporated in this chapter for streamlining purposes.

3.2.1 Gasoline

Motor gasoline represents the largest share of LD vehicle and commercial light truck fuel consumption, both now (98.4 percent of total fuel consumption in 2022) and in the future (65.9 percent in 2050) based on the CAFE Model projections.[10] While the share of gasoline for LD vehicle fuel consumption is projected to decline into 2050, gasoline is projected to become a larger portion of HDPUV fuel consumption, increasing from 55.0 percent of total fuel consumption in 2022 to 69.3 percent in 2050 based on the CAFE Model. Gasoline is a product of refining crude oil and other petroleum liquids. In 2021, motor gasoline made up 44 percent of all U.S. petroleum consumption, averaging about 8.8 million barrels per day, or 369 million gallons per day. Of the motor gasoline consumed, 63 percent was consumed by the transportation sector, while the remaining gasoline was consumed across the industrial, residential, commercial, and electrical power sectors (EIA 2022c). Gasoline remains the largest component of fuel consumption among the LD vehicle and HDPUV fleet and, therefore, warrants a more detailed discussion of its affected environment and potential environmental impacts.

Gasoline production begins with the extraction of crude oil or other petroleum liquids, such as natural gas liquids and condensates, from underground reservoirs using drilling rigs. Crude oil is the most common petroleum liquid used in gasoline production due to its abundance and is largely the focus of the following discussions on petroleum production. Crude oil contains a complex mixture of

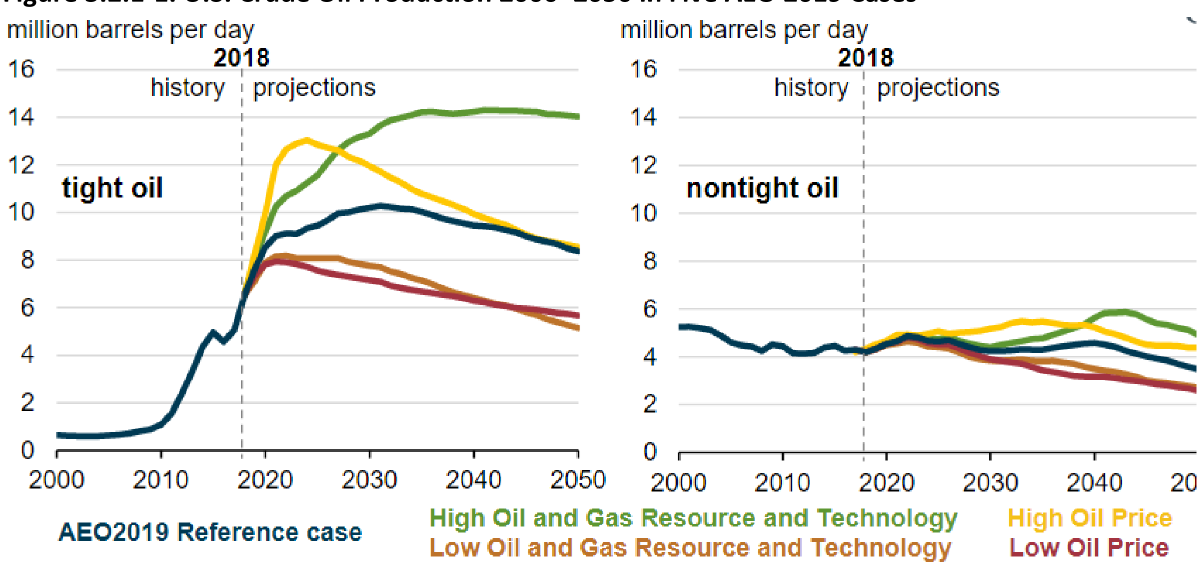
[10] Where motor gasoline excludes E85, a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable).

hydrocarbons formed from organic materials that have been buried and subjected to high pressures and temperatures over time, transforming them into crude oil. Crude oil is extracted via oil wells, transported to refineries where it must undergo intensive refining processes to produce gasoline, and finally stored and distributed to be sold to consumers. Sections 3.2.1.1, *Petroleum Extraction*, 3.2.1.2, *Petroleum Transportation*, 3.2.1.3, *Petroleum Refining*, and 3.2.1.5, *Fuel Transportation, Storage, and Distribution*, describe the steps of the gasoline production process, as well as the potential environmental impacts that may occur over this process. Section 3.2.1.4, *Petroleum Imports*, describes the dynamics in U.S. petroleum imports.

The affected environment of U.S. gasoline production varies widely by how the petroleum liquids used in its production are sourced from either conventional or unconventional oil resources. Conventional oil resources include those that are easily accessible and can be extracted using traditional methods, such as vertical drilling. Unconventional oil resources, on the other hand, require more complex and invasive extraction methods, such as horizontal drilling and hydraulic fracturing. There are several sources of unconventional oil, the most common source being tight oil. Also known as shale oil, tight oil is crude oil that is trapped within low-permeability rock formations, such as shale, sandstone, and carbonate. Tight oil must be extracted through horizontal drilling and hydraulic fracturing, which involves injecting water, sand, and chemicals at high pressure to create fractures in the rock and release the oil. Unconventional oil resources require more energy-intensive refining processes than conventional oil because they contain higher impurities and viscosity, or thickness, making them more difficult to pump and transport, which results in both higher processing costs and greater environmental effects.

The share of unconventional oil production in the United States has been increasing in recent years due to advancements in technology and the development of tight oil resources, including improvements to drilling efficiencies and reductions in costs. According to AEO 2019, U.S. tight oil production became the most common form of crude oil production in 2015 and is projected to continue to drive future U.S. crude oil production into 2050. As of 2018, tight oil makes up 61 percent of total U.S. crude oil production. Figure 3.2.1-1 illustrates the development of tight oil versus non-tight oil production and shows that tight oil production will be higher than that of non-tight oil for the AEO 2019 reference case and side cases.

Figure 3.2.1-1. U.S. Crude Oil Production 2000–2050 in Five AEO 2019 Cases



Source: EIA 2019a

When considering total vehicle life-cycle emissions, GHG emissions from the extraction, refining, supply, and combustion of gasoline 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). Based on future energy production projections and the growing use of unconventional oil resources, one study estimates that the incremental GHG emissions from replacing conventional oil with unconventional oil would amount to 4 to 21 gigatons of carbon dioxide equivalents (CO_2e) over 4 decades from 2010 to 2050 (Nduagu and Gates 2015). Although upstream emissions are associated with conventional oil production and refining, there is less consensus on the life-cycle assessment impacts of unconventional sources of petroleum, including shale oil production. In the following subsections, NHTSA presents results from its literature search of the environmental impacts of crude oil production and refining into gasoline.

3.2.1.1 Petroleum Extraction

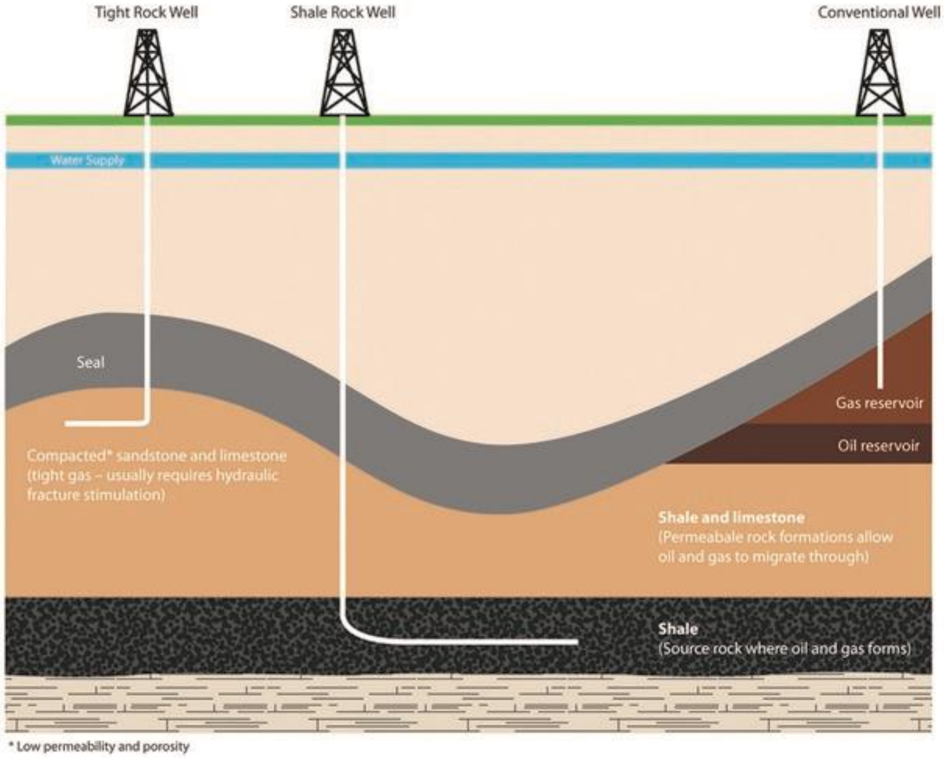
Petroleum extraction is the process of recovering crude oil and other petroleum liquids from underground or underwater reservoirs. The extraction process involves several stages, including exploration, drilling, and production. Petroleum exploration involves searching for potential oil deposits using a variety of techniques, such as seismic surveys and drilling exploratory wells. These techniques vary based on whether the reservoir is located onshore (i.e., on land) or offshore (i.e., at sea). Once a potential oil deposit is identified, a drilling rig is used to drill a well into the reservoir. The drilling process involves using specialized equipment to bore a hole through layers of rock and sediment until the well reaches the oil-bearing formation. After the well has been drilled, production equipment is installed to extract the oil from the reservoir. Depending on the characteristics of the reservoir, this may involve pumping the oil to the surface using artificial lift techniques, such as pumps or gas injection, or relying on the natural pressure of the reservoir to push the oil to the surface. The extracted oil is then transported via pipelines or tanker ships to refineries for further processing to produce gasoline and other petroleum products.

Petroleum exploration is crucial for identifying the location and size of oil reserves. In all cases, exploration involves conducting preliminary surveys of the land's surface to find the location of potential oil deposits, seismic surveys to create maps of the subsurface geology, and drilling exploratory wells to determine if the deposit is a viable source of petroleum. One study of Venezuelan petroleum exploration indicated that the initial surveying of onshore oil reservoirs requires bulldozing and clearing thousands of kilometers of land to conduct seismic tests and mappings of an area's geological formations. Ground surface disturbances following the identification of onshore oil reserves, including site clearance; construction of roads, tank batteries, brine pits and pipelines; and other landfill modifications, encroach on natural habitats and result in habitat destruction (Baynard 2011). These activities affect benthic (i.e., bottom-dwelling) populations, migratory bird populations, and marine mammals in particular (Borasin et al. 2002; U.S. Fish and Wildlife Service 2009; National Oceanic and Atmospheric Administration 2012; Bakke et al. 2013). These activities also result in CH_4 emissions. Oil exploration in Canada's peatlands was found to increase CH_4 emissions by 4.4 to 5.1 kilotons per year, or 7 to 8 percent more than otherwise undisturbed conditions (Strack et al. 2019).

Oil exploration of offshore locations requires specialized seismic surveys that send powerful sound waves through the water to penetrate the seafloor and record details of the subsurface geology. The loud, low-frequency sounds generated by seismic air guns used in these surveys can cause physical harm to fish and marine mammals, including hearing damage, tissue damage, and behavioral changes (Anderson et al. 2011). Marine mammals, including whales and dolphins, as well as sea turtles have been shown to be sensitive to the sounds and can experience distress and displacement from their natural habitats, while sonic disturbances to fish result in similar effects as well as death. Some specific impacts are not well known. Direct information on the extent to which seismic pulses could damage hearing is difficult to obtain and, as a consequence, the impacts on hearing remain poorly known (Gordon et al. 2003; Nelms et al. 2016).

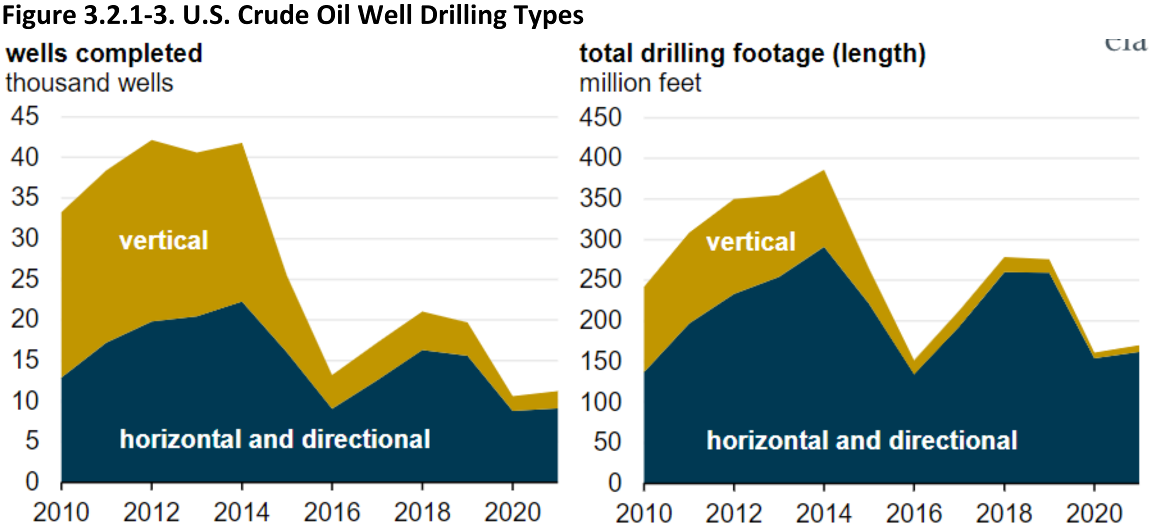
Once a viable crude oil extraction site discovered, an oil well is developed by drilling several kilometers into the earth to tap into the oil reserve. Mining of conventional oil resources involves straightforward vertical drilling into largely shallow deposits, while unconventional oil extraction requires multistage horizontal drilling or fracking activities that use large quantities of water and, therefore, produce large quantities of wastewater. Figure 3.2.1-2 illustrates the different geological formations of oil reserves and types of drills used to access different oil sources. Similarly, Figure 3.2.1-3 shows the number of wells completed and feet drilled in vertical versus horizontal or directional drilling, depicting the rise of unconventional methods of oil extraction. The drilling process itself can cause soil and vegetation disruption, habitat fragmentation, and land degradation (Baynard et al. 2014; Chowdhury et al. 2017). Drilling operations can also generate noise and vibrations that can affect wildlife and their habitats (Roberts and Elliot 2017). The extent of these effects vary by the source of oil being extracted (i.e., from a conventional or unconventional source). One study quantifying the land use GHG intensity of petroleum extraction activities in both the United States and Canada concluded that unconventional oil mining causes significantly more land disturbances over the entire petroleum production process than conventional oil extraction, in terms of both acres used in mining and necessary land reclamation efforts in the wake of environmental degradation. The authors also found that land disturbances contribute only a small portion of GHGs to life-cycle emissions of conventional oil production (less than 0.4 percent), while unconventional oil production land use accounts for 0.9 percent to 11 percent of its GHG life-cycle emissions (Yeh et al. 2010).

Figure 3.2.1-2. Diagram of Geological Formations of Oil Reserves and Oil Wells



Source: Government of Western Australia no date

Figure 3.2.1-3. U.S. Crude Oil Well Drilling Types



Source: EIA 2022d

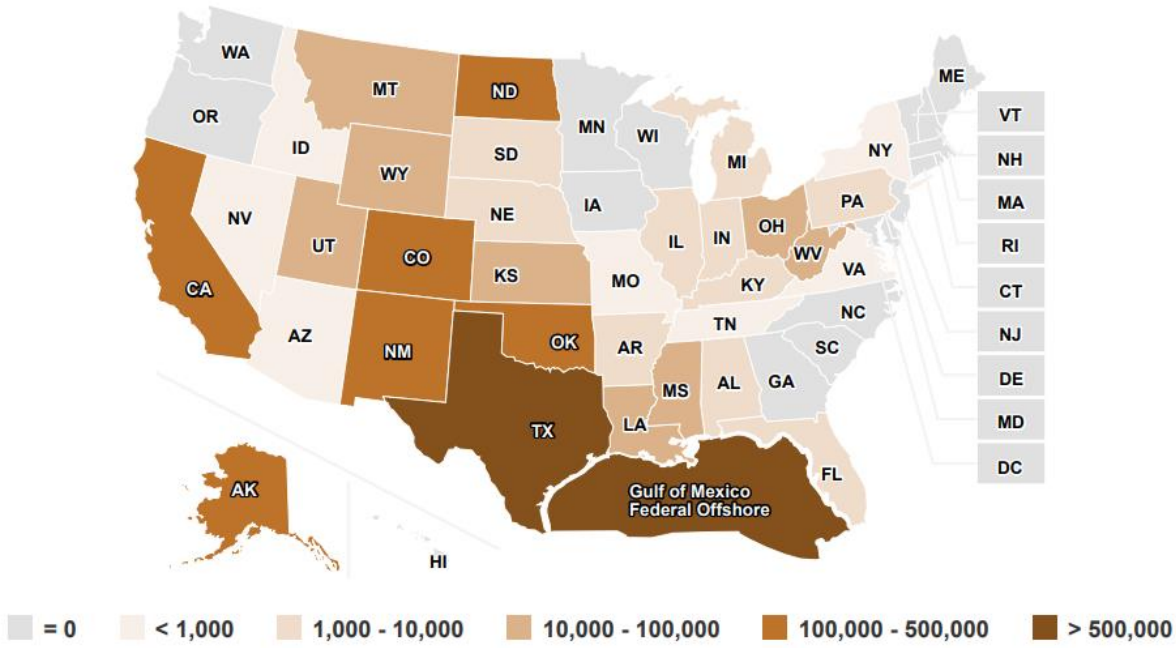
Extraction of tight oil requires multistage horizontal drilling or fracking activities that produce large quantities of wastewater, unlike the vertical drilling necessary for conventional oil. Wastewater produced during oil extraction activities is treated through various physical and chemical processes such as sedimentation tanks, filters, and chemical treatments. The treated wastewater can be reused for certain purposes or disposed of through underground injection wells or surface impoundments. Improper disposal of untreated wastewater may leak into nearby groundwater sources causing lasting effects on the surrounding environment, including persistent sediment pollution, groundwater pollution, and ecological harm (Atoufi and Lampert 2020; Epstein et al. 2002). Case studies of tight oil extraction sites, such as the Osage–Skiatook Petroleum Environmental Research sites and the Bakken Shale Formation located throughout Montana, North Dakota, and the Canadian province of Saskatchewan, have found that high levels of chemical compounds used in fracking fluids can remain in affected areas even after decades of natural attenuation (Shrestha et al. 2017; Kharaka et al. 2005). Other forms of wastewater disposal through injection underground and their environmental effects have not been thoroughly studied; however, one study has suggested that such techniques of disposal may induce earthquakes (Frohlich and Brunt 2013). Oil extraction processes, fracking in particular, can generate significant amounts of waste and wastewater, potentially resulting in contamination of groundwater sources and other ecological damage.

Damage to the environment has also been a product of offshore petroleum extraction wells. The drilling necessary for establishing an oil rig at sea poses harm to marine life from the sonic disturbances (Govoni et al. 2008). Offshore environmental impacts from oil extraction can result from the release of improperly treated wastewater into the water surrounding an oil platform (EPA 2000a; Bakke et al. 2013; OSPAR Commission 2014). Offshore platform spills, although rare,[11] can have significant 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 2012b, 2016a). Oil spills from oil rigs at sea also have significant effects on the ocean and its ecosystems, including aquatic habitat disruption and harm to marine life (Epstein et al. 2002). Most notably, the aftermath of the 2010 Deepwater Horizon oil spill is projected to continue to contaminate seafloor sediment and seawater and cause harm to the ocean's fauna and flora for decades (Allan et al. 2012; Sammarco et al. 2013; Schwacke et al. 2021). Crude oil is produced in 32 U.S. states and in U.S. coastal waters. In 2021, about 71 percent of total U.S. crude oil production came from five states, the most prevalent of which is Texas. Figure 3.2.1-4 presents a map of crude oil production by state (EIA 2022e). Of these crude oil production sites, there are six key areas of tight oil extraction in particular, presented in Figure 3.2.1-5. These locations are particularly susceptible to the environmental impacts discussed.

Oil extraction's impacts on local soil, water, and air can, in turn, affect public health among communities living near oil reservoirs. Several studies have assessed the risks of residents living near active onshore oil extraction sites and found evidence that such activities lead to exposure pathways via resource area impacts as well as waste fluids (Johnston et al. 2019; O'Callaghan-Gordo et al. 2016). In particular, hydraulic fracking has been associated with CH_4 and chemical contaminated drinking water due to contamination of shallow aquifers with fugitive hydrocarbon gases, contamination of surface water and shallow groundwater from spills and disposal of inadequately treated fracking wastewater, accumulation of toxic and radioactive elements in soil or stream sediments, and overextraction of water resources for high-volume hydraulic fracturing that could lead to water shortages or conflicts with other water users (Kuwayama et al. 2015; Vengosh et al. 2014). Individuals exposed to the chemical mixtures used over the oil extraction process through drinking water or other exposure pathways may develop a host of health impacts, such as cancer, liver damage, immunodeficiency, and neurological symptoms. To date, research has shown that oil extraction activities can have negative impacts on the health of nearby communities, but continued research and monitoring are necessary to better understand these risks in the future.

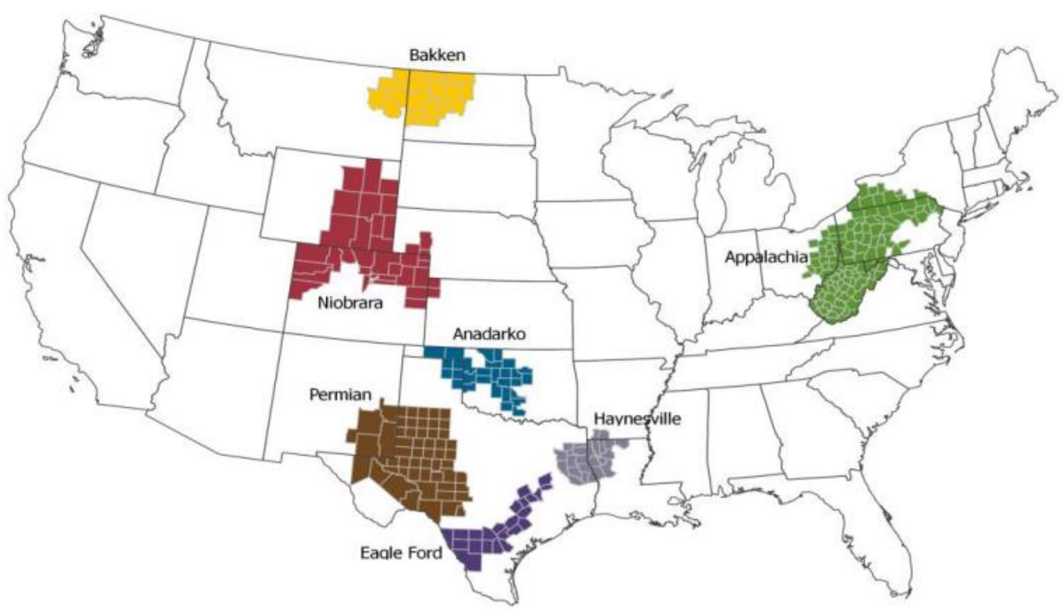
[11] Historically, there were six spills per 100 billion barrels of oil produced from offshore oil platforms between 1964 and 2010 (Anderson et al. 2012).

Figure 3.2.1-4. U.S. Crude Oil Production by State in 2021 (1,000 barrels)



Source: EIA 2022e

Figure 3.2.1-5. Key U.S. Tight Oil Regions



Source: EIA 2023a

In the last stages of petroleum extraction, oil wells are plugged and abandoned. According to a report by EPA, there are an estimated 3 million abandoned oil wells as of 2020, including orphaned wells and other non-producing wells (EPA 2023a). Studies investigating the effectiveness of well abandonment have found that large volumes of CH_4 are released from abandoned wells and that the probability of an unresolved leakage and the amount of CH_4 emitted per leak have both increased in recent years

(Schiffner et al. 2021; Boothroyd et al. 2016). CH_4 makes up roughly 95 to 99 percent of the gas leaked from oil and gas wells and accounted for roughly 6.2 percent of all U.S. CH_4 GHGs in 2020, excluding the 1.1 percent of CH_4 GHGs caused by abandoned oil and gas wells specifically (EPA 2023a). Furthermore, recent studies of CH_4 emissions from oil and gas infrastructure in Alberta, Canada on CH_4 releases and leaks from oil extraction sites show significantly higher emissions than previously accounted for in government reporting (Radhakrishnan et al. 2023; Willyard and Schade 2019; Johnson et al. 2017). These discrepancies should be considered when discussing the CH_4 estimates, as well as the environmental impacts of oil extraction. Furthermore, the uncertainty in emissions estimates from oil extraction wells requires additional research and attention.

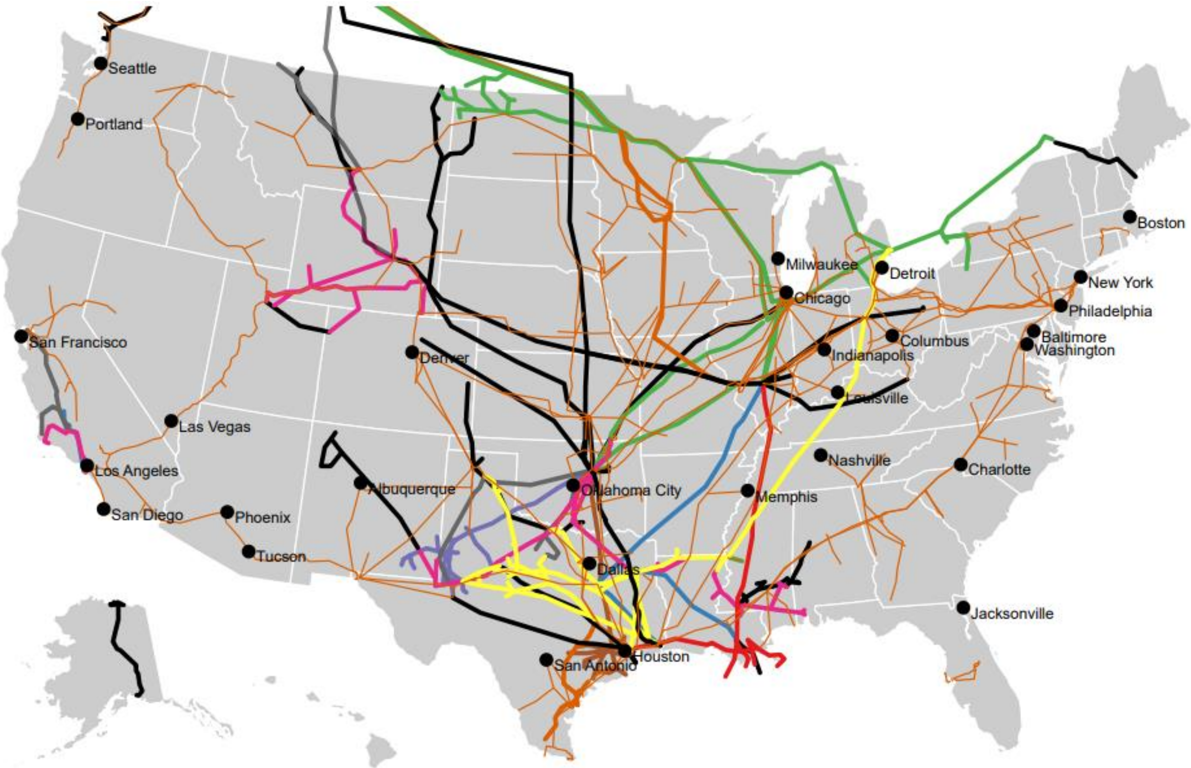
3.2.1.2 Petroleum Transportation

Once oil is extracted from the ground, it is transported to refineries where it can be processed into various petroleum products. The transportation process involves a range of methods, including pipelines, tanker trucks, railcars, and oil tankers. Tanker trucks and railcars are used for transporting smaller volumes of oil in specialized tanks over shorter distances, such as within a country or region, while oil tankers are ships designed to transport large volumes of crude oil over long distances across oceans.

Pipelines are the primary means of transporting oil over long distances domestically, and as of 2021, there were 84,916 miles of pipelines used in the transportation of crude oil (Pipeline and Hazardous Materials Safety Administration [PHMSA] 2023a). Figure 3.2.1-6 illustrates the network of crude oil and petroleum pipelines across the United States. Pipelines are typically made of steel and are buried underground to transport large volumes of crude oil more effectively. However, despite their design features, pipeline ruptures can still occur due to various factors, such as equipment failure due to manufacturing defects, improper maintenance, or wear and tear; corrosion via water, chemicals, or other corrosive materials; and external damage such as excavation or construction work in the area around the pipeline, natural disasters, or vandalism. These types of damage weaken the pipeline structure and make it more vulnerable to ruptures. In 2022, PHMSA recorded 294 pipeline incidents in which unrefined crude oil or refined petroleum products were leaked, resulting in a total of nearly 79,945 barrels leaked (PHMSA 2023b).[12]

[12] PHMSA defined an incident as a release of at least 5 gallons of hazardous liquids as defined under 49 CFR 195.50.

Figure 3.2.1-6. Map of U.S. Crude Oil and Petroleum Pipelines



Source: EIA 2023b, 2023c; Oyler 2016[13]

Pipeline ruptures can be a serious environmental and safety hazard, potentially causing oil spills that can contaminate waterways and soil, harming aquatic life, birds, and other animals that rely on these resources. There have been several pipeline ruptures in recent years that illustrate the damaging effects of these events. In 2017, the Keystone Pipeline in North Dakota ruptured and leaked an estimated 5,000 barrels of crude oil into a wetland area due to a fatigue crack that likely originated from mechanical damage to the pipe exterior during pipeline installation (Fox and Lamm 2021). In 2016, a pipeline ruptured near Santa Barbara, California, spilling nearly 3,000 barrels of crude oil into the ocean. The spill affected beaches and wildlife in the area, including birds, marine mammals, fish, and marine invertebrates and their habitats.[14] On average, however, the pipeline incident per 1,000 miles rate has decreased since 2014, to where it stands at roughly 0.41 accident per every 1,000 miles of crude oil or other refined petroleum products transported by pipeline (PHMSA 2023c).

Many modes of crude oil transportation pass by or directly cross over freshwater and saltwater systems, increasing the risk to aquatic ecosystems (Cederwall et al. 2020). When oil spills occur, aquatic ecosystems are particularly vulnerable because oil spreads quickly across the water's surface, increasing the area of contamination and complicating clean-up efforts. For example, pipelines and rail transport in or near the Great Lakes basin are heavily relied upon to move oil from source regions such as North Dakota, Montana, and Alberta. An analysis of the effects of pipeline ruptures and rail spills that

[13] Although this source is not published in a peer-reviewed scientific journal, it provides the open access code that combines EIA's U.S. Energy Atlas Crude Oil Pipeline and Petroleum Product Pipeline dataset layers.

[14] Discharge of Oil from the Plain All American Pipeline Line 901 Into the Pacific Ocean Near Santa Barbara County, California, May 19, 2015, 84 FR 8508 (Mar. 8, 2019).

occurred in the Great Lakes basin found that the toxicity of oil to aquatic species affects not only individual groups of organisms but entire food webs (Murry et al. 2018). When crude oil is spilled into water, the subsequent contaminated water and sediment can affect a range of organisms from phytoplankton to fish and larger aquatic predators. Crude oil has been found to physically smother fish and other aquatic organisms, damage their nervous and immune systems, and accumulate in fish tissues, leading to bioaccumulation and biomagnification of toxic contaminants in the food chain, which can pose health risks for humans and wildlife that consume contaminated organisms (Almeda et al. 2014; Goldstein et al. 2011; Beyer et al. 2016).

In other cases, rail spills have the potential to cause serious fires due to crude oil's flammability and ability to re-ignite, posing risks to the environment (Walker et al. 2016). Rail spills that result in fires typically occur on land, where rail transport of crude oil typically occurs. However, there is a potential for spills to result in fires on bodies of water when trains carrying crude oil are involved in accidents or derailments near waterways. In such cases, the spilled oil can ignite and lead to fires on the water's surface, which can be difficult to contain and extinguish (Lehr and Simecek-Beatty 2004). The environmental impacts of a crude oil spill and fire on water can be especially severe because the oil can spread quickly and contaminate large areas of the water and shoreline, causing long-term environmental damage. Furthermore, the severity of these impacts varies based on a wide range of factors, including the type of oil, the viscosity of the oil, the specific location of the incident, and subsequent weathering.

3.2.1.3 Petroleum Refining

Petroleum refining is a complex process that involves the conversion of crude oil into various useful products, including motor gasoline. The process typically starts with the separation of crude oil into its various components, such as light and heavy hydrocarbons, that are then further processed to produce gasoline. Specifically, gasoline production involves the removal of impurities and contaminants, such as sulfur and nitrogen compounds, using chemical treatments and/or catalysts. Subsequent blending of lighter hydrocarbon fractions, catalytic cracking, and reforming produce the final product of gasoline.

Over the refining process, these techniques potentially produce large volumes of air, water, soil, thermal, and noise pollution, as well as hazardous waste resulting from equipment leaks and hazardous waste disposal (O'Rourke and Connolly 2003). One of the main environmental impacts of petroleum refining is air pollution. The refining process can release large quantities of volatile organic compounds (VOCs), sulfur oxides (SO_X), nitrogen oxides (NO_X), carbon monoxide (CO), particulate matter (PM), and other air pollutants, that can affect air quality (NAP 2015). One of the primary air pollutants released by oil refineries is sulfur dioxide (SO_2), which is a major contributor to acid rain. SO_2 is produced when sulfur-containing compounds in crude oil are burned during the refining process. When released into the atmosphere, SO_2 can react with water vapor to form sulfuric acid, which can harm plant and animal life (Epstein et al. 2002). Another major air pollutant released by oil refineries is NO_X, which can react with other compounds in the atmosphere to form ground-level ozone, a key component of smog. Ground-level ozone can cause respiratory problems that affect human, plant, and animal health.

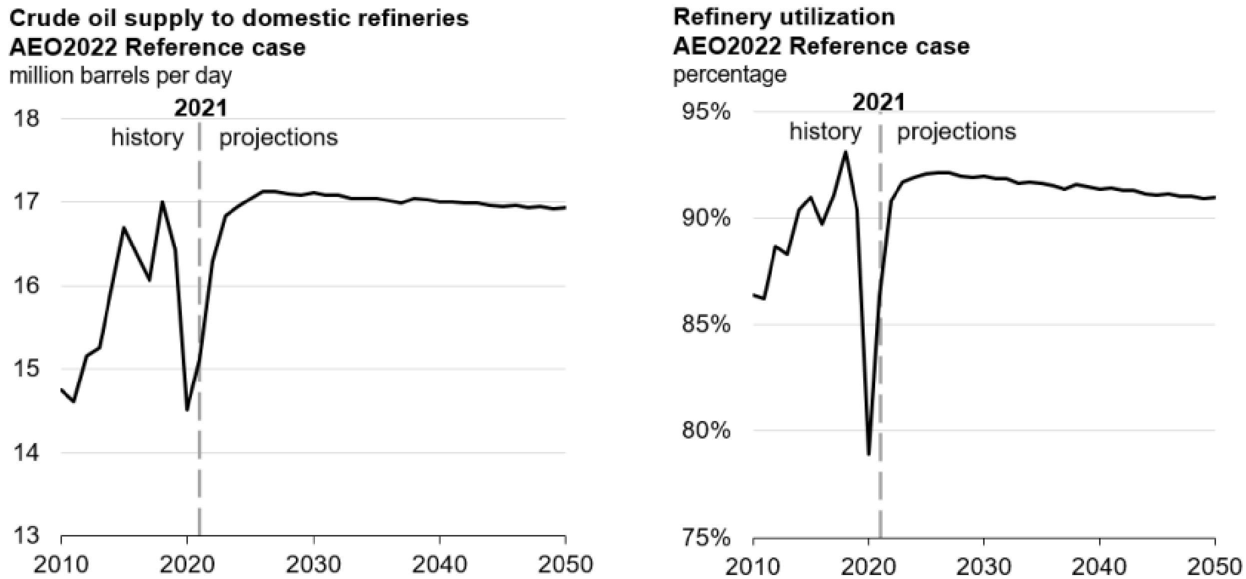
GHG emissions from petroleum refining constitute roughly 6.8 percent of all GHGs released by the U.S. oil industry in 2021 (EPA 2023a). Globally, the oil refining industry is the third-largest source of GHG emissions from stationary sources, as emissions from oil refineries grew by 24 percent from 2010 to 2018 (International Energy Agency [IEA] 2021). The large amounts of energy used by oil refineries for separation and distillation result in further upstream GHG emissions, with heavier oils (e.g., shale oil) requiring more energy to produce a given petroleum product than lighter oils (Hirshfeld and Kolb 2012).

In addition to GHGs, solid residuals created during the refinery process, including spent catalysts, coke dust, tank bottoms, and sludges from the treatment process, can contaminate soil through leaks or spills on- or off-site when transporting the refined petroleum products. Refining also produces wastewater containing oil residuals and other hazardous wastes. This wastewater poses a risk of groundwater contamination when disposed of or recycled throughout the refining process. The waste discharged into surface waters is subject to state discharge regulations and regulated under the Clean Water Act. These discharge guidelines limit the amounts of sulfides, ammonia, suspended solids, and other compounds that may be present in the wastewater. Although these guidelines are in place, significant contamination from past discharges may remain in surface waterbodies and be damaging to the environment. In some cases, exposure to petroleum-derived pollutants created over the refining process can affect the development, health, and morbidity of fish when runoff enters aquatic habitats (Cherr et al. 2017). The environmental impacts of wastewater are discussed in more detail in Section 3.2.1.1, *Petroleum Extraction*.

The processes involved in producing gasoline result in the effects described above. Specifically, catalyst cracking, which involves breaking down larger hydrocarbon molecules into smaller ones, contributes to the release of air pollutants. Similarly, hydrotreating, which is conducted to remove sulfur from crude oil and other hydrocarbons, can also produce hydrogen sulfide, a toxic gas that can harm animals and their habitats by causing respiratory distress, organ damage, and even death in wildlife. Lastly, blending of gasoline involves adding various chemicals to achieve desired properties, such as octane rating and volatility. However, some of the chemicals used are toxic and pose environmental risks. For example, benzene is a common additive in gasoline and is a known carcinogen that can harm aquatic and terrestrial wildlife through exposure to contaminated water or soil (Epstein et al. 2002).

According to AEO 2022, six U.S. refineries closed between 2020 and 2021 in response to pandemic-related demand decreases and the conversion to renewable diesel production. Refinery closures in the United States corresponded to a decline in the national crude oil distillation operating capacity by approximately 3.5 percent in the wake of the coronavirus disease of 2019 (COVID-19) pandemic (EIA 2022a). However, refinery utilization rates are projected to remain stable over the long run because the total production of refined products will remain below peak levels. Trends in crude oil supply to domestic refineries and refinery utilization are shown in Figure 3.2.1-7, which depicts the decline in refinery utilization in 2020 and the subsequent rebound projected over the following years.

Figure 3.2.1-7. Crude Oil Supply to Domestic Refineries and Refinery Utilization

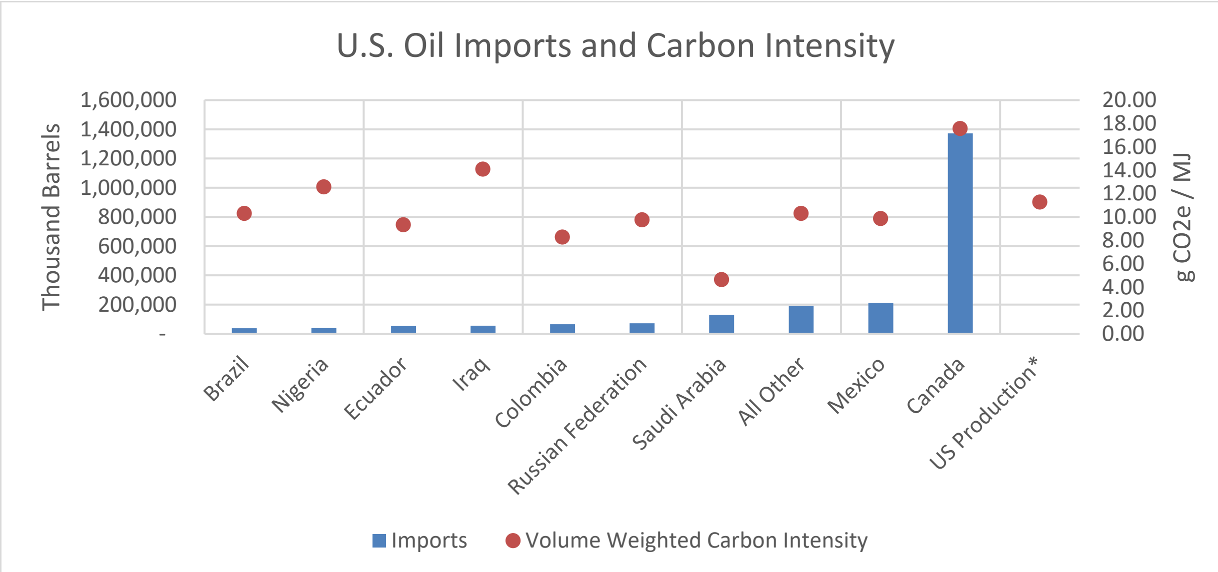


Source: EIA 2022a

3.2.1.4 Petroleum Imports

In addition to domestic extraction of petroleum liquids, the United States is a large importer of crude oil used in the production of gasoline. In 2021, the United States had gross imports of over 2.2 billion barrels of crude oil. AEO 2022 projects that the United States will continue to be a net importer of petroleum, with net imports of 1.31 billion barrels in 2021 declining to 0.97 billion barrels in 2050. The emissions intensity of crude oil production varies substantially from country to country from as low as 3.3 grams CO_2e per megajoule (g CO_2e/MJ) (Denmark) to 29.8 g CO_2e/MJ (Syria) based on recent research (Masnadi et al. 2018). Some of the biggest drivers in emissions intensity of crude oil production include emissions associated with the energy required for extraction and processing (heavy oils and oil sands being the most energy intensive), flaring rates (process of burning excess gas) or venting rates (directly emitting CH_4), and CH_4 leakage. The environmental effects from reducing petroleum imports and associated CO_2e may differ substantially depending on where that supply comes from. In 2021, 91 percent of gross U.S. crude oil imports were from Canada (61.5 percent), Mexico (9.5 percent), Saudi Arabia (5.8 percent), the Russian Federation (3.3 percent), Colombia (2.9 percent), Iraq (2.5 percent), Ecuador (2.4 percent), Nigeria (1.8 percent), and Brazil (1.7 percent). All other countries account for under 9 percent of gross 2021 U.S. crude oil imports. Figure 3.2.1-8 displays the quantity of imported crude oil from each country in 2021 (EIA 2021e) with estimated emission intensities of crude oil production in those countries (Masnadi et al. 2018).

Figure 3.2.1-8. U.S. Crude Oil Imports and Carbon Intensity



*U.S. production provided to compare carbon intensity
Source: EIA 2021e; Masnadi et al. 2018

3.2.1.5 Fuel Transportation, Storage, and Distribution

After crude oil is refined into gasoline, gasoline is transported, stored, and distributed via a network of pipelines, storage tanks, and terminals, as well as tanker trucks and railcars, before being utilized by consumers. Similar to the environmental risks of transporting unrefined crude oil, transportation and storage of gasoline affect the environment primarily through the risk of spills and leaks. Tanker trucks and railcars can experience equipment malfunctions, such as ruptured hoses, valve failures, or tank punctures, releasing gasoline onto the ground, into waterways, or into the air. Accidents can also happen during loading or unloading of gasoline, resulting in the spillage or leakage of gasoline into the environment.

Storage of gasoline in tanks also poses a risk of leaks or spills, which can result in significant environmental damage. Common causes of leaks or spills include corrosion, equipment failure, and natural disasters. When spilled, gasoline can contaminate soil, water, and air, and can harm people, plants, and animals by exposing them to harmful toxins or igniting into fires and explosions. The inherent nature of gasoline also makes it difficult to contain when stored. Fuel evaporative losses, or vapor losses, occur from storage tanks when tanks are refueled or damaged and saturated vapor is released as clean or less saturated air enters the tank. This process affects all types of storage tanks, including vehicle tanks, canisters, and underground storage tanks or aboveground storage tanks. The discrepancy in the density of saturated gasoline vapors and clean air means evaporated gasoline is readily released, resulting in an estimated 0.5 percent of all liquid gasoline dispensed in storage tanks being released into the atmosphere as a vapor form (Hilpert et al. 2015).

At gas stations, motor gasoline is released by both liquid spillage and vapor losses, leading to atmospheric pollution and soil and groundwater contamination. Although there is a lack of more recent data on gasoline spills at gas stations, one study quantifying fuel spill frequency and amounts at gas stations in California found that roughly 0.007 percent to 0.01 percent of all dispensed gasoline is spilled in liquid form, and other studies have suggested the percentage is even higher (Morgester et al. 1992;

Mueller 1989). After leaking from nozzles or pipes at gas stations, gasoline may infiltrate the concrete slabs covering gas stations and contaminate the underlying sediment through pathways such as cracks and faulty joints in the concrete (Hilpert and Breysse 2014). These events can result in the release of toxic pollutants, including hydrocarbons, into the environment and can cause long-lasting damage to the soil, water, and air. Runoff water from gasoline distribution sites also carries contaminants to sources of fresh or salt water, affecting aquatic life as described in Section 3.2.1.1, *Petroleum Extraction*. EPA has studied the vaporous movement of common constituents of gasoline, such as CH_4 and VOCs, and found higher concentrations in the air within 200 meters of gas stations than ambient air levels (EPA 2006). The release of gasoline through either liquid spills or vapor losses leads to the emission of toxins that contribute to GHGs and result in a host of environmental effects (Epstein et al. 2002).

3.2.2 Electricity

Electricity currently makes up 0.2 percent of LD vehicle and commercial light truck fuel use, but the CAFE Model projects this proportion to increase to 33.9 percent by 2050, representing the largest share of fuel consumption outside of gasoline. For HDPUVs, electricity currently makes up 0.1 percent of fuel use, and the CAFE Model projects this proportion to increase to 25.5 percent by 2050. Current U.S. policies expanding the Federal electric vehicle (EV) fleet and improving vehicle charging infrastructure are anticipated to drive this number higher. NHTSA's CAFE Model projects that by MY 2050, the share of total LD vehicles sold in that MY that run on electricity only (i.e., dedicated EVs) will reach 92 to 97 percent across the alternatives.[15] The share of HDPUVs sold in MY 2050 running on electricity only is projected to reach approximately 51 percent.[16] Worldwide, projections estimate that nearly 1.6 billion LD vehicles will be on the road by 2030 (EIA 2021b), of which nearly 250 million are expected to be EVs (IEA 2023). Even as EVs increase in sales and proportion of VMT, the higher efficiency of EVs relative to conventional vehicle powertrains will mean that electricity use will be a smaller portion of energy use relative to total VMT.

EVs use battery technologies to provide power, reducing or even eliminating liquid fuel consumption during vehicle operation. EVs cover a range of different engine types, including plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs) (Notter et al. 2010; Patterson et al. 2011; DOE 2013a).[17] PHEVs are fitted with a large-capacity rechargeable battery that can be charged from the electric grid; they also use an internal combustion engine (ICE) or fuel cell as backup when battery power is depleted. BEVs are purely electrically powered, require charging from the electric grid, and do not incorporate an ICE. For more information on EVs and market trends, see Section 3.3.2, *Cumulative Impacts*.

EVs require charging infrastructure to connect batteries to the electricity grid. According to DOE, the increasing interest in EV ownership has spurred an expansion of private and public EV charging infrastructure over the last decade (DOE 2022a). Annual investment in the hardware and installation of home and public charging infrastructure in the United States has increased nearly 300 percent from over

[15] These projections include 7 to 8 percent for battery electric vehicles (BEVs) Level 1 (150- to 200-mile driving range), 56 to 59 percent for BEVs Level 2 (250- to 300-mile driving range), 25 to 33 percent for BEVs Level 3 (300-mile driving range), and 1 percent for BEVs Level 4 (400-mile driving range).

[16] These projections include 43 percent for BEVs Level 1 and 8 percent for BEVs Level 2.

[17] Hybrid electric vehicles (HEVs) incorporate a battery and electric motor combined with an internal combustion engine (ICE) or fuel cell, and have regenerative charging capabilities (e.g., regenerative braking), but they are not charged by the electric grid so they are not included for purposes of this discussion of upstream electricity energy use.

$350 million in 2016 to $1.3 billion in 2021 (BNEF 2022). In addition, in 2022, all 50 states took policy actions to support electrification, including financial incentives pertaining to charging infrastructure (NC Clean Energy Technology Center 2023).[18] Similar trends have been seen in the private sector as companies roll out expansive charging infrastructure expansion plans for customers, employees, and company fleets (DOE 2022a). Between 2012 and 2021 the charging industry overall attracted $4.6 billion in venture capital funding and mergers and acquisitions (Hampleton Partners 2023). The rise in EVs and the consequential need for expanded charging infrastructure is a consideration when understanding EV impacts on grid resilience, built infrastructure, and overall environmental impacts.

To understand the impact that the increasing share of EVs will have on emissions and the environment, understanding the projections for U.S. electricity production is critical. The AEO provides a closer look at projections for U.S. electricity consumption through 2050. In the AEO reference case, the average annual increase in electricity use is expected to be below 1 percent for most of the projected period up to 2050 (which will be slightly offset by efficiency improvements). While the transportation sector continues to make up under 3 percent of the economy's electricity consumption from 2021 to 2050 (EIA 2022a), the sector is projected to have the highest growth in electricity demand driven by the increasing share of EVs.

It is projected that the share of renewables—solar, wind, and hydropower—in the electricity generation mix will more than double from approximately 19 to 41 percent in 2050, complemented by increased battery storage capacity. [19] In the United States, solar makes up the largest share of additional generating capacity, 70 percent of which is utility-scale photovoltaic (PV) power plants (and 30 percent residential and commercial rooftop solar installations). For solar, these projections include both utility-scale and end-use PV electricity generation. Wind energy additional capacity is largely dependent on policies like the extension of tax credits. Natural gas will continue to comprise a large share of the electricity generation mix (37 percent in 2021 to 34 percent in 2050), while coal and nuclear are expected to decline (from 23 percent to 10 percent, and 19 percent to 12 percent, respectively) (EIA 2022a).[20]

3.2.2.1 Electricity Generation: Oil, Coal, Natural Gas, and Renewables

Electricity generation accounts for around 38 percent of energy consumption in the United States, more than any other energy-use sector (EIA 2022b). As it is a secondary source of energy, electricity is generated using energy from a primary source, such as fossil fuels or renewable energy (EIA 2022f). In 2021, natural gas accounted for 37 percent of electricity generation, while coal accounted for 23 percent, nuclear for 19 percent, and renewables (e.g., wind, solar, conventional hydropower) for 19 percent of electricity generation. The remaining 2 percent came from biomass, petroleum, and geothermal (EIA 2022a, 2022f). Once generated, electricity can be distributed and converted to mechanical energy or heat, making it a prime source of power for the transportation, industrial, residential, and commercial sectors.

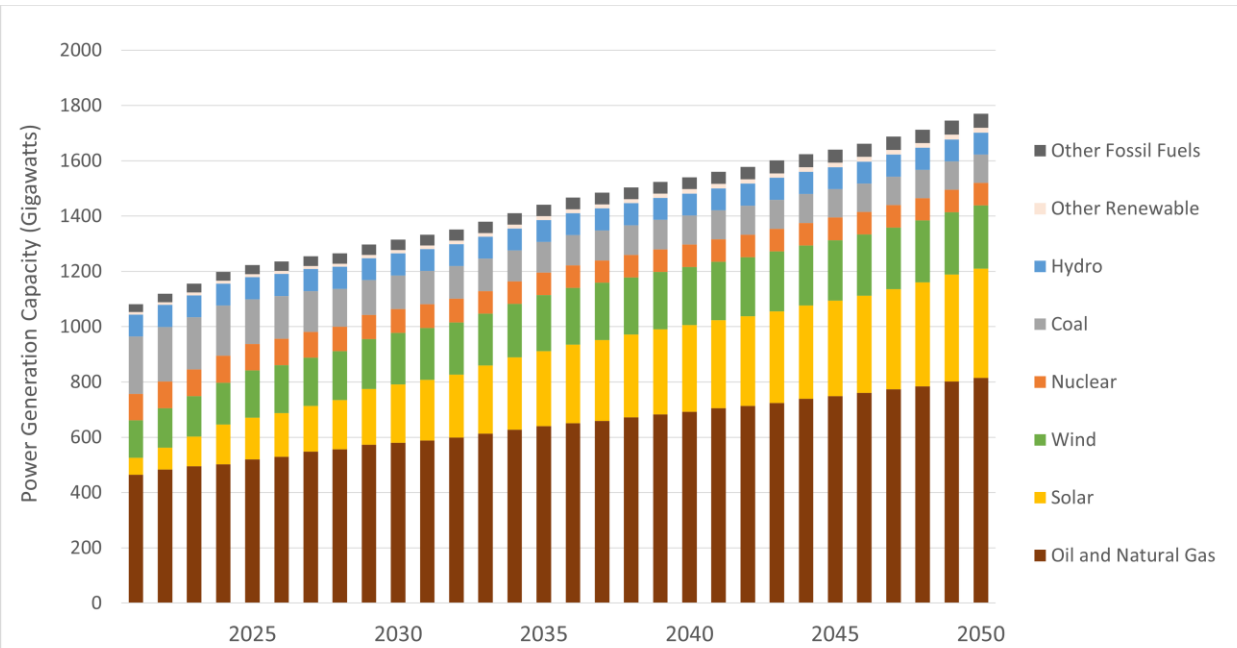
[18] Financial incentives include "new state or investor-owned utility incentive programs or changes to existing incentive programs for electric vehicles and charging infrastructure" (NC Clean Energy Technology Center 2023).

[19] This description of renewable energy resources does not include biomass or geothermal energy, which are renewables that combined make up 1.7 percent of 2021 total U.S. electricity generation (EIA 2022a).

[20] NHTSA used AEO 2022 Reference Case during EIS development due to the availability of the AEO data at the time of modeling. AEO 2023 was released in spring 2023 and used different emissions assumptions. NHTSA will consider the feasibility of updating to AEO 2023 for the Final EIS.

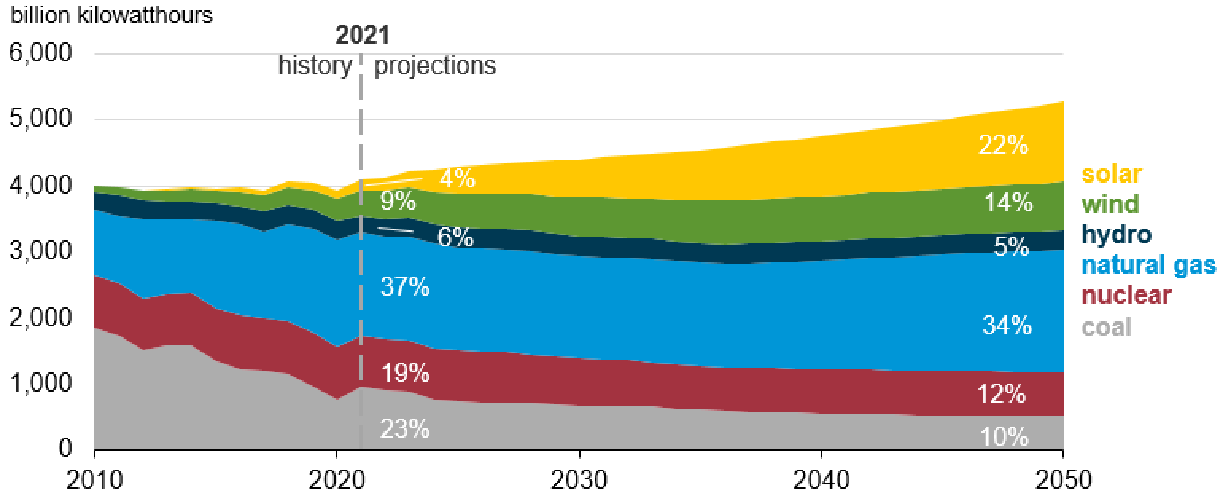
Coal is a conventional energy source that generates electricity via combustion to power a generator. Through this process, coal is burned to boil water and generate steam, which turns turbines that drive a generator. Byproducts of coal-fired power plants include coal ash, SO_2, NO_X, mercury, carbon dioxide (CO_2), and other GHG emissions (EIA 2022g). In 2021, coal was used to generate 10.8 percent of total U.S. energy consumption, with 91.9 percent of that consumption attributed to the electric power sector (EIA 2022g). Despite being the largest consumer of coal, Figure 3.2.2-1 shows that coal electricity generating capacity is gradually declining as other energy sources like natural gas and renewable energy increase capacity (EIA 2022g). Figure 3.2.2-2 also illustrates this decline, showing that U.S. electricity generation from coal fell from approximately 1,847 billion kilowatt-hours (kWh) in 2010 to 954 billion kWh in 2021, reflecting the combined impact of additional natural gas and renewable energy generating capacity and historically low natural gas prices (EIA 2022a). AEO 2022 projects that electricity generation from coal will continue to gradually decline through 2050 (EIA 2022a).

Figure 3.2.2-1. U.S. Electricity Generating Capacity by Year, Projections to 2050



Source: EIA 2022a
Note: The data in this figure is for the power sector only and does not include end-use capacity.

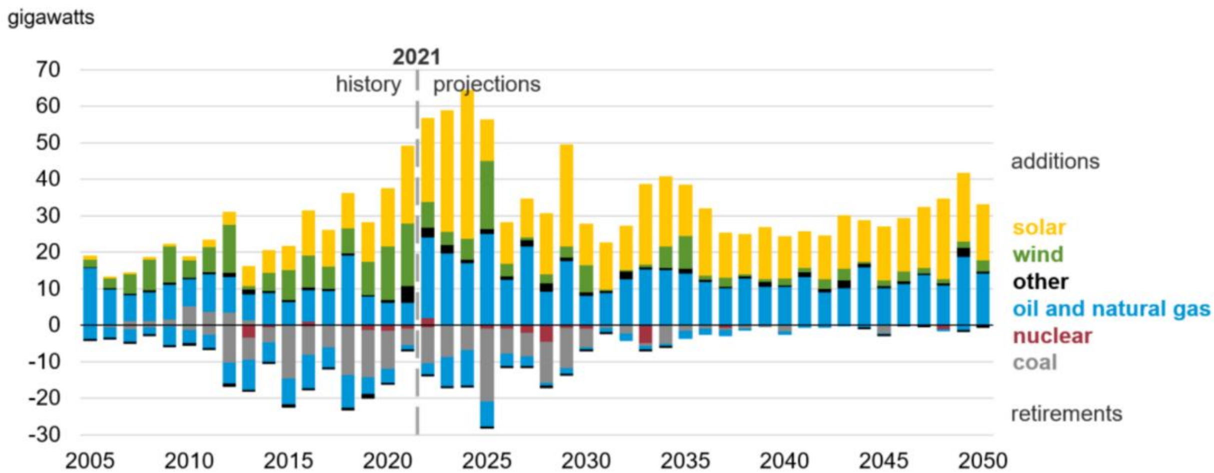
Figure 3.2.2-2. 2021 Estimates of U.S. Electricity Generation from Selected Fuels



Source: EIA 2022a
Note: This figure includes utility-scale and end-use solar photovoltaic electricity generation.

The majority of U.S. utility-scale electricity generation retirements are projected to be from coal generation, whereas the majority of additions will be from solar, wind, and oil and natural gas. Figure 3.2.2-3 shows the historical and projected additions and retirements to U.S. electricity capacity including utility-scale and end-use solar.

Figure 3.2.2-3. Historical and Projected U.S. Electric Capacity Additions and Retirements



Source: EIA 2022a
Note: This figure includes utility-scale and end-use solar photovoltaic electricity generation.

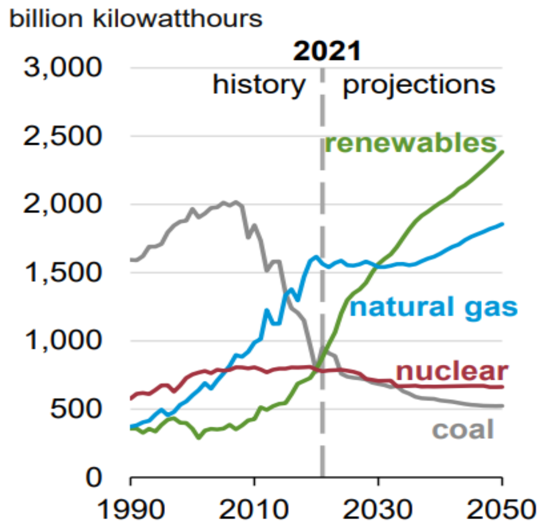
The production of coal can have many environmental and health impacts. Building coal mines requires the clearing of surrounding land, especially for surface mines (or strip mines) (EIA 2022g). To establish surface mines, trees, plants, and topsoil are removed from the area, which alters the ecosystem and can block streams or other nearby waterways (Dontala et al. 2015). There is also risk of acid mine drainage from coal mines, which results when water containing toxic levels of coal, heavy metals, and other minerals runs off or leaks from the mining site and contaminates nearby soil and water sources (Dontala et al. 2015). Non-GHG byproducts from coal production can also have adverse impacts on the environment and human health. These include SO_X, NO_X, PM, and heavy metals such as lead, mercury, and arsenic. These substances can increase the risk of respiratory issues and cardiovascular diseases and can be carcinogenic (Munawer 2018).

Natural gas is another fossil-based energy source. Like coal, natural gas generates electricity through combustion, which powers a generator. However, when natural gas is substituted for coal to produce heat or electricity, emissions of SO_2, NO_X, and mercury are lower (Moore et al. 2014). Natural gas is typically sourced via a drilling and gas collection process known as hydraulic fracturing, or fracking. During fracking, liquid is injected into cracks in the ground to force natural gas out through a well to be captured at the surface (EIA 2016). The gas is transported via pipelines to power plants, where it is combusted to generate hot air that spins a turbine to power a gas generator. Natural gas has recently become a significantly larger portion of U.S. electricity generation, reaching 37 percent in 2021 (EIA 2022a). That share is projected to decrease to 34 percent of generation capacity by 2050, though the overall amount of electricity generated from natural gas is projected to increase by 19 percent in the same timeframe (EIA 2022a). The decline in the natural gas share of electricity generation is due to the anticipated growth in electricity generation from renewable sources.

Exploring, drilling, producing, and transporting natural gas can have many environmental impacts. During the exploration phase, land may need to be cleared and leveled to build new drilling sites, which can affect surrounding wildlife and ecosystems (EIA 2022h). There are also significant risks associated with the fracking process. A large quantity of water from nearby ground or surface water sources is used with chemical additives for fracking. Water withdrawal can affect the amount of fresh water available for consumption or other uses in the surrounding area, particularly in areas susceptible to drought, and can affect aquatic ecosystems (Gallegos et al. 2015). While research is still developing, there is concern that chemical additives in water used for fracking could leak into and contaminate groundwater resources used for drinking water. If wastewater from fracking is not properly treated it can also contaminate drinking water sources. The impact of fracking for natural gas is discussed further in Section 3.3.2, *Cumulative Impacts*. Additionally, the injection of large quantities of wastewater in deep wells can create risk of seismic events. This risk varies depending on the geology of the region (Gallegos et al. 2015). To transport natural gas, land is cleared to build and bury pipelines. These pipelines pose a risk to soil quality, wildlife, and water sources in the instance of a leak or spill (EIA 2022h; Bonvicini et al. 2015). While pipeline failures are rare, a single instance can have a significant impact (Bonvicini et al. 2015). Renewable energy has also experienced capacity growth in the electricity sector and generates significantly less emissions than natural gas, diesel, or other fossil fuels. For example, electricity generation from photovoltaic cells produces approximately 43 g CO_2e/kWh in total life-cycle emissions compared to natural gas, which produces approximately 486 g CO_2e/kWh (National Renewable Energy Laboratory [NREL] 2021a).

As of 2021, renewables account for 20 percent of total U.S. utility-scale electricity generation. Wind power generates 9.2 percent of electricity using blowing wind to spin large-scale wind turbine blades that power a generator (EIA 2022f). Hydropower harnesses kinetic energy from the natural flow of water to power a generator, and accounts for 6.3 percent of electricity generation (EIA 2022f). Solar power only makes up 2.8 percent of current U.S. utility-scale electricity generation, but it is one of the fastest-growing energy technologies, as shown in Figure 3.2.2-2 (EIA 2022a). Solar power plants can generate electrical energy either by using large fields of ground-mounted solar arrays, or by using concentrated solar power systems where mirrors reflect and concentrate solar energy to heat a receiver and run a steam-powered generator. While there are less-common sources of renewable energy-powered electrical generation, including biomass and geothermal, most power plants utilize wind, hydropower, or solar energy technologies. Renewable energy is projected to be the leading source of electricity generation by 2050, per Figure 3.2.2-4.

Figure 3.2.2-4. Net Electricity Generation by Source (1990 to 2050)



Source: EIA 2022a

While renewables are critical to reducing overall emissions from electricity generation, there are important environmental impacts that must be considered. The production of PV cells for solar energy involves potentially hazardous materials and chemicals that can have negative environmental impacts if mishandled or not lawfully disposed of at the solar panel's end of life (EIA 2022i). Some of these materials include silicon, cadmium, copper, and more, which involve mining and purification processes if not sourced from recycled products. Some of the materials and chemicals used in the manufacturing process are carcinogenic and have other negative health impacts (Tawalbeh et al. 2021). Construction of solar plants may also require land clearing, which may disturb surrounding habitats and displace land that could be used for other purposes like agriculture (Tawalbeh et al. 2021). Construction of dams for hydropower can also have significant environmental impacts by causing significant change to surrounding ecosystems. Dam construction alters the flow of the river, which can diminish water quality, impede migration routes for fish, and change aquatic ecosystems by altering water temperature and flow conditions (EIA 2022j). For wind energy, research has shown an increase in bird and bat fatalities from collision with wind turbines, and the materials and metals used to create wind turbines have additional environmental impacts (Wang and Wang 2015).

When considering the multiple energy sources for electricity generation, it is important to understand the upstream environmental impacts of electricity, including emissions. *Upstream emissions* are defined as the emissions from producing and distributing electricity–extraction, processing or refinement, transportation, storage, and more (NREL 2021a). In the CAFE Model, upstream GHG emissions are calculated using aggregate estimates of emissions from all stages of production and distribution, per unit of fuel energy supplied (Shaulov et al. 2023). For the analysis, emissions factors are estimated using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model 2022, which draws upon electricity generation projections from AEO 2022. The CAFE Model considers the upstream emissions of energy sources for electricity generation to understand the overall life-cycle emissions of EVs and how different vehicle standards affect air quality, which is discussed further in Chapter 2, Section 2.5.2, *Upstream Emissions*; Chapter 4, *Air Quality* (throughout); and Chapter 6, Section 6.1, *Introduction*.

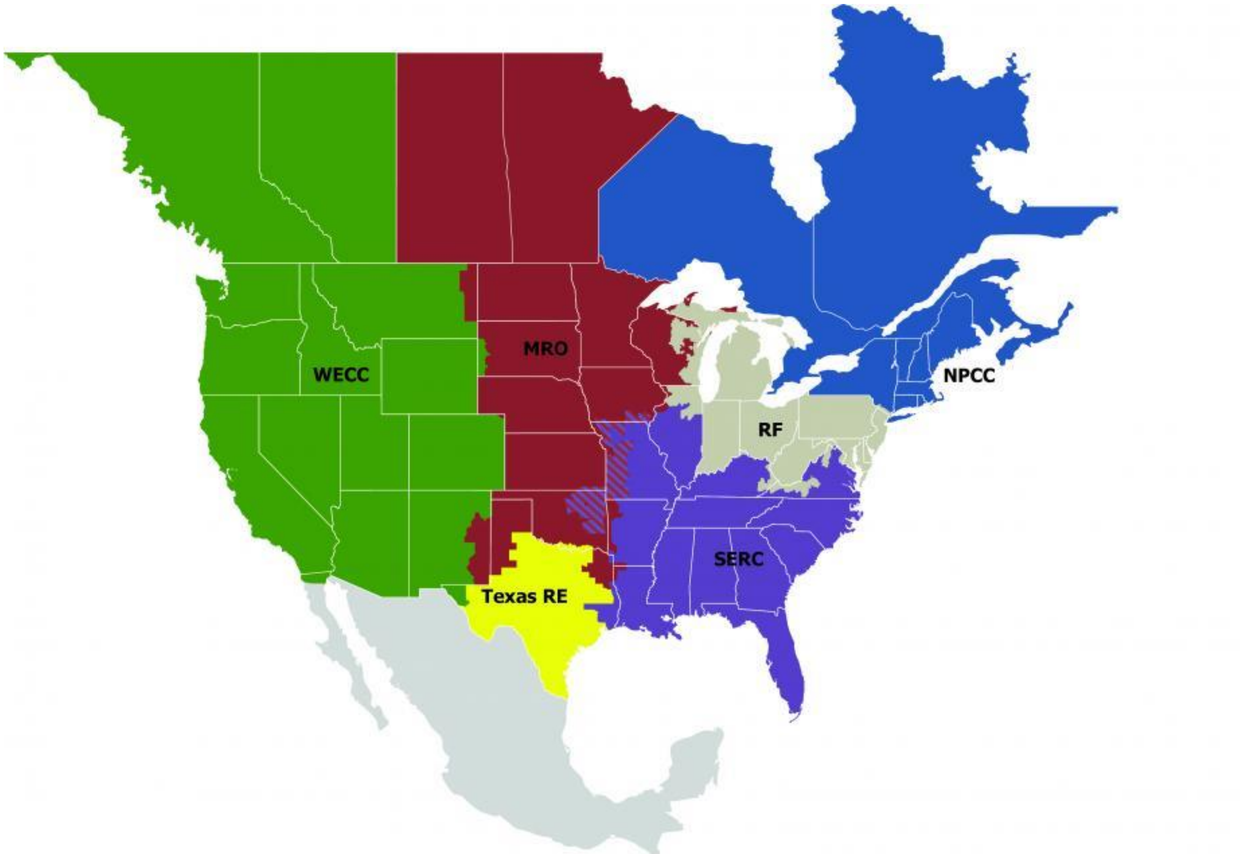
The CAFE Model upstream emissions calculation results vary based on the emissions factor of the energy source used to generate the electricity. For electricity generated by renewable energy resources, the majority of life-cycle GHG emissions are attributed to upstream emissions from manufacturing energy technologies. According to NREL, upstream processes account for 92 percent of the 13 g CO_2e/kWh total life-cycle emissions of wind energy technology and 65 percent of the 43 g CO_2e/kWh life-cycle emissions from PV solar energy technology (NREL 2021a). For both energy sources, these emissions are from raw material extraction, manufacturing of wind turbines or solar cells, and constructing the wind or solar farm site (NREL 2021a). Upstream emissions of hydropower facilities account for 30 percent of the 21 g CO_2e/kWh total life-cycle emissions because hydropower also has higher ongoing emissions associated with freshwater biogenic GHG emissions (NREL 2021a).

Upstream emissions make up a small portion of the total life-cycle emissions of fossil fuel-generated electricity, which emits most of its emissions during the combustion portion of electricity generation. However, overall fossil fuel emissions are high per kWh of electricity generated, so even a small portion of overall life-cycle emissions has a large impact on air quality. For coal-powered electricity, upstream processes make up less than 1 percent of the 1,001 g CO_2e/kWh total life-cycle emissions. Coal has nearly 100 times the life-cycle emissions of wind energy (NREL 2021a). Natural gas that generates electricity via a combined-cycle process has nearly half the life-cycle emissions of coal, at an average of 486 g CO_2e/kWh, and less than 1 percent of these are upstream emissions (NREL 2021a). Most upstream natural gas emissions are fugitive CH_4 emissions from unintended leaks in storage tanks, pipelines, or wells, which have a high global warming capacity.

3.2.2.2 Region-Specific Electricity Grid Impacts

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 North American Electric Reliability Corporation (NERC) regions (Figure 3.2.2-5) and EPA Emissions & Generation Resource Integrated Database (eGRID) subregions (Figure 3.2.2-6), 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 2021a). A breakdown of grid mix by eGRID subregion, as of 2021, is shown in Figure 3.2.2-7.

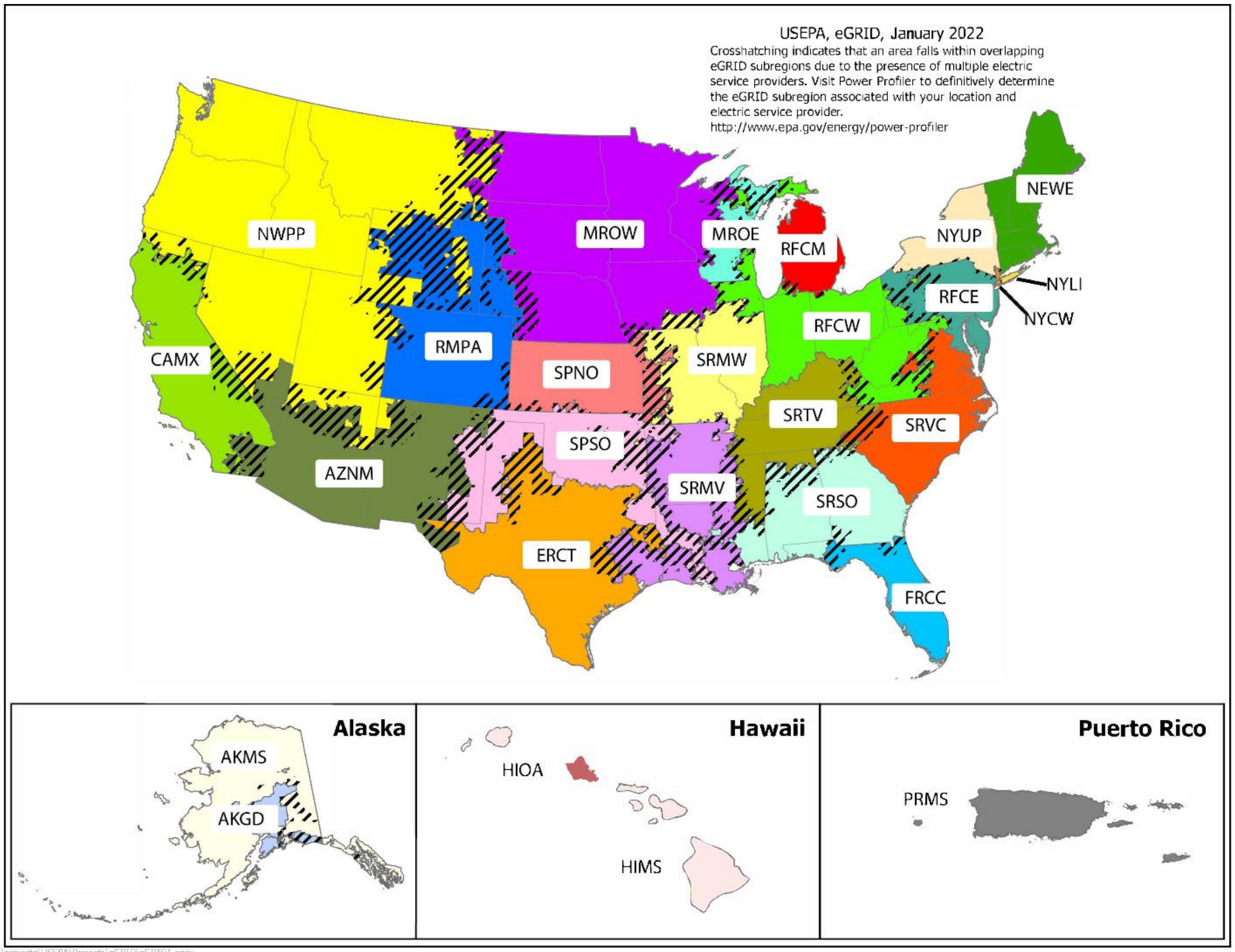
Figure 3.2.2-5. North American Electric Reliability Corporation Regional Map



Source: EPA 2019a

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

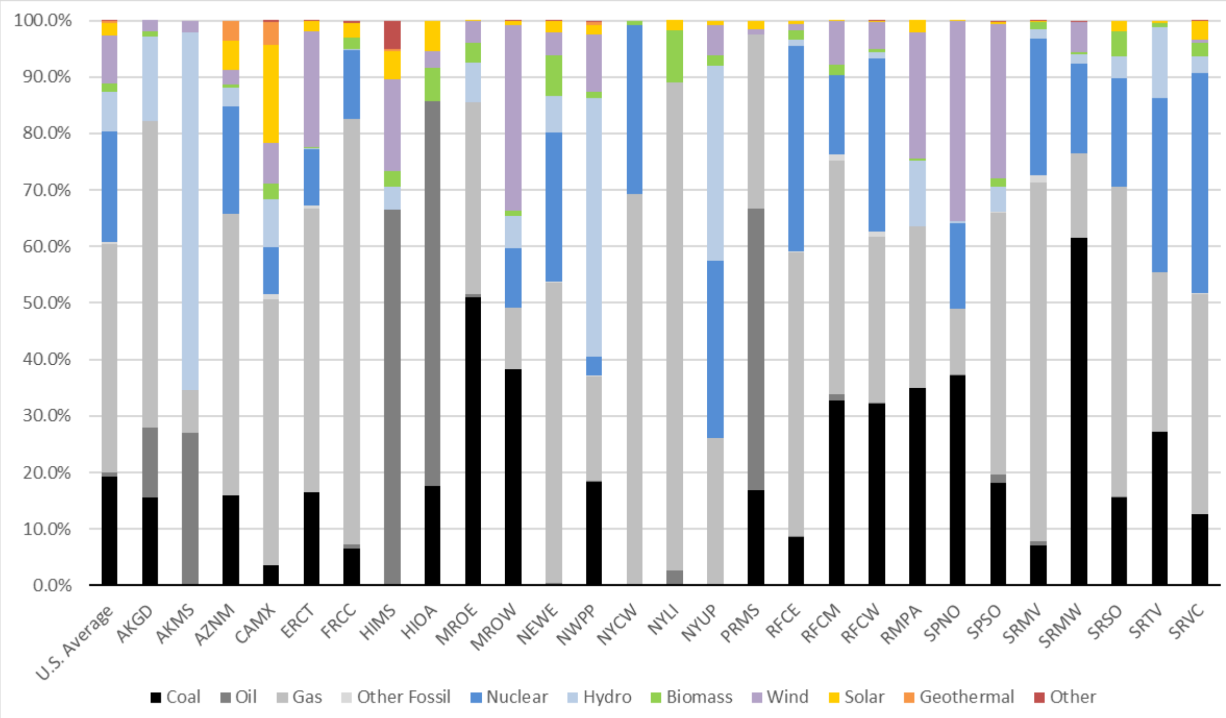
Figure 3.2.2-6. Environmental Protection Agency eGRID Subregions



Source: EPA 2022b

eGRID = Emissions & Generation Resource Integrated Database. eGRID subregions are derived from NERC names: FRCC = FRCC All; MROE = 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.

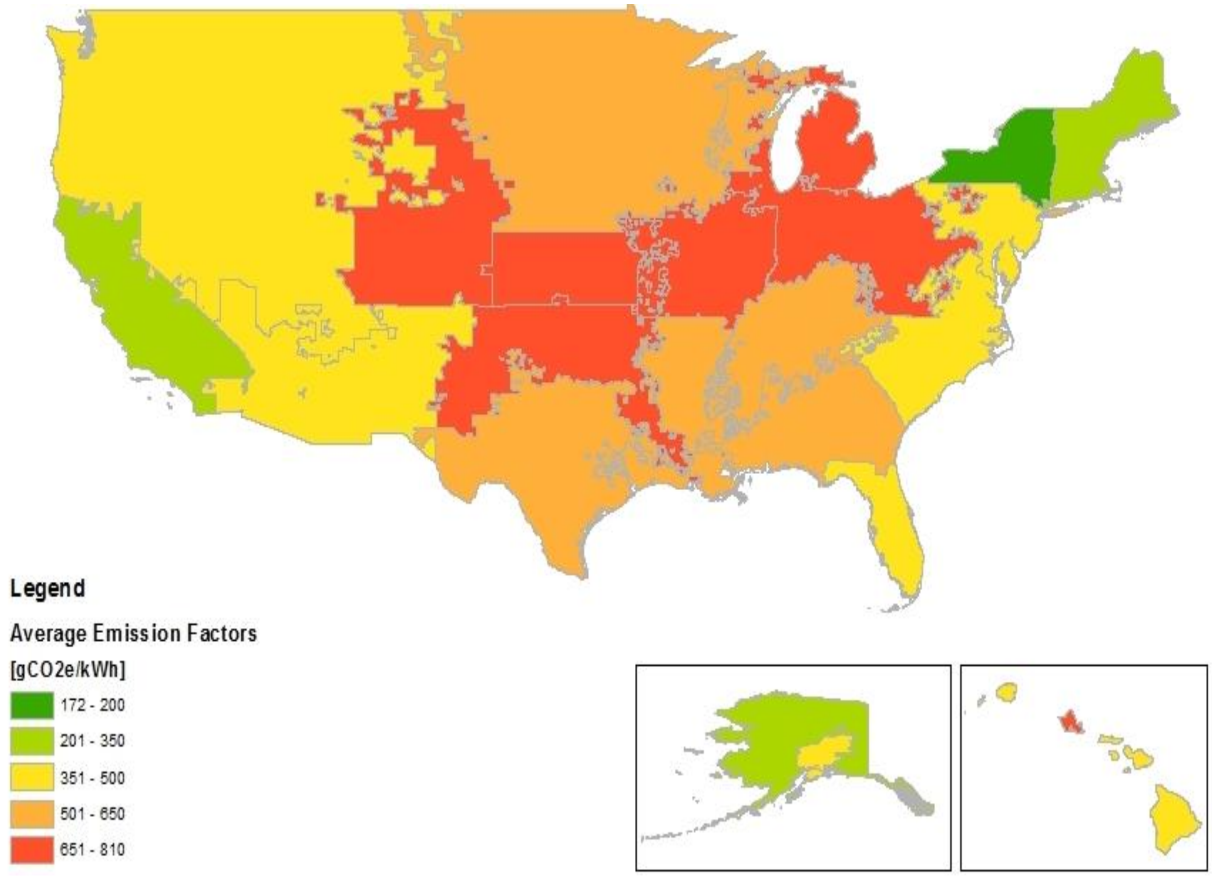
Figure 3.2.2-7. 2021 U.S. Average and eGRID Subregion Grid Mix



Source: EPA 2022c
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 emissions factors vary significantly by subregion, with the most carbon-intensive subregion of the United States emitting more than 4.7 times as much CO_2e/kWh relative to the least carbon-intensive subregion, as shown in Figure 3.2.2-8. Generally, average emissions factors 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 emissions rates for most eGRID subregions have declined by more than 20 percent between 2012 and 2020 (EPA 2015a, 2022c).

Figure 3.2.2-8. eGRID Subregion Average Emission Factors for Electricity (g CO_2e/kWh)



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

Given the expected growth in EVs over the next 25 to 30 years, in response to market forces, fuel efficiency improvements, and anticipated baseline growth in EV adoption, it is important to understand where the electricity used to fuel these vehicles is being sourced. The level of use-phase GHG emissions from EVs depends on several factors, including where they are charged and the energy sources of the electricity grid being used to charge the vehicle (Elgowainy et al. 2010; Holland et al. 2014; Nealer and Hendrickson 2015; Onat et al. 2015; McLaren et al. 2016, Tamayao et al. 2015; Kawamoto et al. 2019; Miller et al. 2020). For example, Miller et al. (2020) found that EV sedans emit approximately 44 percent fewer emissions than ICE vehicles based on national annual average electricity. Based on grid data from 2018 to 2019, the study found that both regional grid variation and time of charging had a large impact on the level of EV emissions (Miller et al. 2020). Another study found that an EV operating in California could have almost 50 percent lower emissions than the national average, whereas an EV operating in Wisconsin could have 50 percent more emissions than the national average given the high share of coal in the grid mix (Wu et al. 2019). A study that priced indirect emissions from electricity use and EV battery manufacturing found that through technological improvements, emissions from electricity and battery production for EVs are more than offset by reductions in the production of gasoline (Wolfram et al. 2021). A 2022 Argonne National Laboratory (ANL) life-cycle analysis of LD vehicle pathways in the United States found that BEVs have the lowest cradle-to-grave CO_2e emissions per mile among all current and future vehicle technologies, with additional reductions possible from the use of solar, wind, and advanced combined cycle with carbon capture and sequestration (Kelly et al. 2022).

Several states have made efforts to improve demand management and increase charging during off-peak hours through smart charging. For example, California, among other states, has begun to allow submetering for EV charging to encourage drivers to charge during lower-cost, off-peak times (California Public Utilities Commission 2022). Additionally, a study from the Pacific Northwest National Laboratory found that if smart charging is used to delay charging to times of least-cost retail electricity rates, the number of LD EVs able to be served could increase from 9 million to 20 million in the Western Electricity Coordinating Council's region (Figure 3.2.2-5) (Pacific Northwest National Laboratory 2020). Additional information about how region-specific emissions impacts are projected to be mitigated are discussed in Section 3.3.2, *Cumulative Impacts*.

The physical infrastructure of regional grids can also have various environmental impacts including land clearing, habitat loss, and bird mortality. These impacts vary regionally depending on the ecosystems surrounding the grid but are a consistent consequence of electricity grid infrastructure. Many of these impacts occur during the building phase of the infrastructure but persist throughout the use phase as well (Biasotto and Kindel 2018). The relationship between size of individual components of the electric power sector and threat to biodiversity indicates that a shift to non-fossil sources, such as solar and wind, could reduce pressures on biodiversity both within the territory where demand for power resides and along international supply chains, but is dependent on the scale of existing fossil resources and effective government management of the transition to electricity (Holland et al. 2019). As the United States works with communities to responsibly deploy clean electricity sources that are increasingly manufactured through domestic suppliers, with the support of trading partners with high standards for environmental protections, efforts to reduce GHG emissions can minimize the effects on biodiversity in the United States and globally (DOE 2022b, 2023a).

3.2.2.3 Downstream Electricity Impacts

Understanding the life-cycle impacts of EVs requires an understanding of downstream environmental impacts and GHG emissions of manufacturing vehicles, building necessary infrastructure, and generating electricity for fuel (Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*).

Downstream emissions associated with generating electricity for use as EV fuel are attributed to the process of retiring a power plant or system (NREL 2021a), because there are no tailpipe emissions. For renewable energy, the downstream emissions of electricity generation involve decommissioning and disposal. Downstream emissions from dismantling wind turbines make up less than 1 percent of the total 13 g CO_2e/kWh life-cycle emissions for a wind farm (NREL 2021a). Concrete, steel, cast iron, and other turbine materials can be recycled to further reduce downstream emissions. Downstream emissions can be higher for a solar PV plant than a wind farm because decommissioning and disposal of solar cells account for 12 percent of the total 43 g CO_2e/kWh life-cycle emissions (NREL 2021a). The higher emissions are due to the recovery and disposal process for heavy metals contained in solar PV cells (NREL 2021a). Downstream emissions make up less than 1 percent of the 21 g CO_2e/kWh life-cycle emissions of hydropower facilities, although hydropower dams are rarely decommissioned (NREL 2021a). Emissions from power generation could be reduced to the extent that energy materials recycling facilities are established, particularly in locations where former fossil fuel infrastructure exists (U.S. Treasury 2023a; DOE 2023b).

For conventional fossil fuels used to generate electricity, the downstream processes include decommissioning the power plant, waste disposal, and rehabilitation of land where the raw fuel was extracted. In the life cycle of a coal power plant, downstream emissions make up less than 1 percent of the 1,001 g CO_2e/kWh total emissions (NREL 2021a). Most downstream coal emissions result from equipment and transportation required to demolish a retired coal plant and dispose of hazardous waste like coal ash (EIA 2022g). Coal ash, or fly ash, contains high levels of arsenic, copper, and selenium and can contain traces of lead, mercury, and cadmium. If not disposed of properly according to EPA rules, coal ash can cause soil acidification, contaminate ground and surface water sources, and may be accidentally consumed by fish and other aquatic species. This can lead to bioaccumulation of these trace metals up the food web, which could lead to negative impacts on human health (Munawer 2018; EPA 2023b). Tax incentives to reinvest in coal communities and brownfields could support redevelopment of these sites, and possible new commercial technologies that can extract critical minerals from waste could reduce environmental impacts by reducing the need for new mining (U.S. Treasury 2023b; DOE 2023c). Downstream electricity impacts may be further reduced in the future. EPA is proposing regulations governing effluents from steam electric power generators, which would reduce pollutants discharged through wastewater from coal-fired power plants by approximately 584 million pounds per year (EPA 2023c). Downstream emissions from natural gas energy make up less than 1 percent of the 486 g CO_2e/kWh life-cycle emissions and are also attributed to power plant retirement, waste disposal, and land rehabilitation, as well as pipeline decommissioning and fugitive CH_4 emissions from abandoned wells (NREL 2021a).

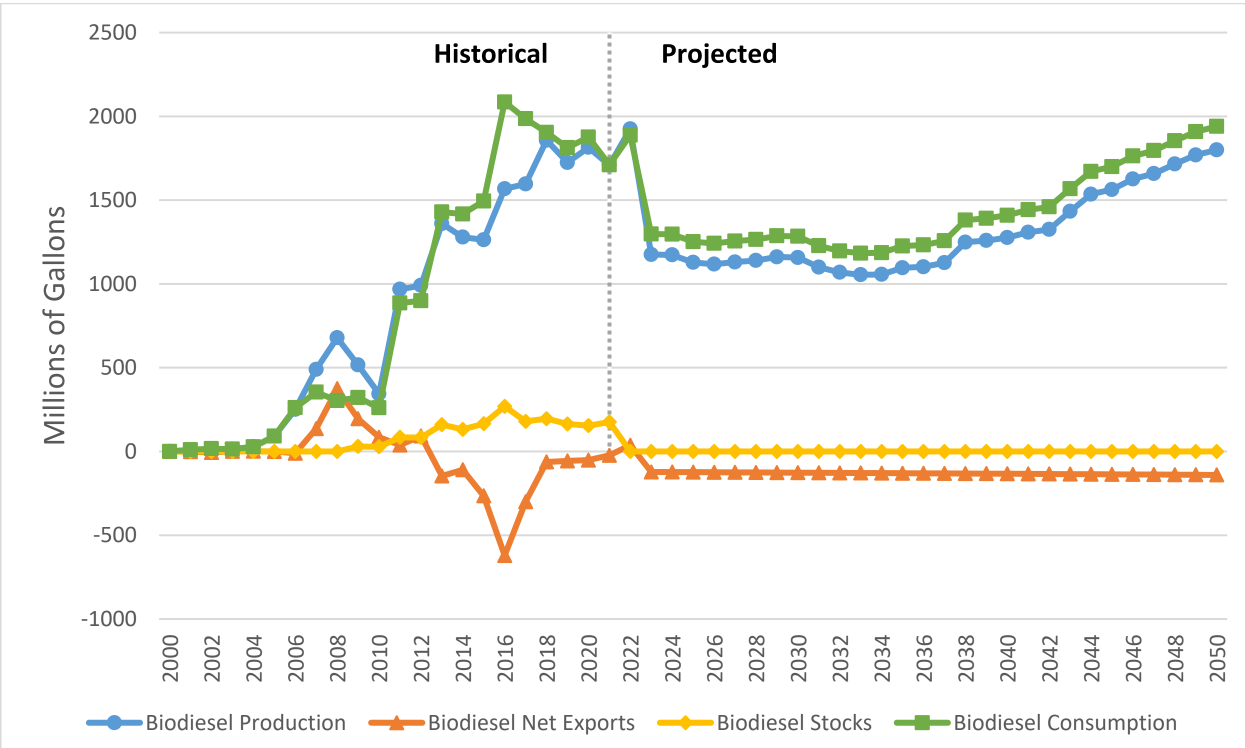
3.2.3 Diesel and Biofuels

Diesel fuel is distillate fuel oil used in motor vehicles with a compression ignition engine. While diesel fuel is not used widely as a fuel source for LD vehicles, it does make up a large share of HDPUV fuel consumption. Diesel currently makes up 0.5 percent of fuel consumption for LD vehicles and commercial light trucks, and the CAFE Model projects this proportion to decrease to 0.1 percent by 2050. For HDPUVs, diesel makes up 44.3 percent of current fuel consumption but is expected to decrease to 5 percent by 2050. Like gasoline, diesel is produced by refining crude oil. Fractional distillation is used to separate crude oil into different components like diesel and gasoline. Diesel fuel is also purified to reduce the sulfur content, which can be harmful to human health (EIA 2022e). The impact of crude oil is further discussed in Sections 3.2.1.1, *Petroleum Extraction*, 3.2.1.2, *Petroleum Transportation*, and 3.2.1.3, *Petroleum Refining*. In 2021, U.S. oil refineries produced approximately 68.4 billion gallons of diesel (EIA 2022e). The life-cycle GHG emissions for petroleum-based diesel is 97 kg CO_2e/million British thermal units (MMBtu) compared to 98.2 kg CO_2e/MMBtu for gasoline (EPA 2022e).

In addition to petroleum-based diesel, there are also biodiesel substitutes. 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). When used as a fuel in on-road vehicles, biodiesel offers significant GHG emissions advantages over conventional petroleum diesel. The life-cycle GHG emissions from biodiesel can range from 13.8 to 69 kg CO_2e/MMBtu depending on the feedstock used (EPA 2022e). 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) (Alternative Fuels Data Center [AFDC] 2017). Low-level biodiesel blends are safe to use in "any compression-ignition engine designed to be operated on petroleum diesel," including LD vehicles and HDPUVs (AFDC 2017).

As illustrated in Figure 3.2.3-1, U.S. biodiesel consumption and production increased significantly from 2005 through 2016, then leveled out through 2020. From 2020 to 2022, there was a sharp drop in biodiesel production and consumption. AEO 2022 projects that domestic production and consumption of biodiesel will steadily increase from approximately 1.25 billion gallons per year back up to nearly 2 billion gallons per year in 2050, as shown in the projected section of Figure 3.2.3-1 (EIA 2022a). EIA projects that the market share for biodiesel will increase over this period as demand for non-petroleum-based fuels increases and the cost of petroleum-based diesel and gasoline rises.

Figure 3.2.3-1. Historical and Projected U.S. Biodiesel Production, Exports, Stocks, and Consumption

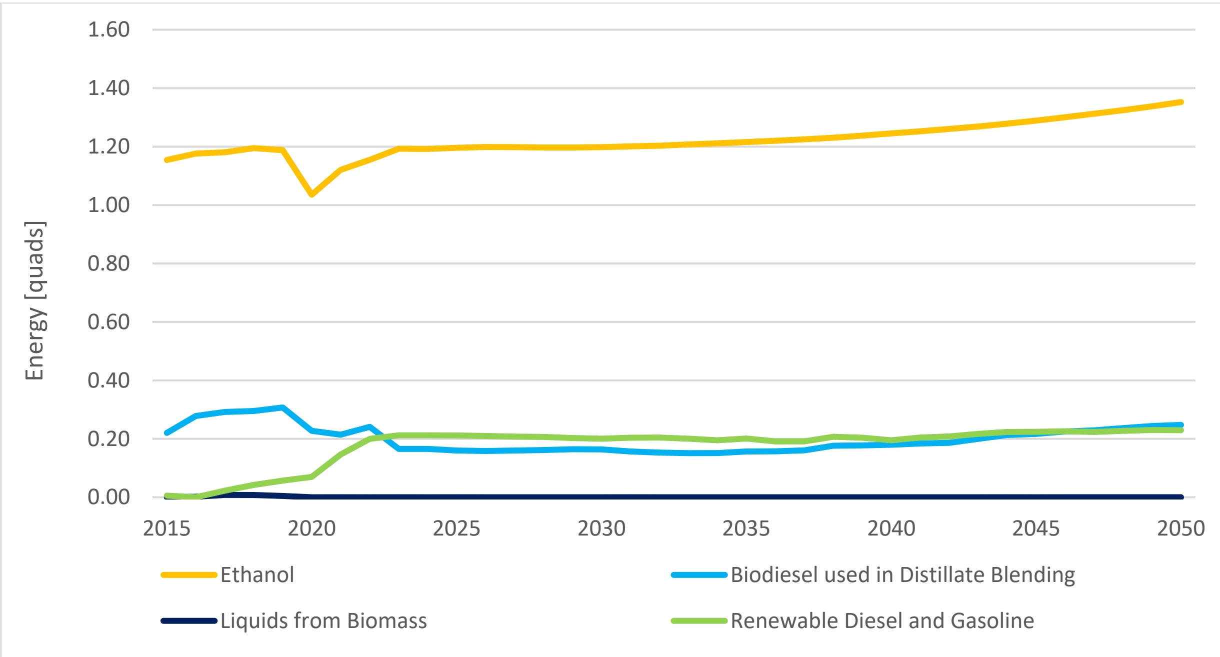


Notes:
Biodiesel stocks refers to excess biodiesel that is stored for future use or export. The EIA projects that biodiesel stocks will remain negligible through 2050.
Source: EIA 2022a

Ethanol is another biofuel that is made by fermenting biomass and adding denaturants. 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 majority (98 percent) of ethanol produced in the United States is manufactured from corn (EIA 2020). 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.

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[21] established the Renewable Fuel Standard, which was expanded by the Energy Independence and Security Act of 2007.[22] 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 3.2.3-2, ethanol is projected to make up the majority of transportation sector renewable fuel, followed by biodiesel, renewable diesel, gasoline, and liquids from biomass.

Figure 3.2.3-2. Transportation Renewable Energy Projections by Source



Source: EIA 2022a

3.2.3.1 Diesel

Most of the diesel produced in the United States is refined from crude oil at petroleum refineries, as described in Section 3.2.1.3, *Petroleum Refining*. The process of producing diesel can have many environmental impacts. In 2021, the total energy consumption from refining distillate fuel oil in the United States was 1.6 trillion Btu (EIA 2022a). Chemical waste from petroleum refineries can enter the environment as “air emissions, wastewater, or solid waste” (Speight 2017). Air emissions from diesel production can cause soil acidification and harm nearby vegetation. These emissions can also have adverse impacts on respiratory health. Chemicals and heavy metals in wastewater from petroleum refineries can harm nearby waterways and have detrimental impacts on human health if they enter drinking water sources (Speight 2017).

Burning diesel fuels also produces emissions that are harmful to the environment and human health. These emissions include CO_2, PM, NO_X, hydrocarbons, CO, and more. In 2021, diesel fuel consumption

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

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

was responsible for approximately 472 million metric tons of CO_2 emissions (EIA 2022e). According to the EPA, "this air pollution can cause heart and lung disease and a range of other health effects," and "can also damage plants, animals, crops, and water resources" (EPA 2022d). The emissions from diesel engines also contribute to the production of ground-level ozone and acid rain, which have significant negative impacts on the surrounding environment.

3.2.3.2 Ethanol (E85)

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.

Corn ethanol has declined in carbon intensity over time, revealing increased GHG emissions savings relative to gasoline and other fossil fuels. In 2022, EPA released an external review draft of their report, *Biofuels and the Environment: Third Triennial Report to Congress*, which was compiled in collaboration with the U.S. Department of Agriculture, DOE, and U.S. Geological Survey and details environmental impacts from the production and use of biofuels like ethanol and biodiesel. Life-cycle emissions of corn ethanol include NO_X, SO_X, CO, VOCs, ammonia, and PM (EPA 2022f). For some of these emissions, corn ethanol has higher life-cycle emissions than gasoline (EPA 2022f).

Aside from GHG emissions, other environmental impacts of corn ethanol are associated with agriculture and biofuel production. Agriculturally, fertilizer use causes dust and ammonia air pollution, as well as nitrate and pesticide water pollution (EPA 2022f). Crop irrigation affects water availability and causes streams to be rerouted, interrupting aquatic habitats and fish diversity (EPA 2022f). Furthermore, the conversion of grasslands to croplands degrades soil quality and contributes to erosion (EPA 2022f). The impact of these factors on biodiversity worsens as cultivated cropland acreage continues to grow (EPA 2022f). Biofuel production impacts include water use, although this is a small and declining percentage of overall life-cycle water use (EPA 2022f).

There are also important differences with regard to potential environmental impacts between splash and match blending of ethanol with gasoline. *Splash blending* consists of adding a specified volume of ethanol to gasoline and is the main blending process used in the United States. This process helps to reduce the toxicity of the gasoline blend because ethanol is less toxic, lowering the overall volume of toxics in the blend. However, if match blending is used, the blend can actually become more toxic. *Match blending* consists of adding additional aromatics so gasoline reaches a certain boiling point; however, this increases the total amount of aromatics in the gasoline blend which is the most toxic component (Anderson et al. 2014).

3.2.3.3 Biodiesel

ANL'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 biodiesel reduces GHG emissions from 3.6 to 3.1 metric tons CO_2e annually, and replacement with a B100 vehicle reduces GHG emissions from 3.6 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 g CO_2e per mile, respectively (ANL 2020). 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 ANL life-cycle assessment 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 2020; 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 2016b).

In addition to life-cycle GHG emissions, other environmental impacts of biodiesel are similar to the impacts of corn ethanol, which are described in Section 3.2.3.2, *Ethanol (E85).* The environmental impacts discussed in EPA's *Biofuels and the Environment: Third Triennial Report to Congress* include both ethanol and biodiesel (EPA 2022f). Increasing production of biofuels means greater usage of water, fertilizers, and pesticides, which can harm the surrounding environment and nearby waterways. As a result, there is a risk of acidification, eutrophication, and loss of biodiversity (Jeswani et al. 2020). There are also concerns that land used for biofuel production could displace cropland, leading to higher prices for corn and other food products, and a risk of land-use change, such as land degradation and deforestation to clear more space to produce biofuel inputs. When controlling land-use change, biodiesel has significantly lower emissions than petroleum-based diesel fuel. However, land-use change has the potential to negate the overall life-cycle emissions reductions benefits of biodiesel. Biodiesel production can also put added pressure on water resources and can degrade the environment, depending on how the land is cultivated (Hasan and Rahman 2017). Thus, land-use change has a significant impact on how environmentally beneficial biodiesel alternatives are.

3.2.4 Natural Gas

While it can be used to generate electricity to power EVs, natural gas can also be used to directly fuel vehicles in compressed or liquid forms. Natural gas fuel can power cars, buses, or trucks in an ICE, similar to how a gasoline-powered car is fueled. Natural gas is far less common as a transportation fuel than petroleum (mostly gasoline and diesel) and biofuels (mostly ethanol). In 2021 natural gas accounted for 3.3 percent of energy used for all transportation compared to 90.6 percent for petroleum and 5.6 percent for biofuels (EIA 2022a). Of that, natural gas represented 0.02 percent of the total fuel supplied for direct use in LD vehicles, and between 0.8 and 1.7 percent of fuel for all freight trucks from 2020 to 2050 (EIA 2022a). Natural gas as a transportation fuel is expected to grow an average of 4.7 percent annually by 2050 (EIA 2022a). 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).

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 2022a, 2021c, 2021d). However, natural gas fuel still results in CH_4 emissions, which have a higher global warming potential than CO_2. Natural gas also requires fracking and pipelines to be sourced and transported, which further increases environmental impacts. Fracking for natural gas involves injecting chemicals into the ground to coax out gas and has been linked to polluted groundwater (EIA 2022h). Studies have also shown increased seismic activity associated with fracking, causing a higher risk of earthquakes near natural gas rigs (EIA 2022h). Once sourced, natural gas is kept in gaseous form or cooled into a liquid, and it is transported via pipelines or tank ships that threaten biodiversity with gas leaks into soil and waterways and interruptions to animal migration and habitat (EIA 2022h).

3.2.5 Hydrogen

Fuel cell vehicles (FCVs) are powered by hydrogen that is converted to electricity via a fuel cell. Current LD FCV hydrogen consumption is less than 0.01 percent of total LD fuel consumption. According to AEO 2022, hydrogen is projected to grow 9.6 percent as a transportation fuel by 2050 (EIA 2022a). Currently in LD road transport, BEVs are more efficient and cost-effective than FCVs, but this is changing as hydrogen fuel cell technology develops and scales up in the market, lowering costs and improving FCV efficiency (IEA 2019). Since 2008, the cost of automotive fuel cells has dropped 70 percent (IEA 2019). Fuel cells powered by hydrogen represent another potential alternative to carbon-intensive fuels, depending on the hydrogen production pathway.

The fuel cell is similar in structure to an EV battery, but active components (i.e., cathode, anode, and electrolyte) use different materials. FCVs 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). Aside from emissions, the environmental impacts of fuel cells include damage to land and water from mining for heavy metals and waste from discarded fuel cells at end-of-life (DOE no date [a]). Life-cycle emissions vary widely based on this hydrogen production technology (Nitta and Moriguchi 2011).

The emissions associated with FCVs depend on how the hydrogen is produced and distributed. If hydrogen is produced from natural gas, FCVs achieve about 40 percent less emissions than gasoline vehicles, due to the higher efficiency of the fuel cell relative to the combustion engine. If the hydrogen is produced via renewable electrolysis or natural gas with carbon capture and sequestration, FCVs achieve about 80 percent lower emissions than gasoline vehicles. Additional environmental impacts associated with natural gas are discussed further in Section 3.2.4, *Natural Gas*, and associated with electricity are discussed further in Section 3.2.2, *Electricity*.

3.3 Environmental Consequences

3.3.1 Direct and Indirect Impacts

3.3.1.1 CAFE Standards

All of the CAFE standard action alternatives are projected to decrease U.S. energy intensity through 2050 relative to the CAFE No-Action Alternative.[23] Under the CAFE No-Action Alternative, the average fuel economy of all LD vehicles in use would increase by 62 percent from 2022 through 2050. Under Alternatives PC1LT3, PC2LT4 (Preferred Alternative for CAFE standards), PC3LT5, and PC6LT8, the average fuel economy of all LD vehicles in use would increase by 62, 62, 64, and 69 percent, respectively, from 2022 through 2050, as older, less-efficient vehicles are replaced by new vehicles that achieve much better fuel economy. Gasoline accounts for 50 percent to 65 percent of total gasoline

[23] For a discussion of the factors in the CAFE No-Action Alternative, see Chapter 2, Section 2.2.2.1, *CAFE No-Action Alternative*. For additional information, see Technical Support Document Chapter 1.

gallon equivalent[24] (GGE) use in 2050 under all of the alternatives, so improvements in fuel economy would reduce net petroleum imports.

In Table 3.3.1-1, LD vehicle fuel consumption is shown in GGE, which includes consumption of gasoline, diesel, biofuel, hydrogen, and electricity used to power the LD vehicle fleet. Table 3.3.1-1 shows 2022 to 2050 fuel use resulting from the Proposed Action and alternatives compared to the CAFE No-Action Alternative.

Table 3.3.1-1. Fuel Consumption and Decrease in Fuel Consumption by CAFE Standards Alternative (billion gasoline gallon equivalent total for calendar years 2022–2050)

	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Fuel Consumption					
Cars	804	797	796	793	767
Light trucks	1,957	1,947	1,932	1,895	1,782
All LD vehicles	2,761	2,744	2,727	2,688	2,548
Decrease in Fuel Use Compared to the CAFE No-Action Alternative					
Cars	--	-7 (-1%)	-8 (-1%)	-11 (-1%)	-37 (-5%)
Light trucks	--	-9 (0%)	-25 (-1%)	-62 (-3%)	-175 (-9%)
All LD vehicles	--	-17 (-1%)	-34 (-1%)	-73 (-3%)	-212 (-8%)

Total LD vehicle fuel consumption from 2022 to 2050 under the CAFE No-Action Alternative is projected to be 2,761 billion GGE. LD vehicle fuel consumption from 2022 to 2050 under the action alternatives is projected to range from 2,744 billion GGE under Alternative PC1LT3 to 2,548 billion GGE under Alternative PC6LT8. All of the action alternatives would decrease fuel consumption compared to the No-Action Alternative, with decreases that range from 17 billion GGE under Alternative PC1LT3 to 212 billion GGE under Alternative PC6LT8.

This decrease in fuel consumption could 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 resource areas, such as air quality, GHG emissions, suface and ground water, land, wildlife, and human health are likely to be minimal. In addition, the reduction in fuel consumption from the CAFE standards could reduce U.S. petroleum imports and potentially reduce global GHG emissions. As discussed in Section 3.2.1.4, *Petroleum Imports,* the GHG intensity of oil production differs depending on the country of import origination. Declining fuel consumption as estimated by the CAFE Model would reduce GHG emissions more if they are associated with a decline in crude oil imports from Canada (17.6 g CO_2e/MJ) than either a decline in imports from other countries (averaging 10.3 g CO_2e/MJ, for individual countries see Figure 3.2.1-4) or from U.S. production (11.3 g CO_2e/MJ).

[24] *Gasoline gallon equivalent* is the amount of an alternative fuel required to equal the energy content of 1 liquid gallon of gasoline.

3.3.1.2 HDPUV FE Standards

All of the action alternatives for HDPUV FE standards contribute to projected ongoing declines in U.S. energy intensity through 2050 compared to the HDPUV No-Action Alternative.

In Table 3.3.1-2, HDPUV fuel consumption is shown in GGE, which includes consumption of gasoline, diesel, biofuel, hydrogen, and electricity used to power the HDPUV fleet. Table 3.3.1-2 shows 2022 to 2050 fuel use resulting from the Proposed Action and alternatives compared to the HDPUV No-Action Alternative.

Total HDPUV fuel consumption from 2022 to 2050 under the HDPUV No-Action Alternative is projected to be 412.2 billion GGE. HDPUV fuel consumption from 2022 to 2050 under the action alternatives is projected to range from 412.1 billion GGE under Alternative HDPUV4 to 403.3 billion GGE under Alternative HDPUV14. All of the action alternatives would decrease fuel consumption compared to the HDPUV No-Action Alternative, with decreases ranging from 0.1 billion GGE under Alternative HDPUV4 to 8.9 billion GGE under Alternative HDPUV14.

Table 3.3.1-2. Fuel Consumption and Decrease in Fuel Consumption by HDPUV FE Standards Alternative (billion gasoline gallon equivalent total for calendar years 2022–2050)

	No-Action	HDPUV4	HDPUV10	HDPUV14
Fuel Consumption				
HDPUV	412.2	412.1	410.3	403.3
Decrease in Fuel Use Compared to the HDPUV No-Action Alternative				
HDPUV	--	-0.1 (0%)	-1.9 (0%)	-8.9 (-2%)

Notes:
HDPUV = heavy-duty pickup trucks and vans

3.3.2 Cumulative Impacts

The cumulative impact analysis for energy 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 cumulative impact of energy is composed of both LD and HDPUV energy use in addition to the potential impacts from AEO side cases, that result from the incremental effects of the action regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Thus, cumulative effects can result from individually minor but collectively significant actions taking place over a period of time. This section first presents the cumulative impacts of the two sets of standards that are being proposed by NHTSA in its notice of proposed rulemaking. The section then goes on to describe other cumulative impacts of NHTSA's Proposed Action and alternatives when considered with other past, present, and reasonably foreseeable future actions.

3.3.2.1 Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards

Table 3.3.2-1 shows the cumulative impacts of specific combinations of CAFE standard and HDPUV FE standard action alternatives on energy use from 2022 through 2050. The combined impact of the two sets of standards is compared to a baseline that combines the CAFE No-Action Alternative and the

HDPUV No-Action Alternative. The specific combinations were chosen to present the full range of cumulative impacts of the two sets of standards that NHTSA is proposing in this rulemaking. That is, Alternatives PC1LT3 and HDPUV4 combine the least stringent CAFE standard action alternative with the least stringent HDPUV FE standard action alternative to show the lowest range of cumulative impacts of the two standards. In contrast, Alternatives PC6LT8 and HDPUV14 combine the most stringent CAFE standard action alternative with the most stringent HDPUV FE standard action alternative to show the highest end of the range of cumulative impacts of the two standards. The other combination of standards presented in Table 3.3.2-1 shows the cumulative impacts of the CAFE standard Preferred Alternative (PC2LT4) and the HDPUV FE standard Preferred Alternative (HDPUV10).

In Table 3.3.2-1, total LD vehicle and HDPUV fuel consumption is shown in GGE, which includes consumption of gasoline, diesel, biofuel, hydrogen, and electricity used to power the LD vehicle and HDPUV fleet. Table 3.3.2-1 shows 2022 to 2050 fuel use resulting from the Proposed Action and alternatives compared to the No-Action Alternatives.

Total LD vehicle and HDPUV fuel consumption from 2022 to 2050 under the No-Action Alternatives is projected to be 3,173 billion GGE. LD vehicle and HDPUV fuel consumption from 2022 to 2050 under the action alternatives is projected to range from 3,156 billion GGE under Alternatives PC1LT3 and HDPUV4 to 2,952 billion GGE under Alternatives PC6LT8 and HDPUV14. All of the action alternatives would decrease fuel consumption compared to the No-Action Alternatives, with decreases ranging from 17 billion GGE under Alternatives PC1LT3 and HDPUV4 to 221 billion GGE under Alternatives PC6LT8 and HDPUV14. The majority of these decreases can be attributed to efficiency improvements in the LD fleet.

Table 3.3.2-1. Fuel Consumption and Decrease in Fuel Consumption Cumulative Impacts of CAFE Standards and HDPUV FE Standards Alternative (billion gasoline gallon equivalent total for calendar years 2022–2050)

	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Fuel Consumption				
LD Vehicles + HDPUVs	3,173	3,156	3,138	2,952
Decrease in Fuel Use Compared to the CAFE + HDPUV No-Action Alternative				
LD Vehicles + HDPUVs	--	-17	-36	-221

Notes:
LD = light-duty; HDPUV = heavy-duty pickup trucks and vans

3.3.2.2 Other Past, Present, and Reasonably Foreseeable Future Actions

Changes in passenger travel, oil and gas exploration, global EV market projections, and EV 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 plug-in electric vehicle (PEV) technologies and manufacturing in response to government mandates (including foreign PEV quotas) may affect market trends and energy use. The CAFE Model includes AEO projections, current regulatory policy, and other foreseeable trends; however, there are uncertainties and more recent impacts that affect central estimates, including major changes to energy markets since AEO 2022 was published as well as uncertainty captured in AEO 2022 side cases.

Since AEO 2022 was published several market, regulatory, and policy changes have occurred that may have cumulative impacts. Effective August 16, 2022, the Inflation Reduction Act of 2022 (IRA)[25] allocates billions of dollars to expand renewable energy and grid storage, incentivize EVs and EV charging, and expand advanced manufacturing. AEO 2022 currently forecasts less than 1 percent market penetration of hydrogen fuel in the transportation sector. However, active research, development, and demonstration in this space along with incentives in the IRA may increase market penetration by 2040. If DOE's research, development, and demonstration targets for fuel cells, storage, and cost of hydrogen fuel are achieved, there is potential for hydrogen fuel cells to account for 10 to 14 percent of trucks in 2050. In addition, the Russia-Ukraine war has affected petroleum and natural gas markets, resulting in price spikes and increased volatility. These potential cumulative actions could result in reduced U.S. petroleum consumption and slightly increased U.S. electricity consumption. Even though U.S. electricity consumption could increase slightly, that electricity usage would be more efficient. To illustrate, NREL assessed that in a scenario of high electrification of the U.S. economy, total primary energy use would decrease around 10 percent (Murphy 2021).[26] NHTSA will consider how to include actions that have happened since the publication of AEO 2022 in the Final EIS.[27]

In addition to the above impacts on electric vehicles and petroleum consumption, future mitigating actions could help reduce environmental impacts from electricity generation. The IRA and Bipartisan Infrastructure Law (BIL) are likely to help scale renewable energy technologies more quickly than previously projected. A recent study from NREL shows much higher rates of deployment of new solar, wind, and battery storage capacity under the IRA and BIL compared to a no new policy alternative (Steinberg et al. 2023). Additionally, various tax incentive and grant programs in the IRA are geared toward investing in clean energy manufacturing and recycling, especially in disadvantaged communities, which can help drive down the carbon intensity of electricity generation (U.S. Treasury 2023a; DOE 2023b).

While emissions impacts can vary significantly from one region to another, there have been efforts across the country to improve the efficiency of grids and charging infrastructure. As these technologies improve, they can help minimize emissions and grid impacts as EVs comprise a larger share of total vehicles. DOE has a new initiative for "virtual power plants," which can help integrate renewables and demand flexibility, including for EV charging, into the grid (DOE 2022c). Additionally, DOE has Smart Grid Grants available through the BIL to help improve the flexibility and efficiency of grids across the country (DOE 2022d). In 2023, FHWA established new standards for federally funded public charging infrastructure that requires equipment to be capable of smart charge management and power sharing (FHWA 2023a). Also, many new technologies and capacity maps are in development that can help facilitate the expansion of charging infrastructure within existing grid capacity. As these efforts continue to progress, grids will be better equipped to manage the increasing numbers of EVs on the road.

Finally, uncertainties and complex interactions between electricity demand and policies targeting coal generation, such as regional greenhouse gas initiatives, state renewable portfolio standards, and clean

[25] H.R. 5376; The Inflation Reduction Act.

[26] Primary energy includes the amount of energy at the point of consumption that is converted to end-use services and energy losses that occur during the conversion of fuels to electricity. This is in contrast to Figure 3.1-1, which did not consider electricity generation.

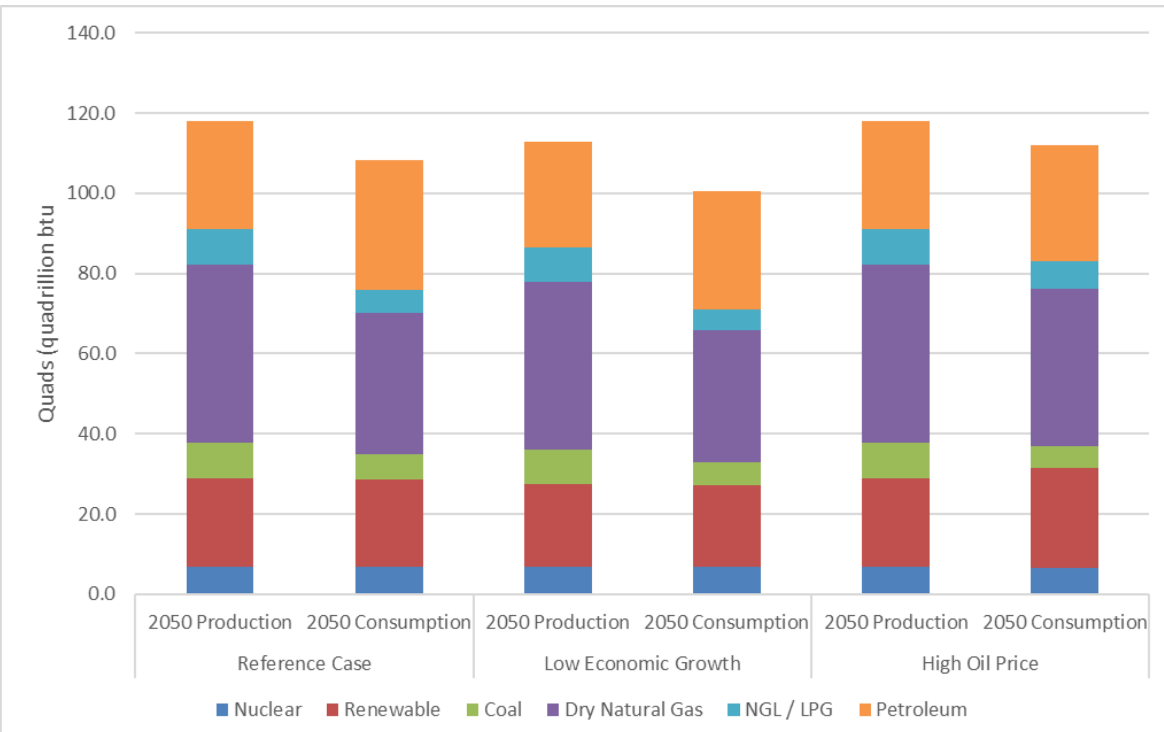
[27] Note that AEO 2023 uses International Energy Outlook (IEO) 2021 natural gas consumption inputs for Europe and Asia, and as such, would not yet fully capture the impacts of the Russia-Ukraine war.

air-act related control standards. mean that the impact of increased electricity demand from EVs on coal generation may not be fully captured.

Projections into the future are inherently uncertain and the AEO 2022 reference case is based on reasonably foreseeable future actions. AEO 2022 publishes additional side cases that could proxy a range of future outcomes where oil consumption is lower based on a range of macroeconomic factors. Since the results of the CAFE and HDPUV FE standards are a decline in oil consumption, examining side cases that also result in lower oil consumption while varying macroeconomic factors provides some insights into the cumulative effects of CAFE standards paired other potential future events.

Figure 3.3.2-1 adds the AEO 2022 side cases for low economic growth and high oil price to the reference case projections from Figure 3.1-1. Both side cases project less petroleum consumption than the reference case. The reference case projects 2050 consumption of petroleum to account for 30 percent of overall energy consumption while the low economic growth side case projects 29.5 percent and the high oil price 25.8 percent. The high oil price side case substitutes renewable energy and natural gas for petroleum. The reference case projects renewable energy to make up 20.0 percent and natural gas 32.5 percent of overall consumption, whereas the high oil price scenario projects that to increase to 22.1 percent for renewables and 35 percent for natural gas.

Figure 3.3.2-1. U.S. Energy Production and Consumption by Source in 2050

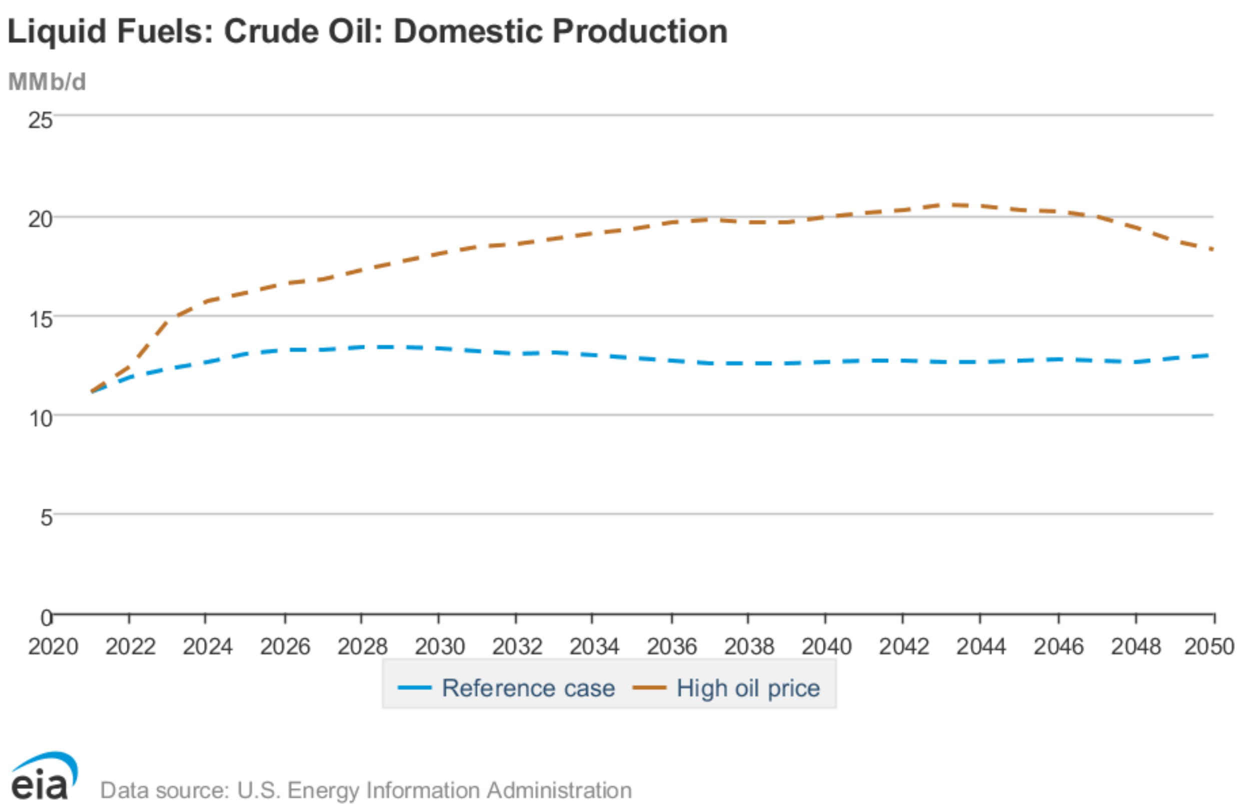


Source: EIA 2022a
Btu = British thermal unit; NGL = natural gas liquid; LPG = liquefied petroleum gas

On the production side, the AEO reference case forecast of U.S. domestic crude oil production shown in Figure 3.3.2-2 appears to show little effect of previously adopted increased in CAFE or HDPUV FE standards for model years through 2026 on domestic production; in fact, the figure illustrates that U.S.

production is projected to continue rising gradually through about 2030. This suggests that reductions in U.S. petroleum consumption on the scale projected to result from the proposed CAFE and HDPUV FE standards is unlikely to reduce U.S. petroleum production, mainly because the financial incentive for U.S. petroleum exploration and production is determined by the global market price of crude oil, with changes in the number of domestic oil wells in production historically following changes in global oil prices with a lag time of about 4 months. Thus, changes in CAFE and HDPUV FE standards are unlikely to have a significant impact on U.S. oil production, because they do not significantly affect global petroleum supply or demand, the forces determining the global market price of crude oil.

Figure 3.3.2-2. AEO 2022 Forecast of Domestic Crude Oil Production



Source: EIA 2022a

Changing CAFE and HDPUV FE standards are expected to reduce gasoline and diesel fuel use in the transportation sector, but are not expected to have any discernable effect on energy consumption by other sectors of the U.S. economy because petroleum products account for a very small share of energy use in other sectors. Gasoline and diesel (distillate fuel oil) account for less than 5 percent of energy use in the industrial sector, less than 4 percent of energy use in the commercial building sector, 2 percent of energy use in the residential sector, and only about 0.2 percent of energy use in the electric power sector.

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 2020a).

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 EIS are carbon monoxide (CO), nitrogen dioxide (NO_2) (one of several oxides of nitrogen), ozone, sulfur dioxide (SO_2), particulate matter (PM) with a diameter equal to or less than 10 microns (PM10) and 2.5 microns (PM2.5, or fine particles), and lead. Vehicles do not directly emit ozone, but this pollutant is evaluated based on emissions of the ozone precursor pollutants nitrogen oxides (NO_X) and volatile organic compounds (VOCs).

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 2021, emissions from on-road mobile sources declined 91 percent for CO, 82 percent for NO_X, 76 percent for PM2.5 (1990 to 2021), 57 percent for PM10, 95 percent for SO_2, and 94 percent for VOCs (EPA 2022g). Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. In 2021, on-road mobile sources were responsible for emitting 15.1 million tons[2] per year of CO (30 percent of total U.S. emissions), 79,000 tons per year (2 percent) of PM2.5, and 206,000 tons per year (1 percent) of PM10 (EPA 2022g). In 2023, passenger cars and light trucks are estimated to contribute 86 percent of U.S. highway emissions of CO, 57 percent of highway emissions of PM2.5, and 65 percent of highway emissions of PM10. In 2023, heavy-duty pickup trucks and vans (HDPUVs) are estimated to contribute 11 percent of highway emissions of CO, 8 percent of highway emissions of PM2.5, and 8 percent of highway emissions of PM10 (EPA 2022h). Almost all of the PM in motor vehicle

[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 (i.e., science-based guidelines) for setting permissible levels.

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

exhaust is PM2.5 (Gertler et al. 2000; EPA 2014b); therefore, this analysis focuses on PM2.5 rather than PM10. In 2021, on-road mobile sources also emitted 1.0 million tons per year (8 percent of total U.S. emissions) of VOCs and 2.2 million tons per year (29 percent) of NO_X, which are chemical precursors of ozone (EPA 2022g). In 2023, passenger cars and light trucks are estimated to emit 81 percent of U.S. highway emissions of VOCs and 49 percent of NO_X, and HDPUVs are estimated to contribute 11 percent of U.S. highway emissions of VOCs and 9 percent of NO_X (EPA 2022h). 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 1 percent of U.S. SO_2 emissions (EPA 2020b) 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

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

Notes:
[a] Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter (mg/m^3) of air, 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 Part 50, as presented in EPA 2016c
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.[4] 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).[5] The MSATs included in this analysis are

[4] *Hazardous air pollutants* refer to substances defined as hazardous by the 1990 CAA amendments. These substances include certain volatile organic compounds, compounds in particulate matter (PM), pesticides, herbicides, and radionuclides that present tangible hazards based on scientific studies of human (and other mammal) exposure.

[5] 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).

acetaldehyde, acrolein,[6] 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 2023b). DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class. On-road mobile sources are responsible (as of 2017[7]) 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 2020c, 2020d, 2020e, 2020f, 2020g).[8]

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), 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. More recent studies continue to show significant concentration gradients of traffic-related air pollution around major roads (Apte et al. 2017; Dabek-Zlotorzynska et al. 2019).

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.[9] 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 16 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.[10] Numerous studies have found adverse health impacts

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[6] 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 Federal Highway Administration's (FHWA's) MSAT guidance (FHWA 2023b).

[7] These numbers are based on the 2017 EPA National Emissions Inventory (NEI), which is the most recent data available. The next iteration, the 2020 NEI, is in development by EPA.

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

[9] 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).

[10] 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.

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. In 2010, an expert panel of the Health Effects Institute (HEI) published a review of hundreds of exposure, epidemiology, and toxicology studies (HEI 2010). The panel rated how the evidence for each type of health outcome supported a conclusion of a causal association with traffic-associated air pollution as "sufficient," "suggestive but not sufficient," or "inadequate and insufficient." The panel categorized evidence of a causal association with traffic-associated air pollution 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 postnatal 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*, summarize the health effects associated with each of the criteria and hazardous air pollutants analyzed in this EIS. Appendix C, *Air Quality*, provides further information on specific health effects of these pollutants. Chapter 5, *Greenhouse Gas Emissions and Climate Change*, 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. Chapter 7, *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 briefly describe the health effects of the five criteria pollutants addressed in this analysis. This information is adapted from EPA (2023d). Appendix C, *Air Quality*, provides further detail on specific health effects of these pollutants.

Ozone

Ozone is a photochemical oxidant and the major component of smog. 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.

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. 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 2019b). PM2.5 has been associated with risk for several respiratory conditions, including coronavirus disease of 2019 (COVID-19) (Pozzer et al. 2020; Wu et al. 2020; Zhou et al. 2021).

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. When CO enters the bloodstream, it acts as an asphyxiant by reducing the delivery of oxygen to the body's organs and tissues. Epidemiological studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease.

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. High concentrations of SO_2 cause severe respiratory distress (difficulty breathing), irritate the upper respiratory tract, and aggravate existing respiratory and cardiovascular disease.

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. 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.

4.1.1.2 Health Effects of Mobile Source Air Toxics

The following sections briefly describe the health effects of the six priority MSATs analyzed in this EIS. This information is adapted from the EPA *Regulatory Impact Analysis for the Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards* (EPA 2021c). Appendix C, *Air Quality*, provides further information on specific health effects of these pollutants.

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected to be human or animal carcinogens or known to have noncancer health effects. These compounds include, but are not limited to, acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. These five air toxics, plus DPM, are the six priority MSATs analyzed in this EIS. These compounds, plus polycyclic organic matter and naphthalene, were identified as national or regional risk drivers or contributors in the EPA 2018 and/or 2019 AirToxScreens and have significant inventory contributions from mobile sources (EPA 2022i). This EIS does not analyze polycyclic organic matter separately, but this matter can occur as a component of DPM and is discussed in *Diesel Particulate Matter*. Naphthalene also is not analyzed separately in this EIS, but it is a member of the polycyclic organic matter class of compounds discussed in *Diesel Particulate Matter*.

Acetaldehyde

In its Fifteenth Report on Carcinogens (National Toxicology Program [NTP] 2021a), 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, 2000b).

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. Individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein. IARC determined that acrolein was "probably carcinogenic" with respect to its carcinogenicity in humans (IARC 2020; Lancet 2021).

Benzene

EPA's Integrated Risk Information System 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 (EPA 2000c; IARC 2018). IARC and the U.S. Department of Health and Human Services have characterized benzene as a human carcinogen (IARC 2018; NTP 2021b). Several adverse noncancer health effects, including blood disorders such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene (California Office of Environmental Health Hazard Assessment 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 2021c). 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]). 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.

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. IARC concluded that diesel exhaust should be regarded as "carcinogenic to humans" (IARC 2014; Silverman 2018).

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. The EPA Diesel HAD notes that "[a]cute 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 contribution of DPM 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.

Formaldehyde

NTP and IARC have concluded that formaldehyde is a known human carcinogen (NTP 2021d; IARC 2012). The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991, in combination with previous animal, human, and mechanistic evidence. Other health effects of formaldehyde were reviewed by the Agency for Toxics Substances and Disease Registry (ATSDR) in 1999 (ATSDR 1999) and supplemented in 2010 (ATSDR 2010), by NTP (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.

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.[11] These stricter standards for passenger cars and light trucks and for HD vehicles are responsible for the declines in total criteria pollutant emissions from motor vehicles, as discussed in Section 4.1.1, *Relevant Pollutants and Standards*. Appendix C, *Air Quality*, provides further information on vehicle emissions standards and trends in vehicle emissions over time.

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.[12] 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[13] 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 Transportation). The General Conformity Rule[14] 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.[15] 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.

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[11] 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.

[12] 42 U.S.C. 7506(c)(1)-(2).

[13] 40 CFR Part 51, Subpart T, and Part 93, Subpart A.

[14] 40 CFR Part 51, Subpart W, and Part 93, Subpart B.

[15] 40 CFR 93.153(b).

The CAFE standards, HDPUV fuel efficiency (FE) 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 and alternatives 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."[16] Because NHTSA's Proposed Action and alternatives would set fuel economy standards for passenger cars and light trucks and FE standards for HDPUVs, they would cause no direct emissions consistent with the meaning of the General Conformity Rule.[17]

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."[18] 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 and FE standards would not be caused by NHTSA's action, but rather would occur because of subsequent activities the agency cannot practically control. "[E]ven if a Federal licensing, rulemaking, or other approving action is a required initial step for a subsequent activity that causes emissions, such initial steps do not mean that a Federal agency can practically control any resulting emissions."[19]

As the CAFE and HDPUV FE standards are performance-based, NHTSA cannot control the technologies vehicle manufacturers use to improve the fuel economy of passenger cars and light trucks and the fuel efficiency of HDPUVs. 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 toxics and criteria pollutants would occur in some nonattainment areas under certain alternatives. However, the

[16] 40 CFR 93.152.

[17] *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 set fuel economy standards for MY 2027–2032 passenger car and light trucks and FE standards for MY 2030–2035 HDPUVs; any emissions increases would occur well after promulgation of a final rule.

[18] 40 CFR 93.152.

[19] 40 CFR 93.152.

Proposed Action and alternatives do not mandate specific manufacturer decisions, consumer purchasing, or driver behavior, and NHTSA cannot practically control any of them.[20]

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 proposed rule.

4.1.2 Methods

This section describes the approaches and methods used to estimate the impacts of the Proposed Action and alternatives in the EIS. Appendix C, *Air Quality*, provides further detail on the methods used for the EIS air quality analysis.

4.1.2.1 Overview

NHTSA uses the CAFE Compliance and Effects Modeling System (the CAFE Model) to estimate manufacturers' potential responses to new CAFE, CO_2, and HDPUV FE standards and to estimate various impacts of those responses. DOT's Volpe National Transportation Systems Center develops, maintains, and applies the model for NHTSA. The basic design of the CAFE Model is as follows: the system first estimates how vehicle manufacturers might respond to a given regulatory scenario, and from that potential compliance solution, the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. NHTSA also uses EPA's Motor Vehicle Emissions Simulator (MOVES) model to estimate "downstream" (tailpipe exhaust) emission factors, and uses Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model to estimate emissions rates from fuel production and distribution processes ("upstream emissions").

To analyze air quality and human health impacts, NHTSA used the CAFE Model to calculate the emissions of criteria pollutants and MSATs from passenger cars and light trucks that would occur under each CAFE standard alternative. Similarly, NHTSA calculated the emissions of criteria pollutants and MSATs from HDPUVs that would occur under each FE standard 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 CAFE standard and HDPUV FE standard action alternative.

The air quality analysis accounted for manufacturers' projected responses to CAFE, HDPUV FE, and CO_2 standards (including agreements some manufacturers have reached with California for MY 2021–2026), zero-emission vehicle mandates in place in California and most Section 177 states,[21] and NHTSA's estimates of future fuel prices, market demand for fuel economy, and the cost and efficacy of fuel-

[20] *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).

[21] *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).

saving technologies. The analysis also accounted for market responses, including demand for new light-duty (LD) vehicles and HDPUVs, scrappage of used LD vehicles and HDPUVs, and demand for travel (i.e., VMT), accounting for the rebound effect. The resultant change in emissions under each CAFE and HDPUV FE 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 tailpipe emissions resulting from slight shifts in passenger car 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 emissions 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 emissions rates than newer vehicles).
- Increases in emissions resulting from increased VMT due to the rebound effect.
- Decreases in tailpipe 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 natural gas (38 percent), followed by renewables (22 percent), nuclear (20 percent), and coal (19 percent) (EIA 2022k).

4.1.2.2 Regional 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 LD vehicles and HDPUVs that are of greatest concern to human health. Appendix D, *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*).

Emissions changes due to the rebound effect would occur from LD vehicles and HDPUVs 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.[22] 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:

- **2035:** A near-term forecast year for passenger cars, light trucks, and HDPUVs; by 2035 manufacturers could be 3 years beyond a full response (MY 2032) to new CAFE standards and in the process of responding to the new FE standards for HDPUVs, with vehicles produced in MYs 2027 and beyond accounting for much of the on-road fleet's VMT.
- **2050:** A long-term forecast year; by 2050, vehicles produced in MYs 2027 and beyond 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 Allocation of Exhaust Emissions to Nonattainment Areas[23]

For each CAFE standard and HDPUV FE standard 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 car, light truck, and HDPUV VMT data for all counties in the United States, consistent with EPA's National Emissions Inventory.[24]

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.

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 2023e). For nonattainment areas that include portions of counties, NHTSA calculated the proportion of county

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[22] 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.

[23] In this section and Section 4.1.2.5, *Allocation of Upstream Emissions to Nonattainment Areas*, the term *nonattainment* refers to both nonattainment areas and maintenance areas.

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

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 2023 nonattainment area definitions. The population estimates utilized projections to the 2035 and 2050 analysis years at 1-kilometer resolution across the country (Gao 2020).

The method for allocation of emissions to nonattainment areas is the same for all geographic areas and pollutants. Appendix C, *Air Quality*, Table C.5.5-1 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 the nonattainment areas for these pollutants encompass the largest human populations. For a complete list of nonattainment and maintenance areas for all pollutants and standards, see Appendix D, *Air Quality Nonattainment Area Results*.

4.1.2.5 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. Commonly, 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.[25] 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, 2022) and the HD FE standards EISs (NHTSA 2011, 2016b). A similar analysis was performed for upstream emissions from electricity for transportation use, accounting for feedstock production and then electricity generation and transmission using a nationally representative grid mix.

4.1.2.6 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. Appendix C, *Air Quality*, Table C.5.7-1 lists the health outcomes NHTSA quantified. 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

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

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.

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 2010a), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2010b), NO_2 NAAQS RIA (EPA 2010c), and most recently updated in *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2018b).[26] NHTSA included additional updates given in Wolfe et al. (2019). Appendix C, *Air Quality*, Table C.5.7-1 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[27] as reported in the epidemiology literature.[28] PM-related mortality reductions provide most of the benefit in each benefit-per-ton estimate.

Appendix C, *Air Quality*, Table C.5.7-2a through Table C.5.7.2e list the incidence-per-ton estimates for PM-related health impacts (derived by the process described in this section and Appendix C, *Air Quality*, Section C.5.7.1, *Quantified Health Impacts*). With these incidence-per-ton estimates, decreases in PM2.5 emissions provide greater reductions in adverse health impacts compared to similar decreases in NO_X emissions and SO_2 emissions. Further, decreases in vehicle tailpipe emissions overall provide greater reductions in adverse health impacts compared to similar decreases in upstream emissions.

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[26] 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.

[27] 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).

[28] The complete method for creating the benefit-per-ton estimates used in this analysis is provided in *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2018b) and Fann et al. (2009). Since the publication of Fann et al. (2009), EPA no longer assumes that there is a threshold in PM-related models of health impacts.

4.2 Environmental Consequences

4.2.1 Direct and Indirect Impacts

This section examines the direct and indirect impacts on air quality associated with the Proposed Action and alternatives. As explained in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, NHTSA's Proposed Action is to promulgate a rulemaking setting CAFE standards (final standards for MY 2027–2031 LD vehicles, augural standards for MY 2032 LD vehicles) and MY 2030–2035 FE standards for HDPUVs, in accordance with the Energy Policy and Conservation Act of 1975, as amended by the Energy Independence and Security Act of 2007. As part of the current rulemaking, NHTSA is considering a range of alternatives for MY 2027–2032 CAFE standards and a range of alternatives for MY 2030–2035 HDPUV FE standards. Section 4.2.1.1, *CAFE Standards*, presents the direct and indirect impacts on air quality associated with Alternative PC2LT4 (Preferred Alternative for CAFE standards) and CAFE standard action alternatives. Section 4.2.1.2, *HDPUV FE Standards*, presents the direct and indirect impacts on air quality associated with Alternative HDPUV10 (Preferred Alternative for HDPUV FE standards) and FE standard action alternatives. For a description of each alternative, please refer to Chapter 2, Section 2.2, *Proposed Action and Alternatives*. For both CAFE and HDPUV FE standards, the analysis shows that the action alternatives would result in different levels of emissions from vehicles when measured against projected trends under the respective 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 relevant No-Action Alternative.

4.2.1.1 CAFE Standards

NHTSA has identified Alternative PC2LT4 as the Preferred Alternative for CAFE standards. This section presents the direct and indirect impacts on criteria and toxic air pollutant emissions and projected impacts on nonattainment areas associated with the Preferred Alternative for CAFE standards and CAFE standard action alternatives.

Criteria Pollutants

Emissions Levels

Table 4.2.1-1 summarizes the total upstream and downstream[29] national emissions by CAFE standard alternative for each of the criteria pollutants and analysis years. Figure 4.2.1-1 compares the percentage differences in emissions among the alternatives for 2035, a near-term forecast year for passenger cars and light trucks. Figure 4.2.1-2 illustrates this information in the context of the total emissions for each alternative.

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	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Carbon monoxide (CO)					
2035	5,849,823	5,821,128	5,806,023	5,761,073	5,612,947
2050	1,970,118	1,953,637	1,904,565	1,810,056	1,423,241

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

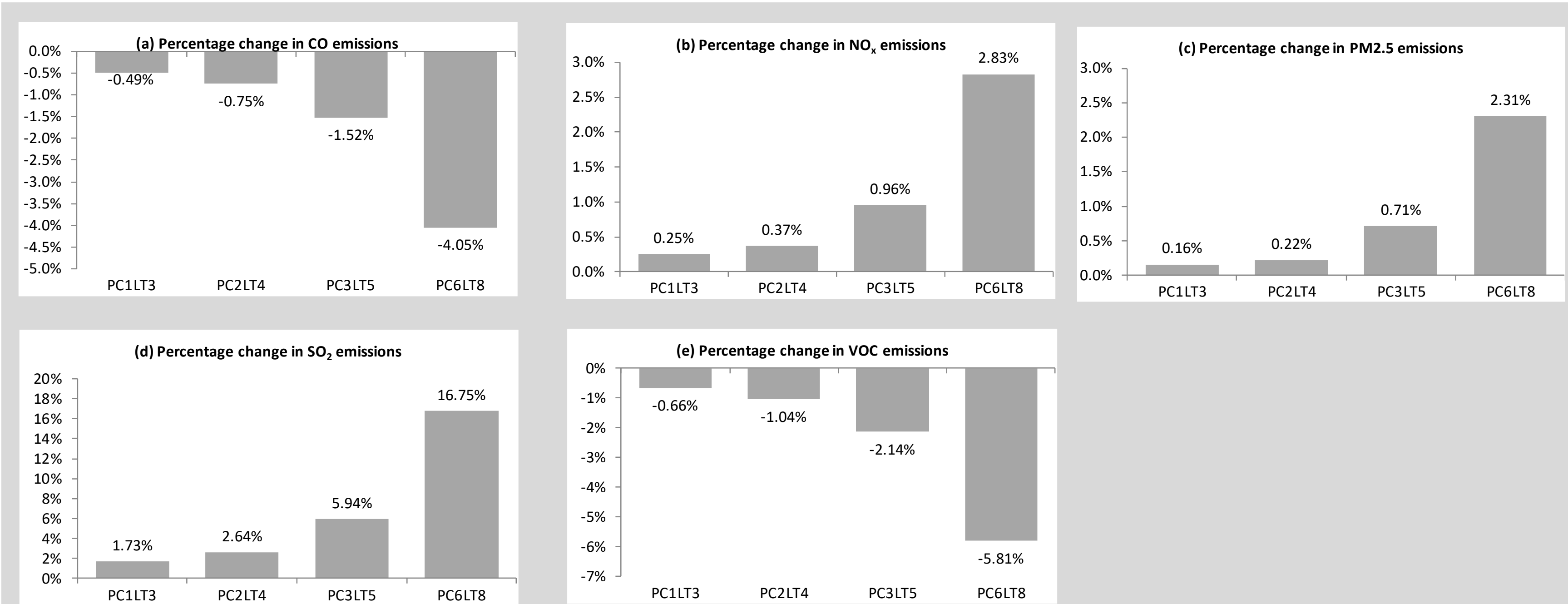
Nitrogen oxides (NO_X)					
2035	282,829	283,541	283,868	285,530	290,838
2050	215,729	215,123	215,034	216,541	220,808
Particulate matter (PM2.5)					
2035	21,875	21,910	21,924	22,031	22,380
2050	18,949	18,876	18,818	18,846	18,779
Sulfur oxides (SO_2)					
2035	85,589	87,066	87,846	90,676	99,927
2050	117,857	117,635	118,612	121,750	132,447
Volatile organic compounds (VOCs)					
2035	694,944	690,351	687,741	680,067	654,594
2050	323,231	321,048	314,312	299,941	248,355

Figure 4.2.1-3 shows the changes over time in total national emissions of criteria pollutants under Alternative PC1LT3 (the least stringent and highest fuel-use action alternative) and Alternative PC6LT8 (the most stringent and lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts over time across CAFE standard action alternatives. Figure 4.2.1-3 shows a consistent time trend among the criteria pollutants except for SO_2. Emissions of CO, NO_X, PM2.5, and VOCs decrease from 2035 to 2050 because of increasingly stringent EPA regulation of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*), despite a growth in total VMT from 2035 to 2050.[30] Those decreases in CO, NO_X, and PM2.5 emissions occur also despite a growth in their upstream emissions due to 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. However, upstream VOC emissions decrease from 2035 to 2050. Emissions of SO_2 increase from 2035 to 2050 under all action alternatives, where tailpipe emissions from vehicles decrease due to reduced fuel consumption over time but upstream power-plant emissions from growth in EV charging increase at a greater rate, leading to a net increase in SO_2 emissions.

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 CAFE standards (passenger cars and light trucks). Table 4.2.1-2 shows the total emissions of criteria pollutants broken out by four components for calendar year 2035 (i.e., cars tailpipe, cars upstream, trucks tailpipe, and trucks upstream).

[30] Continued growth in VMT is projected to occur under all alternatives until 2044; a slight decrease is projected to occur from 2045 to 2050.

Figure 4.2.1-1. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Action Alternative Compared to the CAFE No-Action Alternative, Direct and Indirect Impacts



Notes:

The vertical (percentage) scale differs by pollutant.

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

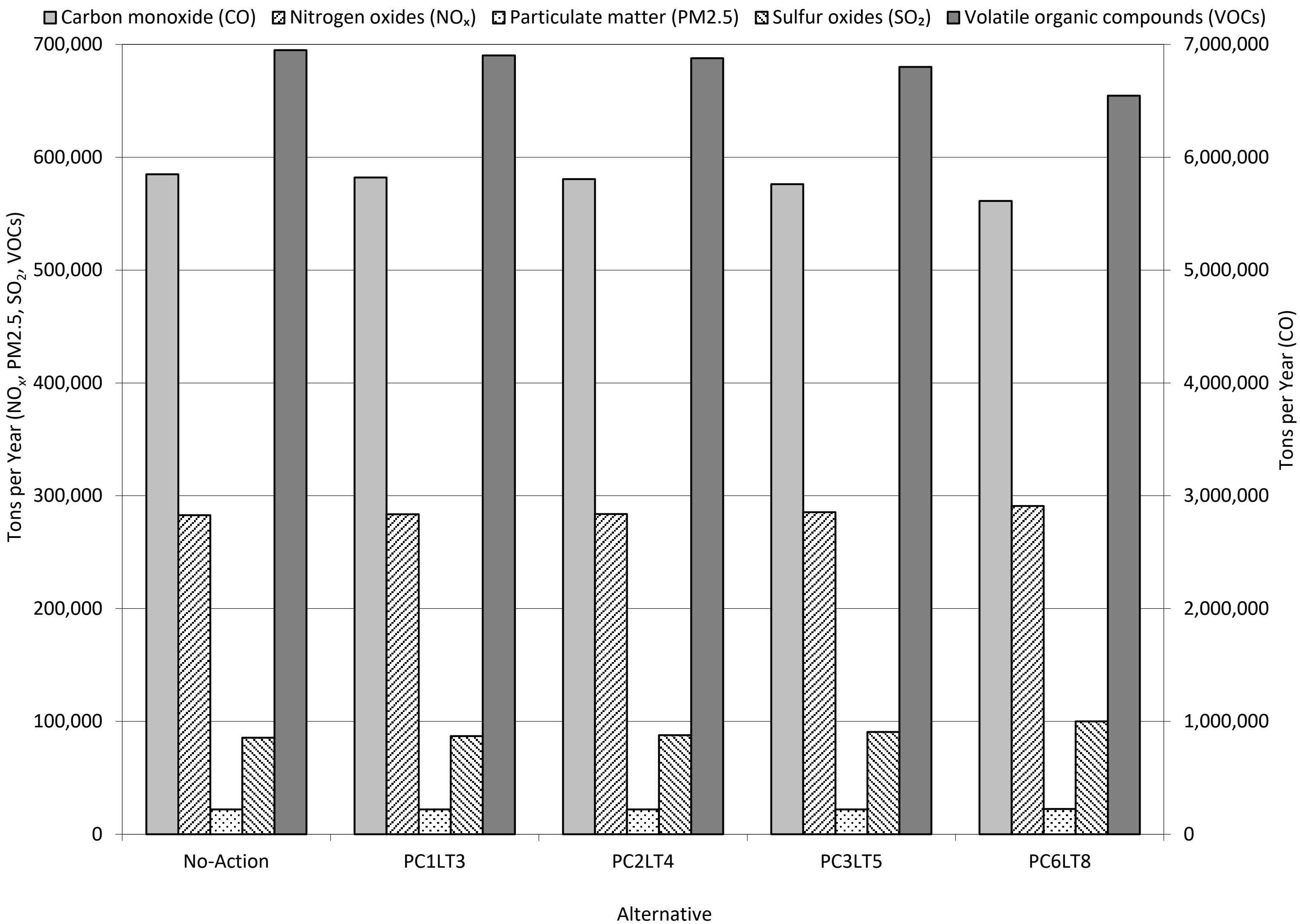


Figure 4.2.1-3. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives PC1LT3 and PC6LT8, Providing the Lowest and Highest Range in Direct and Indirect Impacts of CAFE Standard Action Alternatives

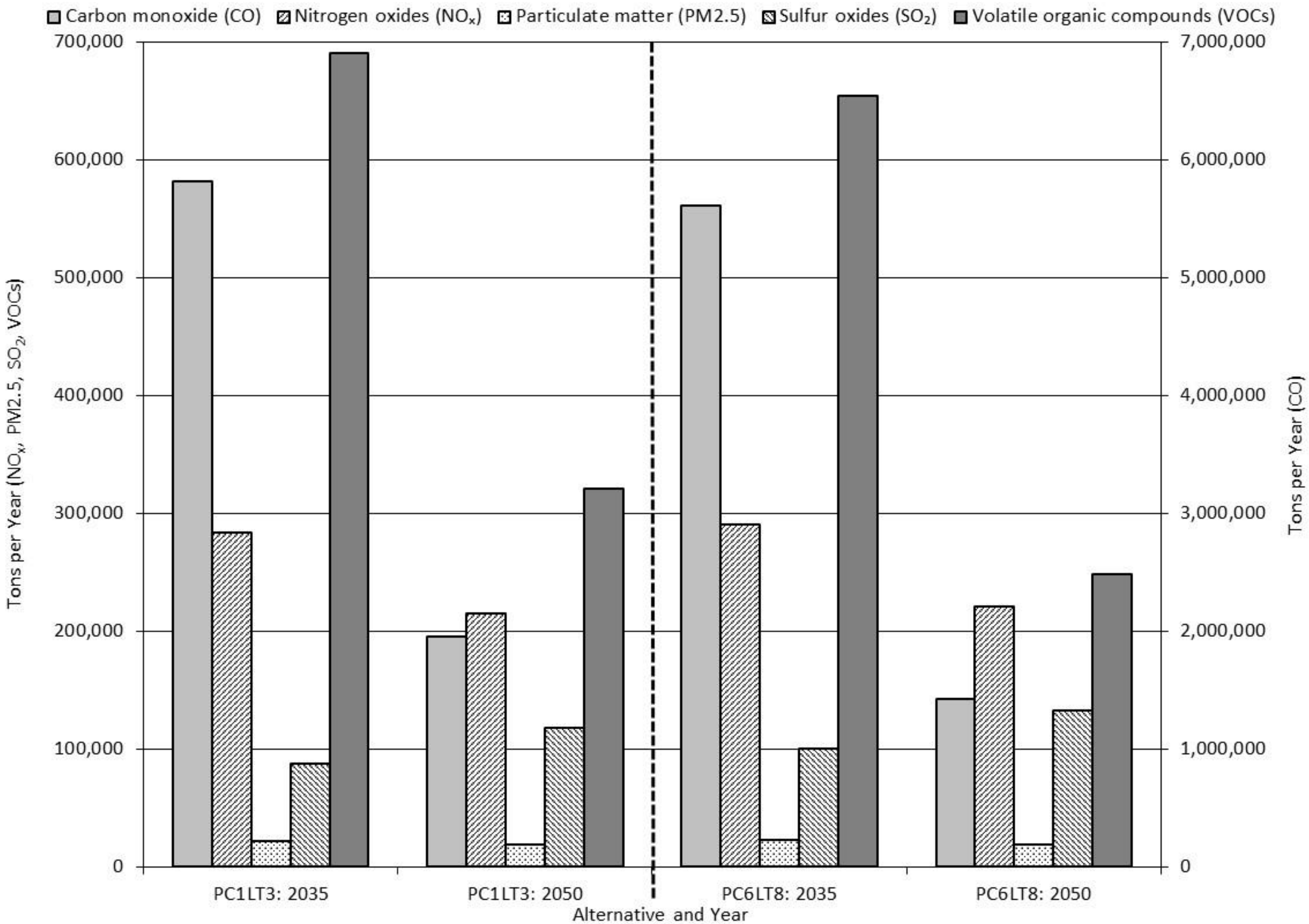


Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks by Emissions Component and Alternative, Direct and Indirect Impacts

Emissions Component	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Carbon monoxide (CO)					
Cars tailpipe	2,056,457	2,046,328	2,049,142	2,040,652	2,006,512
Cars upstream	24,305	24,504	24,435	24,724	25,778
Trucks tailpipe	3,713,889	3,694,404	3,676,015	3,637,750	3,517,890
Trucks upstream	55,171	55,892	56,431	57,947	62,767
Total	5,849,823	5,821,128	5,806,023	5,761,073	5,612,947
Nitrogen oxides (NO_X)					
Cars tailpipe	39,052	38,839	38,888	38,703	37,927
Cars upstream	46,019	46,281	46,167	46,606	48,152
Trucks tailpipe	90,367	89,970	89,590	88,780	86,241
Trucks upstream	107,390	108,452	109,223	111,442	118,518
Total	282,829	283,541	283,868	285,530	290,838
Particulate matter (PM2.5)					
Cars tailpipe	3,357	3,328	3,333	3,305	3,200
Cars upstream	3,372	3,399	3,390	3,428	3,570
Trucks tailpipe	7,487	7,427	7,372	7,265	6,930
Trucks upstream	7,660	7,757	7,829	8,033	8,680
Total	21,875	21,910	21,924	22,031	22,380
Sulfur oxides (SO_2)					
Cars tailpipe	1,320	1,299	1,299	1,284	1,214
Cars upstream	25,865	26,233	26,138	26,592	28,326
Trucks tailpipe	3,865	3,818	3,777	3,674	3,355
Trucks upstream	54,539	55,717	56,631	59,125	67,032
Total	85,589	87,066	87,846	90,676	99,927
Volatile organic compounds (VOCs)					
Cars tailpipe	170,161	169,586	169,805	169,370	167,609
Cars upstream	68,777	67,814	67,831	67,212	64,207
Trucks tailpipe	259,652	258,583	257,543	255,272	248,153
Trucks upstream	196,354	194,369	192,563	188,214	174,625
Total	694,944	690,351	687,741	680,067	654,594

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 CAFE 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 proposed rule preamble, Technical Support Document (TSD) Chapter 2, and Preliminary Regulatory Impact Analysis (PRIA) Chapter 3.2 issued concurrently with this EIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates.

Table 4.2.1-2 shows that tailpipe emissions in 2035 of CO, NO_X, PM2.5, SO_2, and VOC decrease under all CAFE standard action alternatives compared to the CAFE No-Action Alternative. Cumulatively across the passenger car and light truck vehicle classes, the tailpipe emissions decreases get smaller from Alternative PC1LT3 to Alternative PC2LT4, and then larger from Alternative PC2LT4 to Alternative PC3LT5 and Alternative PC6LT8. These decreases suggest that declines in tailpipe emissions rates (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). If the estimates of 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.

Table 4.2.1-2 shows that, cumulatively across the passenger car and light truck vehicle classes, upstream emissions in 2035 of CO, NO_X, PM2.5, and SO_2 increase under all CAFE standard action alternatives compared to the CAFE No-Action Alternative, while VOC emissions decrease. The emissions changes get smaller from Alternative PC1LT3 to Alternative PC2LT4, and then larger from Alternative PC2LT4 to Alternative PC3LT5 and Alternative PC6LT8. The increases in CO, NO_X, PM2.5, and SO_2 emissions reflect the projected increase in EV use, 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 over time.

Table 4.2.1-3 lists the net changes in nationwide emissions for each CAFE standard action alternative for each criteria pollutant and analysis year compared to the CAFE No-Action Alternative in the same year. Figure 4.2.1-1 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 2035, emissions of NO_X, PM2.5, and SO_2 do not increase substantially under any of the CAFE standard action alternatives. Further, modeled increases are very small relative to reductions from the historical levels represented in the current CAFE standard. Relative to the No-Action Alternative, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 that get larger from Alternative PC1LT3 through Alternative PC6LT8 (the most stringent alternative in terms of estimated required miles per gallon). The increases in NO_X, PM2.5, and 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. For CO and VOCs, the emissions decreases in 2035 get larger from Alternative PC1LT3 through Alternative PC6LT8 relative to the No-Action Alternative.
- In 2050, emissions of NO_X and SO_2 marginally increase under some CAFE standard action alternatives and decrease under others, compared to the CAFE No-Action Alternative. NO_X emissions decrease

under Alternatives PC1LT3 and PC2LT4 but increase under Alternatives PC3LT5 and PC6LT8, compared to the No-Action Alternative. SO_2 emissions decrease under Alternative PC1LT3 but increase under Alternatives PC2LT4 through PC6LT8, and the increases get larger from Alternative PC2LT4 through Alternative PC6LT8. In 2050, as in 2035, the increases in NO_X and 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. PM2.5 emissions in 2050 decrease under all action alternatives, but the decrease under Alternative PC3LT5 is less than the decrease under Alternative PC2LT4. As in 2035, emissions in 2050 of CO and VOCs decrease under the action alternatives compared to the No-Action Alternative. The CO and VOC emissions decreases get larger from Alternative PC1LT3 through Alternative PC6LT8.

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

Year	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Carbon monoxide (CO)					
2035	0	-28,695	-43,800	-88,750	-236,876
2050	0	-16,481	-65,552	-160,062	-546,877
Nitrogen oxides (NO_X)					
2035	0	713	1,039	2,701	8,009
2050	0	-606	-695	812	5,078
Particulate matter (PM2.5)					
2035	0	35	48	156	505
2050	0	-73	-131	-103	-170
Sulfur oxides (SO_2)					
2035	0	1,477	2,256	5,087	14,338
2050	0	-223	754	3,892	14,590
Volatile organic compounds (VOCs)					
2035	0	-4,593	-7,203	-14,878	-40,350
2050	0	-2,183	-8,918	-23,290	-74,876

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

Under each CAFE standard action alternative compared to the CAFE 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 16.8 percent under Alternative PC6LT8 in 2035 compared to the No-Action Alternative. While tailpipe emissions of SO_2 from vehicles decrease due to reduced fuel consumption (as is true for all the criteria pollutants), over 90 percent of SO_2 emissions are from upstream sources, and power-plant emissions of SO_2 from EV charging increase at a greater rate than the decreases in tailpipe emissions; this leads to net increases in SO_2 emissions. On the other hand, pollutants for which the increases in emissions due to EV charging are less than the decreases in tailpipe emissions due to reduced fuel consumption show a net decrease in emissions. The largest relative decreases in emissions would occur for CO, for which emissions would decrease by as much as 27.8 percent under Alternative PC6LT8 in 2050 compared to the No-Action Alternative (Table 4.2.1-1). Percentage increases and decreases in emissions of NO_X, PM2.5, and VOCs would be less.

The differences in national emissions of criteria air pollutants among the CAFE standard action alternatives compared to the CAFE No-Action Alternative would range from less than 1 percent to about 28 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.

Nonattainment Areas

Table 4.2.1-4 summarizes the CAFE standards criteria air pollutant analysis results by nonattainment area.[31] For each pollutant, Table 4.2.1-4 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur. Appendix D, *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 D indicates that, for CO, NO_X, PM2.5, and SO_2, the majority of nonattainment areas would experience decreases in emissions across all CAFE standard action alternatives in 2035 and 2050, compared to the CAFE No-Action Alternative. For VOCs, across all alternatives, all nonattainment areas would experience decreases in emissions in 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	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Carbon monoxide (CO)	Maximum increase	200	2050	PC6LT8	Archuleta County; Pagosa Springs, CO [PM10 (1987 24-hour)]
	Maximum decrease	-25,763	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); Ozone (2008 and 2015 8-hour)]
Nitrogen oxides (NO_X)	Maximum increase	690	2035	PC6LT8	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-263	2050	PC6LT8	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]

[31] In the *Nonattainment Areas* subsections of Section 4.2.1.1, *CAFE Standards,* Section 4.2.1.2, *HDPUV FE Standards*, and Section 4.2.2.1, *Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards*, the term *nonattainment* refers to both nonattainment areas and maintenance areas.

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Particulate matter (PM2.5)	Maximum increase	159	2050	PC6LT8	Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE [Ozone (2015 8-hour)]
	Maximum decrease	-43	2050	PC6LT8	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]
Sulfur oxides (SO_2)	Maximum increase	2,220	2050	PC6LT8	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-31	2050	PC1LT3	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Volatile organic compounds (VOCs)	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-3,068	2050	PC6LT8	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]

Each nonattainment area implements emissions controls and other requirements, in accordance with its SIP, that aim to reduce emissions so 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 a CAFE standard 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 emissions reductions.

Toxic Air Pollutants

Emissions Levels

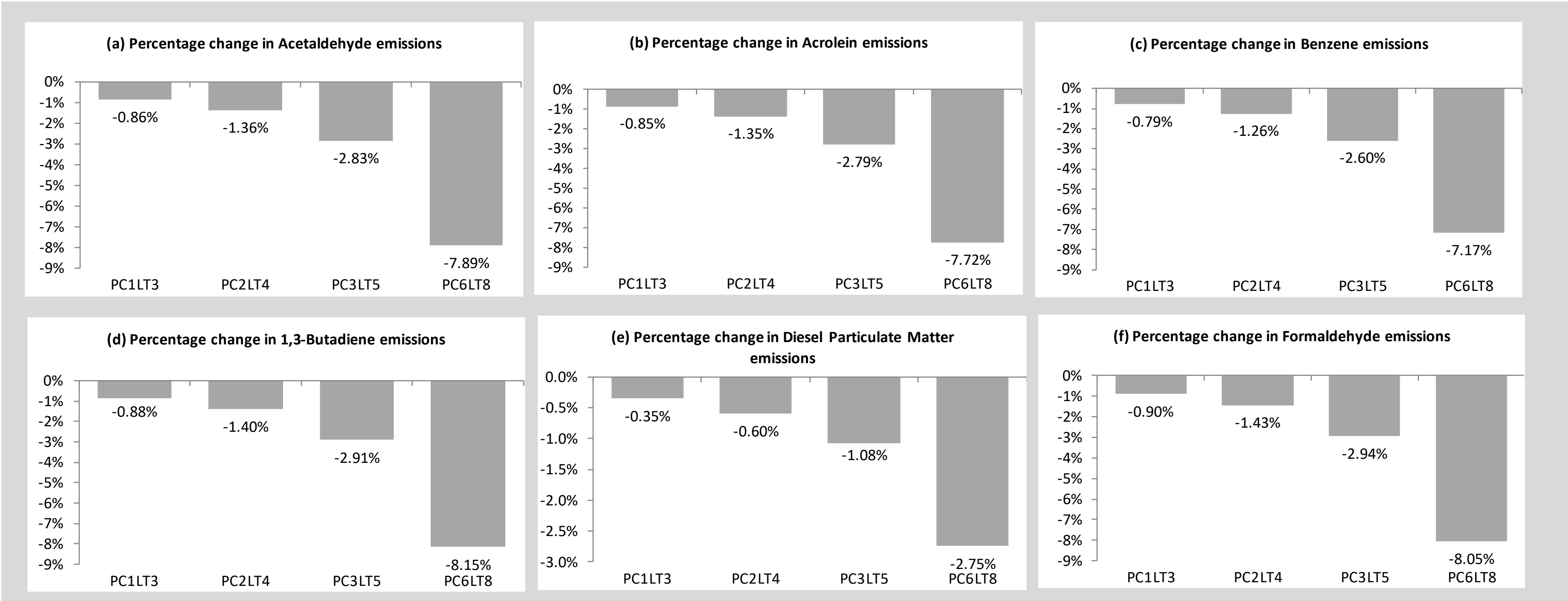
Table 4.2.1-5 summarizes the total upstream and downstream[32] emissions of toxic air pollutants by CAFE standard alternative for each of the toxic air pollutants and analysis years. Figure 4.2.1-4 compares the percentage differences in toxic air pollutant emissions for each alternative in 2035.

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

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

Year	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Acetaldehyde					
2035	1,844	1,828	1,819	1,792	1,698
2050	649	644	622	581	420
Acrolein					
2035	123	122	121	120	114
2050	43	43	42	39	28
Benzene					
2035	7,259	7,201	7,167	7,070	6,738
2050	2,748	2,728	2,646	2,487	1,872
1,3-Butadiene					
2035	740	734	730	719	680
2050	261	259	250	234	168
Diesel particulate matter (DPM)					
2035	34,636	34,515	34,429	34,263	33,685
2050	28,235	28,161	27,970	27,679	26,770
Formaldehyde					
2035	1,497	1,483	1,475	1,453	1,376
2050	540	536	518	483	349

Figure 4.2.1-4. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Action Alternative Compared to the CAFE No-Action Alternative, Direct and Indirect Impacts



Notes:
The vertical (percentage) scale differs by pollutant.
Negative values indicate emissions decreases; positive values are emissions increases.

Figure 4.2.1-5 shows the changes over time in total national emissions of toxic air pollutants under Alternative PC1LT3 (the least stringent and highest fuel-use action alternative) and Alternative PC6LT8 (the most stringent and lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts over time across the CAFE standard action alternatives. Figure 4.2.1-5 shows a consistent time trend among the toxic air pollutants, where emissions decrease from 2035 to 2050 because of increasingly stringent EPA regulations of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*) and from reductions in upstream emissions from fuel production, despite a growth in total VMT.[33]

As with criteria pollutant emissions, total toxic pollutant 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 CAFE standards (passenger cars and light trucks). Table 4.2.1-6 shows the total emissions of air toxic pollutants by four components for calendar year 2035 (i.e., cars tailpipe, cars upstream, trucks tailpipe, and trucks upstream). Tailpipe emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde, cumulative across the two vehicle classes, decrease under all CAFE standard action alternatives compared to the CAFE No-Action Alternative. The emissions decreases get smaller from Alternative PC1LT3 to Alternative PC2LT4, and then larger from Alternative PC2LT4 to Alternative PC3LT5 and Alternative PC6LT8. This suggests that declines in tailpipe emissions rates (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline, and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). Tailpipe emissions in 2035 remain unchanged for DPM in the action alternatives relative to the No-Action Alternative. Table 4.2.1-6 also indicates that upstream emissions of all air toxic pollutants decrease under all action alternatives compared to the No-Action Alternative, and the decreases, cumulative across the two vehicle classes, get smaller from Alternative PC1LT3 to Alternative PC2LT4, and then larger from Alternative PC2LT4 to Alternative PC3LT5 and Alternative PC6LT8. 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.

Table 4.2.1-7 lists the net change in nationwide emissions for each CAFE standard action alternative for each toxic air pollutant and analysis year compared to the CAFE No-Action Alternative in the same year. Figure 4.2.1-4 shows these changes in percentages for 2035. Toxic air pollutant emissions across the action alternatives show decreases in 2035 and 2050 relative to the No-Action Alternative due to increasingly stringent regulation of vehicle emissions and reductions in fuel usage. The decreases get larger from Alternative PC1LT3 through Alternative PC6LT8.

The largest relative decreases in emissions generally would occur for acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde for which emissions would decrease by as much as 36 percent under Alternative PC6LT8 in 2050 compared to the CAFE No-Action Alternative (Table 4.2.1-7). Percentage decreases in emissions of benzene and DPM would be less. These trends are accounted for by the extent of technologies assumed to be deployed under the different CAFE standard action alternatives to meet the different levels of fuel-economy requirements.

[33] Continued growth in VMT is projected to occur under all alternatives until 2044; a slight decrease is projected to occur from 2045 to 2050.

Figure 4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives PC1LT3 and PC6LT8, Providing the Lowest and Highest Range in Direct and Indirect Impacts

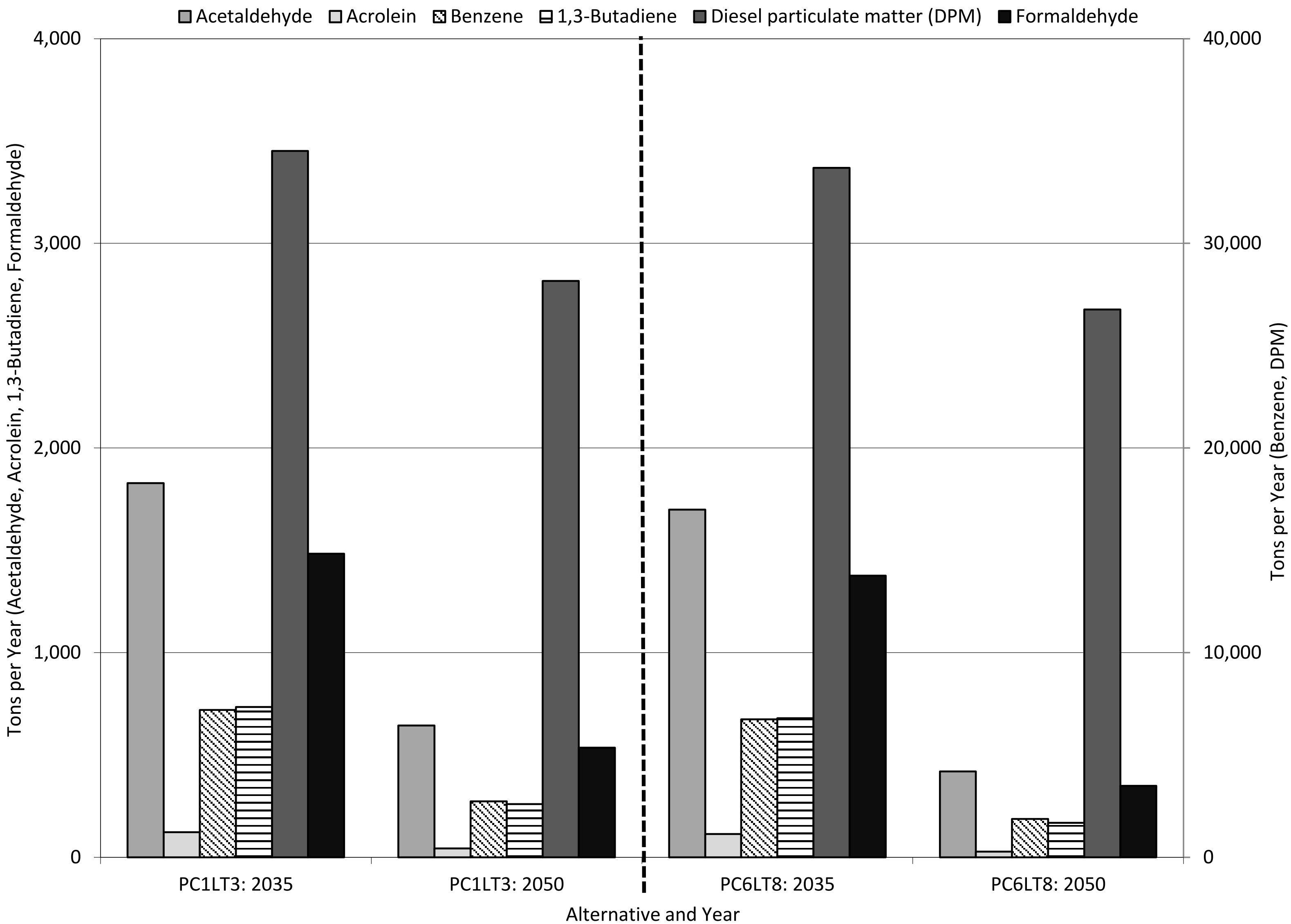


Table 4.2.1-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks, by Emissions Component and Alternative, Direct and Indirect Impacts

Emissions Component	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Acetaldehyde					
Cars tailpipe	576	571	572	567	545
Cars upstream	13	13	13	13	12
Trucks tailpipe	1,216	1,206	1,196	1,175	1,107
Trucks upstream	39	38	38	37	34
Total	1,844	1,828	1,819	1,792	1,698
Acrolein					
Cars tailpipe	38	37	37	37	36
Cars upstream	2	2	2	2	2
Trucks tailpipe	79	78	78	76	72
Trucks upstream	5	5	5	5	4
Total	123	122	121	120	114
Benzene					
Cars tailpipe	2,177	2,161	2,164	2,150	2,087
Cars upstream	225	221	221	219	207
Trucks tailpipe	4,199	4,170	4,140	4,077	3,874
Trucks upstream	657	649	642	625	570
Total	7,259	7,201	7,167	7,070	6,738
1,3-Butadiene					
Cars tailpipe	238	236	236	234	225
Cars upstream	0	0	0	0	0
Trucks tailpipe	501	497	493	484	455
Trucks upstream	1	1	1	1	1
Total	740	734	730	719	680
Diesel particulate matter (DPM)					
Cars tailpipe	8	8	8	8	8
Cars upstream	9,514	9,460	9,452	9,440	9,334
Trucks tailpipe	31	31	31	31	31
Trucks upstream	25,083	25,016	24,939	24,784	24,312
Total	34,636	34,515	34,429	34,263	33,685
Formaldehyde					
Cars tailpipe	366	362	363	360	349
Cars upstream	94	93	93	92	86
Trucks tailpipe	761	756	750	739	702
Trucks upstream	276	272	269	262	239
Total	1,497	1,483	1,475	1,453	1,376

Table 4.2.1-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks by CAFE Standard Alternative, Direct and Indirect Impacts [a]

Year	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Acetaldehyde					
2035	0	-16	-25	-52	-146
2050	0	-5	-27	-67	-229
Acrolein					
2035	0	-1	-2	-3	-10
2050	0	0	-2	-4	-15
Benzene					
2035	0	-58	-91	-189	-520
2050	0	-20	-103	-262	-877
1,3-Butadiene					
2035	0	-6	-10	-22	-60
2050	0	-2	-11	-27	-93
Diesel particulate matter (DPM)					
2035	0	-121	-207	-373	-951
2050	0	-73	-265	-556	-1,464
Formaldehyde					
2035	0	-13	-21	-44	-120
2050	0	-4	-22	-57	-191

Notes:

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

The differences in national emissions of toxic air pollutants among the CAFE standard action alternatives compared to the CAFE No-Action Alternative would range from less than 1 percent to over 35 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.

Nonattainment Areas

EPA has not designated nonattainment areas for toxic air pollutants. To provide a regional perspective, changes in toxic air pollutant emissions were evaluated for areas that are in nonattainment for criteria pollutants. For each pollutant, Table 4.2.1-8 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur.[34] Appendix D, *Air Quality Nonattainment Area Results*, lists the estimated emissions changes for each nonattainment area. The increases and decreases would not be uniformly distributed to individual nonattainment areas. In 2035 and 2050, emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde would decrease under all CAFE standard action alternatives in all nonattainment areas compared to the CAFE No-Action Alternative. For DPM in 2035, emissions would decrease in the majority of nonattainment areas

[34] 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.

compared to the No-Action Alternative. For DPM in 2050, emissions would decrease in the majority of nonattainment areas under Alternatives PC1LT3 and PC2LT4 and would decrease in all nonattainment areas under Alternatives PC3LT5 and PC6LT8, compared to the No-Action Alternative.

Table 4.2.1-8. 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	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-10	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
Acrolein	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.7	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
Benzene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-36	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
1,3-Butadiene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-4	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum increase	0.002	2035	PC6LT8	Phoenix, AZ [CO (1971 8-hour)]

Air Toxic	Maximum Increase/ Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Diesel particulate matter (DPM)	Maximum decrease	-202	2050	PC6LT8	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Formaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-7	2050	PC6LT8	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]

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

Health Impacts

Adverse health impacts from criteria pollutant emissions are expected to decrease nationwide in 2035 and 2050 under all CAFE standard action alternatives. This is due to decreases in the downstream emissions of NO_x, SO_2, and particularly PM2.5 in these years under each action alternative relative to the No-Action Alternative. As discussed in Section 4.1.2.6, *Health Impacts*, the health impacts per ton of emissions are substantially larger for downstream emissions than upstream emissions, and substantially larger for PM2.5 emissions than NO_X and SO_2 emissions. Though there are increases in upstream emissions for some years and action alternatives, and though the PM2.5 emissions changes sometimes are smaller than the emissions changes for NO_X and SO_2, the decreases in downstream emissions, particularly for PM2.5, lead to decreases (or no changes) in adverse health impacts. The decreases in impacts from downstream PM2.5 emissions are larger than the increases in impacts from upstream emissions.

The improvements to health impacts (or decreases in health incidences) would get larger from Alternative PC1LT3 to Alternative PC6LT8 in 2035 and 2050. These decreases reflect the generally increasing stringency of the action alternatives as they become implemented. As discussed in Appendix C, Section C.5.7, *Health Impacts*, the values in Table 4.2.1-9 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. As discussed in Appendix C, Section C.5.7, *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 2013b).

Under any CAFE standard action alternative, total emissions from passenger cars and light trucks are expected to decrease over time compared to existing (2022) 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 4.2.1-9. 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,c]

Year	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Premature mortality (Krewski et al. 2009)					
2035	0	-4	-7	-10	-27
2050	0	-7	-21	-37	-114
Emergency room visits: respiratory					
2035	0	-3	-6	-10	-26
2050	0	-4	-13	-24	-76
Acute bronchitis					
2035	0	-8	-14	-25	-68
2050	0	-10	-33	-62	-198
Lower respiratory symptoms					
2035	0	-107	-181	-316	-855
2050	0	-127	-415	-786	-2,509
Upper respiratory symptoms					
2035	0	-156	-264	-462	-1,251
2050	0	-180	-592	-1,128	-3,605
Minor restricted activity days					
2035	0	-5,368	-8,962	-16,211	-44,146
2050	0	-5,330	-18,183	-35,805	-115,425
Work-loss days					
2035	0	-902	-1,507	-2,719	-7,400
2050	0	-909	-3,089	-6,061	-19,524
Asthma exacerbation					
2035	0	-184	-311	-547	-1,480
2050	0	-212	-698	-1,330	-4,253
Hospital admissions: cardiovascular					
2035	0	-1	-2	-3	-7
2050	0	-2	-6	-10	-30
Hospital admissions: respiratory					
2035	0	-1	-2	-2	-6
2050	0	-2	-5	-9	-28
Non-fatal heart attacks (Peters et al. 2001)					
2035	0	-4	-7	-11	-29
2050	0	-7	-22	-38	-119
Non-fatal heart attacks (All other studies)					
2035	0	0	-1	-1	-3
2050	0	-1	-2	-4	-13

Notes:

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

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

[c] Impacts have been rounded to the nearest whole number.

4.2.1.2 HDPUV FE Standards

NHTSA has identified Alternative HDPUV10 as the Preferred Alternative for HDPUV FE standards. This section presents the direct and indirect impacts on criteria and toxic air pollutant emissions levels and projected impacts on nonattainment areas associated with the Preferred Alternative for HDPUV FE standards and HDPUV FE standard action alternatives.

Criteria Pollutants

Emissions Levels

Table 4.2.1-10 summarizes the total upstream and downstream[35] national emissions by HDPUV FE standard action alternative for each of the criteria pollutants and analysis years. Figure 4.2.1-6 compares the percentage differences in emissions among the alternatives for 2035, a near-term forecast year for HDPUVs. Figure 4.2.1-7 illustrates this information in the context of the total emissions for each alternative.

Figure 4.2.1-8 shows the changes over time in total national emissions of criteria pollutants under Alternative HDPUV4 (the least stringent and highest fuel-use action alternative) and Alternative HDPUV14 (the most stringent and lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts over time across HDPUV FE standard action alternatives. Figure 4.2.1-7 shows a consistent time trend among the criteria pollutants except for SO_2. Emissions of CO, NO_X, PM2.5, and VOC decrease from 2035 to 2050 because of increasingly stringent EPA regulation of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*), despite a growth in total VMT from 2035 to 2050. Those decreases in CO, NO_X, and PM2.5 emissions occur also despite a growth in their upstream emissions due to 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. However, upstream VOC emissions decrease from 2035 to 2050. Emissions of SO_2 increase from 2035 to 2050 under all action alternatives, where emissions from vehicles decrease but upstream power-plant emissions from EV charging increase at a greater rate.

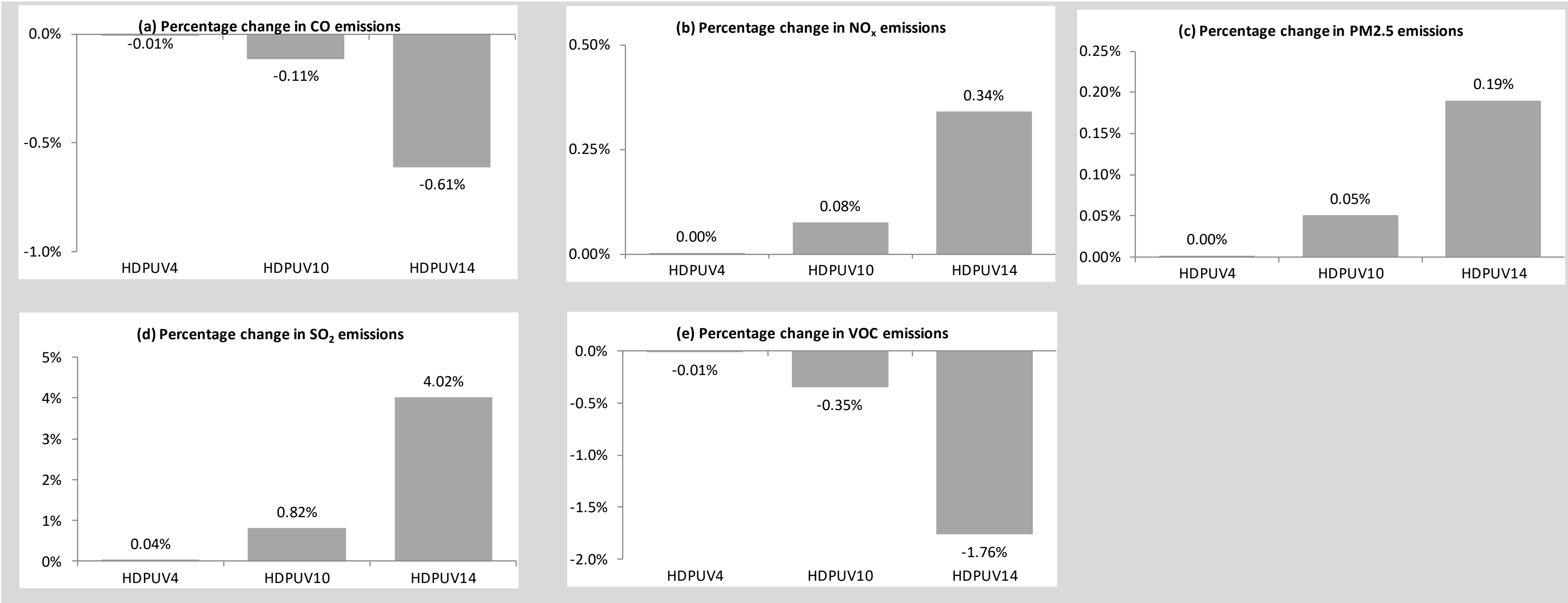
Total HDPUV emissions consist of two components: downstream (i.e., tailpipe) emissions and upstream emissions. Table 4.2.1-11 shows the total HDPUV emissions of criteria pollutants by component for calendar year 2035. The directions and magnitudes of the changes in total emissions are not consistent across all pollutants, which reflects the complex interactions between tailpipe emissions rates, 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 proposed rule preamble, TSD Chapter 2, and PRIA Chapter 3.2 issued concurrently with this EIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates.

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

Table 4.2.1-10. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans by Alternative, Direct and Indirect Impacts

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Carbon monoxide (CO)				
2035	521,233	521,206	520,646	518,052
2050	257,422	257,223	253,245	242,827
Nitrogen oxides (NO_X)				
2035	95,207	95,210	95,279	95,531
2050	43,926	43,932	44,043	44,168
Particulate matter (PM2.5)				
2035	4,806	4,806	4,808	4,815
2050	4,004	4,004	3,996	3,966
Sulfur oxides (SO_2)				
2035	11,679	11,683	11,774	12,149
2050	18,924	18,937	19,192	19,727
Volatile organic compounds (VOCs)				
2035	95,175	95,161	94,843	93,500
2050	86,658	86,595	85,235	81,733

Figure 4.2.1-6. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Heavy-Duty Pickup Trucks and Vans for 2035 by Action Alternative Compared to the HDPUV No-Action Alternative, Direct and Indirect Impacts



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

Notes:
The vertical (percentage) scale differs by pollutant.
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 4.2.1-7. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans for 2035 by Alternative, Direct and Indirect Impacts

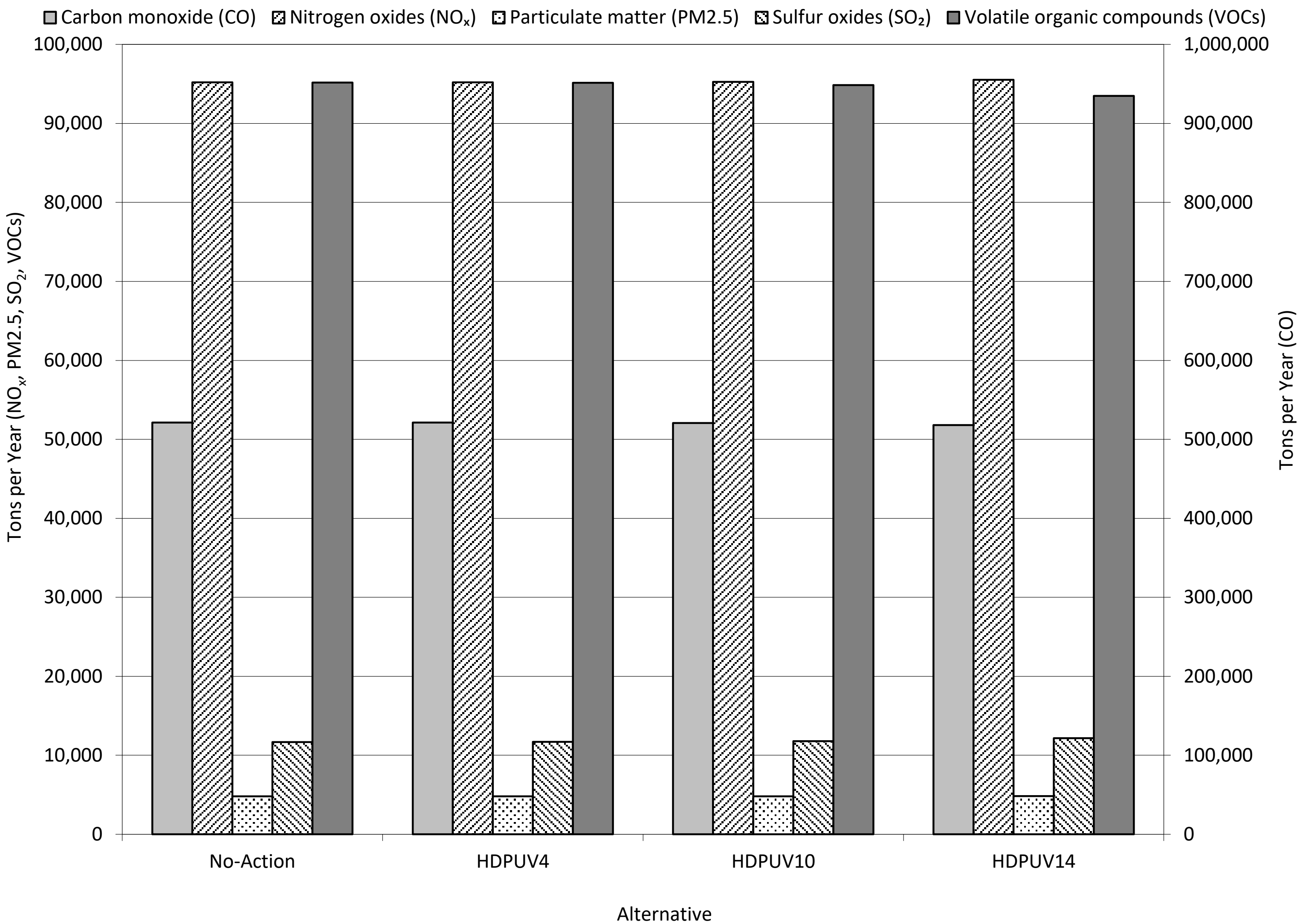


Figure 4.2.1-8. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans under Alternatives HDPUV4 and HDPUV14, Providing the Lowest and Highest Range in Direct and Indirect Impacts

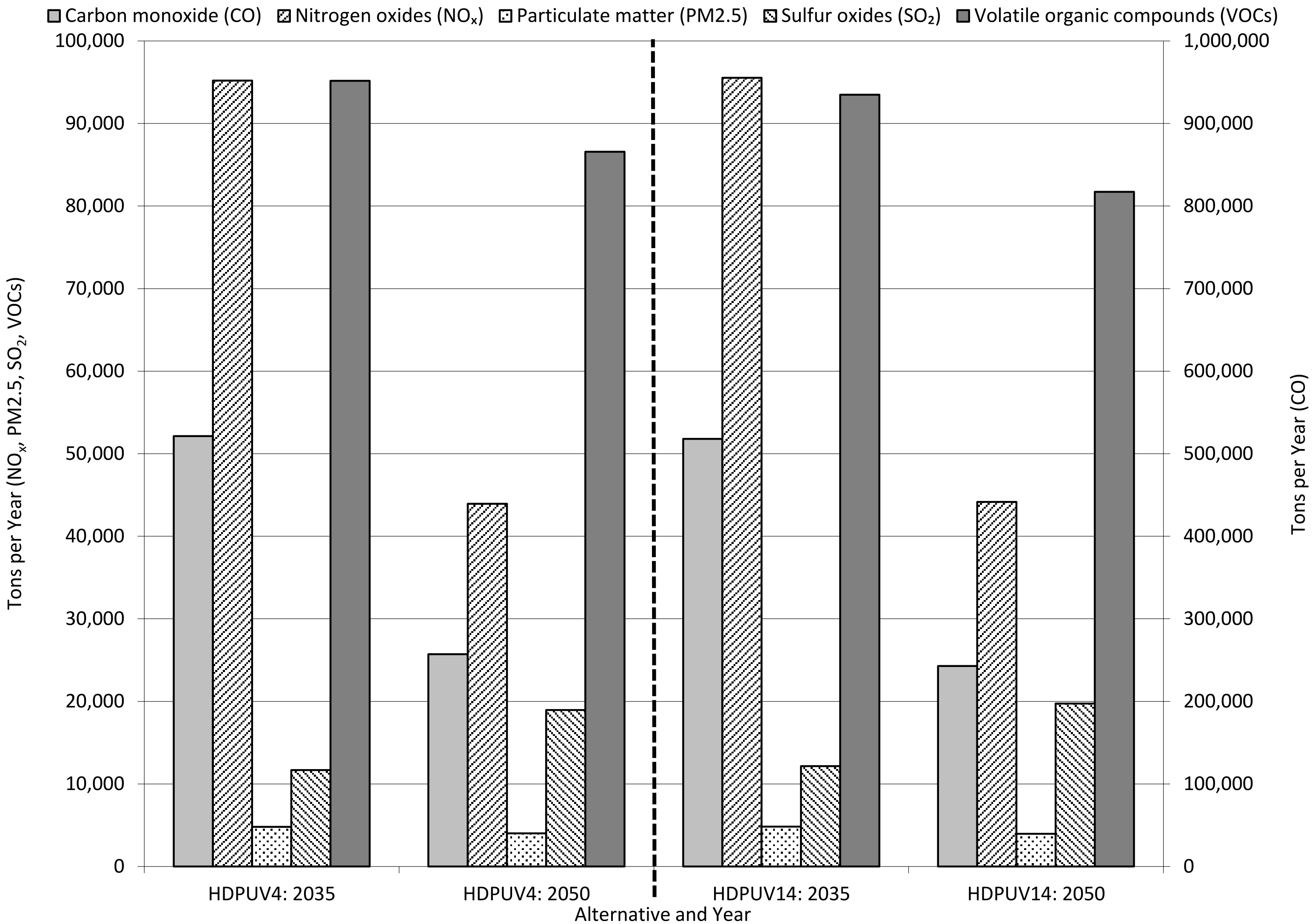


Table 4.2.1-11. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Heavy-Duty Pickup Trucks and Vans by Emissions Component and Alternative, Direct and Indirect Impacts

Emissions Component	No-Action	HDPUV4	HDPUV10	HDPUV14
Carbon monoxide (CO)				
Heavy-duty trucks and vans tailpipe	510,701	510,671	510,052	507,214
Heavy-duty trucks and vans upstream	10,532	10,535	10,594	10,838
Total	521,233	521,206	520,646	518,052
Nitrogen oxides (NO_X)				
Heavy-duty trucks and vans tailpipe	74,950	74,948	74,930	74,824
Heavy-duty trucks and vans upstream	20,257	20,261	20,349	20,707
Total	95,207	95,210	95,279	95,531
Particulate matter (PM2.5)				
Heavy-duty trucks and vans tailpipe	3,350	3,350	3,344	3,319
Heavy-duty trucks and vans upstream	1,455	1,456	1,464	1,496
Total	4,806	4,806	4,808	4,815
Sulfur oxides (SO_2)				
Heavy-duty trucks and vans tailpipe	707	707	703	689
Heavy-duty trucks and vans upstream	10,972	10,976	11,071	11,460
Total	11,679	11,683	11,774	12,149
Volatile organic compounds (VOCs)				
Heavy-duty trucks and vans tailpipe	64,050	64,043	63,878	63,159
Heavy-duty trucks and vans upstream	31,124	31,118	30,966	30,341
Total	95,175	95,161	94,843	93,500

Table 4.2.1-11 shows that tailpipe emissions in 2035 of CO, NO_X, PM2.5, SO_2, and VOC decrease under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, and that the decreases get larger from Alternative HDPUV4 through Alternative HDPUV14. These decreases suggest that declines in tailpipe emissions rates (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline, and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). 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.

Table 4.2.1-11 shows that upstream emissions in 2035 of CO, NO_X, PM2.5, and SO_2 increase under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, while VOC emissions decrease, and that the changes in emissions get larger from Alternative HDPUV4 through Alternative HDPUV14. The increases in CO, NO_X, PM2.5, and SO_2 emissions reflect the projected increase in EV use, 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 over time.

Table 4.2.1-12 lists the net changes in nationwide emissions for each HDPUV FE standard action alternative for each criteria pollutant and analysis year compared to the HDPUV No-Action Alternative in the same year. Figure 4.2.1-6 shows these changes in percentages for 2035.

- In 2035, emissions of NO_X, PM2.5, and SO_2 do not increase substantially under any of the HDPUV FE standard action alternatives. Further, modeled increases are very small relative to reductions from the historical levels represented in the current FE standard. Relative to the No-Action Alternative, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 that get larger from Alternative HDPUV4 through Alternative HDPUV14 (the most stringent alternative in terms of the estimated required fuel consumption metric [gallons of fuel per 100 ton-mile]). The increases in NO_X, PM2.5, and 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. For CO and VOCs, the emissions decreases in 2035 get larger from Alternative HDPUV4 through Alternative HDPUV14 relative to the No-Action Alternative.
- In 2050, emissions of NO_X and SO_2 marginally increase under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, and the increases get larger from Alternative HDPUV4 through Alternative HDPUV14. In 2050, as in 2035, the increases in NO_X and 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. Emissions of CO, PM2.5, and VOCs decrease under all action alternatives compared to the No-Action Alternative, and the decreases get larger from Alternative HDPUV4 through Alternative HDPUV14.

Table 4.2.1-12. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans by HDPUV FE Standard Alternative, Direct and Indirect Impacts [a]

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Carbon monoxide (CO)				
2035	0	-28	-587	-3,181
2050	0	-199	-4,177	-14,595
Nitrogen oxides (NO_X)				
2035	0	3	72	324
2050	0	6	117	242
Particulate matter (PM2.5)				
2035	0	0	2	9
2050	0	0	-8	-39
Sulfur oxides (SO_2)				
2035	0	4	95	469
2050	0	12	268	802
Volatile organic compounds (VOCs)				
2035	0	-14	-331	-1,674
2050	0	-64	-1,423	-4,926

Notes:
[a] Changes for the HDPUV No-Action Alternative are shown as zero because the No-Action Alternative is the baseline to which the HDPUV FE standard action alternatives are compared.

Under each HDPUV FE standard action alternative compared to the HDPUV No-Action Alternative, the largest relative increases in emissions among the criteria pollutants would occur for SO_2, for which emissions would increase by as much as 4.2 percent under Alternative HDPUV14 in 2050 compared to the No-Action Alternative. The largest relative decreases in emissions would occur for CO and VOCs, for which emissions would decrease by as much as 5.7 percent under Alternative HDPUV14 in 2050 compared to the No-Action Alternative (Table 4.2.1-12). Percentage increases and reductions in emissions of NO_X and PM2.5 would be less.

The differences in national emissions of criteria air pollutants among the HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative would range from less than 1 percent to about 6 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.

Nonattainment Areas

Table 4.2.1-13 summarizes the criteria air pollutant analysis results by nonattainment area.[36] For each pollutant, Table 4.2.1-13 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur. Appendix D, *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 D indicates that for CO, NO_X, PM2.5, and SO_2, the majority of nonattainment areas would experience decreases in emissions across all HDPUV FE standard action alternatives in 2035 and 2050, compared to the HDPUV No-Action Alternative. For VOCs, across all alternatives, all nonattainment areas would experience decreases in emissions in 2035 and 2050, compared to the No-Action Alternative.

Table 4.2.1-13. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Carbon monoxide (CO)	Maximum increase	12	2050	HDPUV14	Archuleta County; Pagosa Springs, CO [PM10 (1987 24-hour)]
	Maximum decrease	-549	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]
Nitrogen oxides (NO_X)	Maximum increase	38	2050	HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-16	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]

[36] In the *Nonattainment Areas* subsections of Section 4.2.1.1, *CAFE Standards,* Section 4.2.1.2, *HDPUV FE Standards*, and Section 4.2.2.1, *Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards*, the term *nonattainment* refers to both nonattainment areas and maintenance areas.

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Particulate matter (PM2.5)	Maximum increase	8	2050	HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-3	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]
Sulfur oxides (SO_2)	Maximum increase	122	2050	HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-1	2050	HDPUV14	Atlanta, GA [Ozone (2008 and 2015 8-hour)]
Volatile organic compounds (VOCs)	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-197	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]

Each nonattainment area implements emissions controls and other requirements, in accordance with its SIP, that aim to reduce emissions so 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 HDPUV FE standard 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 emissions reductions.

Toxic Air Pollutants

Emissions Levels

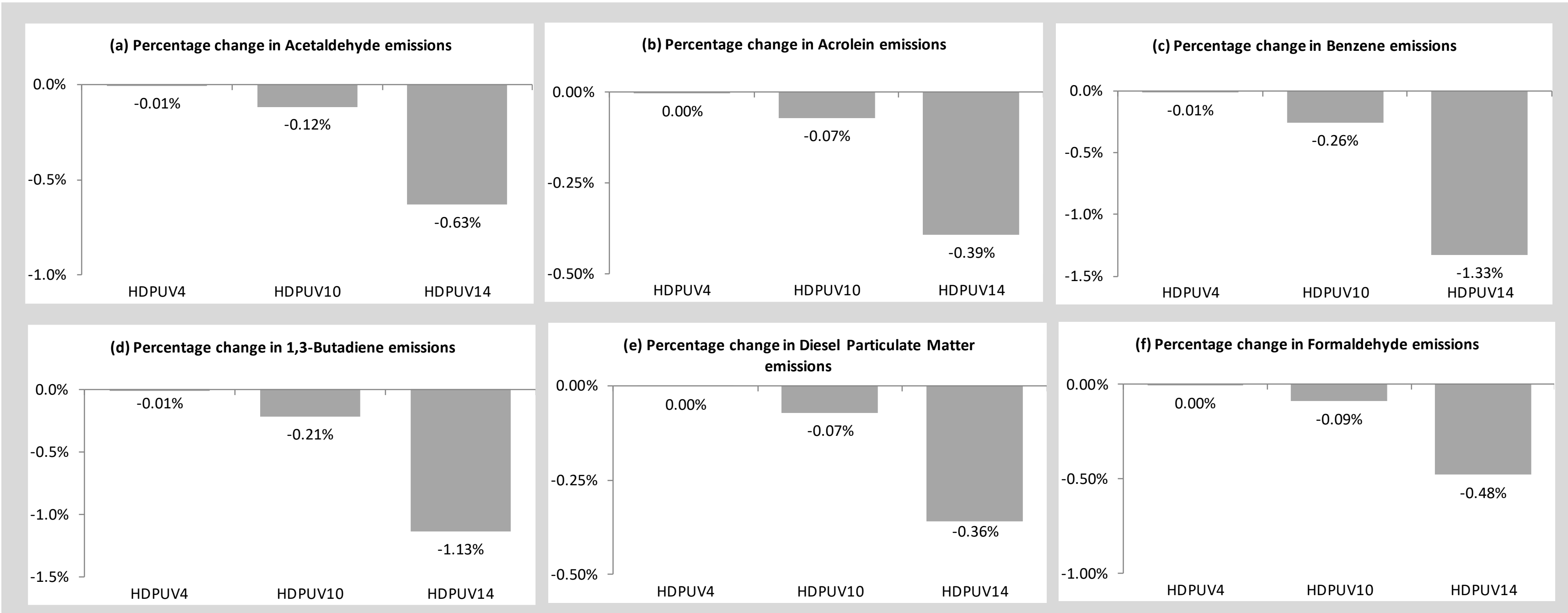
Table 4.2.1-14 summarizes the total upstream and downstream[37] emissions of toxic air pollutants by HDPUV FE standard action alternative for each of the toxic air pollutants and analysis years. Figure 4.2.1-9 compares the percentage differences in toxic air pollutant emissions for each alternative in 2035.

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

Table 4.2.1-14. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans by Alternative, Direct and Indirect Impacts

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Acetaldehyde				
2035	535	535	534	532
2050	232	232	228	218
Acrolein				
2035	57	57	57	56
2050	17	17	17	16
Benzene				
2035	1,229	1,229	1,226	1,213
2050	939	938	921	878
1,3-Butadiene				
2035	118	118	118	117
2050	81	81	79	76
Diesel particulate matter (DPM)				
2035	5,973	5,973	5,969	5,951
2050	5,119	5,118	5,103	5,039
Formaldehyde				
2035	696	696	695	692
2050	212	212	208	198

Figure 4.2.1-9. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Heavy-Duty Pickup Trucks and Vans for 2035 by Action Alternative Compared to the HDPUV No-Action Alternative, Direct and Indirect Impacts



Notes:
The vertical (percentage) scale differs by pollutant.
Negative values indicate emissions decreases; positive values are emissions increases.

Figure 4.2.1-10 shows the changes over time in total national emissions of toxic air pollutants under Alternative HDPUV4 (the least stringent and highest fuel-use action alternative) and Alternative HDPUV14 (the most stringent and lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts over time across HDPUV FE standard action alternatives. Figure 4.2.1-10 shows a consistent time trend among the toxic air pollutants, where emissions decrease from 2035 to 2050 because of increasingly stringent EPA regulations of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*) and from reductions in upstream emissions from fuel production, despite a growth in total VMT through 2050.

As with criteria pollutant emissions, total HDPUV toxic pollutant emissions consist of two components: downstream (i.e., tailpipe) emissions and upstream emissions. Table 4.2.1-15 shows the total HDPUV emissions of air toxic pollutants by component for calendar year 2035, indicating that tailpipe emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde decrease or remain the same under all HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative, suggesting that declines in tailpipe emissions rates (on a per-VMT basis) under the action alternatives are attributable to shifts in modeled technology adoption from the baseline, and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). Tailpipe emissions in 2035 remained the same or increase slightly for DPM under the action alternatives relative to the No-Action Alternative. Table 4.2.1-15 also indicates that upstream emissions of all air toxic pollutants decrease or remain the same under all action alternatives compared to the No-Action Alternative. 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.

Table 4.2.1-16 lists the net change in nationwide emissions for each of the toxic air pollutants and analysis years under the HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative in the same year. Figure 4.2.1-9 shows these changes in percentages for 2035. Toxic air pollutant emissions across the action alternatives remain the same or decrease in 2035 and 2050 relative to the No-Action Alternative due to increasingly stringent regulation of vehicle emissions and reductions in fuel usage. The decreases get larger from Alternative HDPUV4 through Alternative HDPUV14.

The largest relative decreases in emissions generally would occur for acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde for which emissions would decrease by as much as 7 percent under Alternative HDPUV14 in 2050 compared to the HDPUV No-Action Alternative (Table 4.2.1-16). Percentage decreases in emissions of DPM would be less. These trends are accounted for by the extent of technologies assumed to be deployed under the different HDPUV FE standard action alternatives to meet the different levels of fuel efficiency requirements.

Figure 4.2.1-10. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans under Alternatives HDPUV4 and HDPUV14, Providing the Lowest and Highest Range in Direct and Indirect Impacts

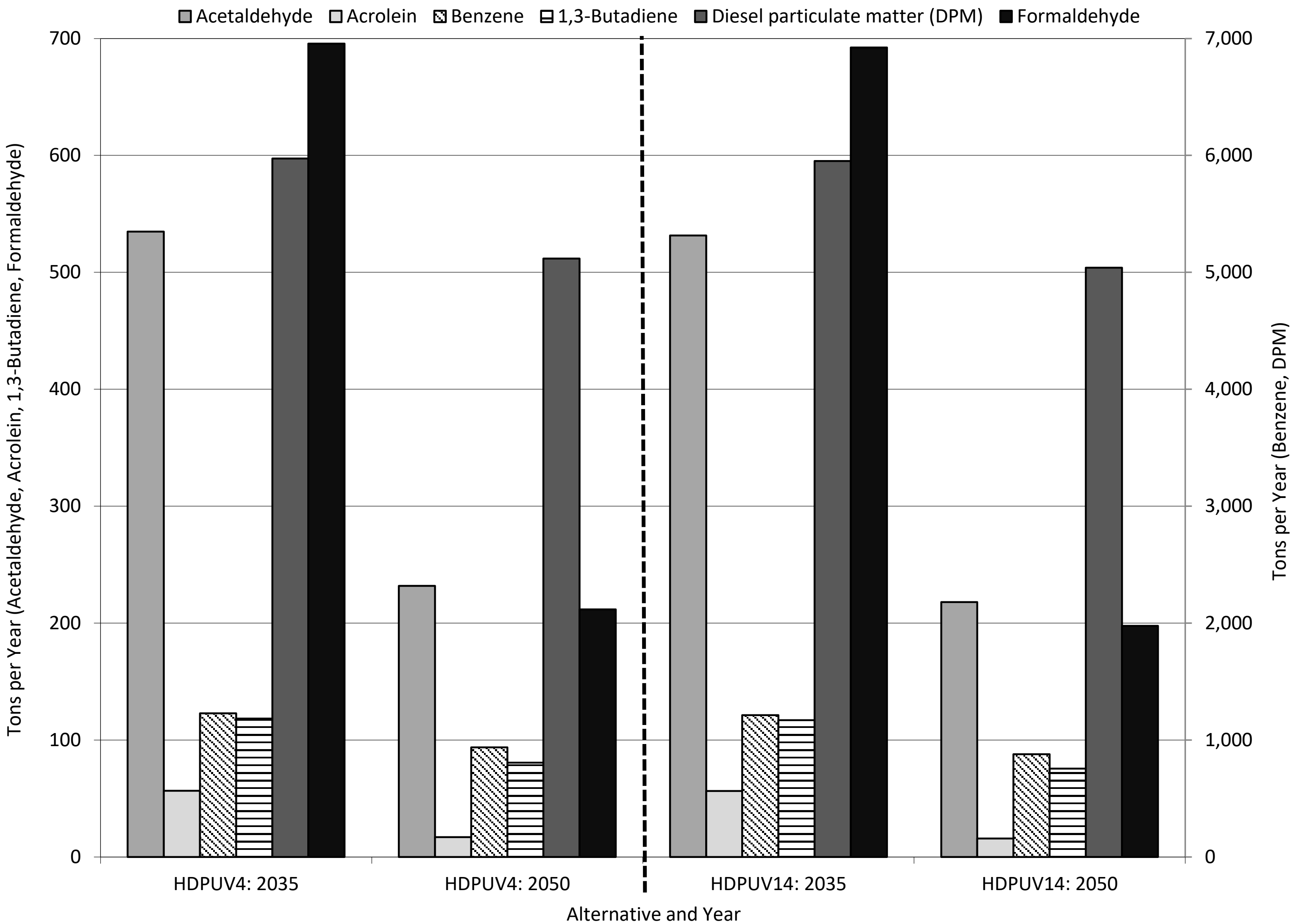


Table 4.2.1-15. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Heavy-Duty Pickup Trucks and Vans, by Emissions Component and Alternative, Direct and Indirect Impacts [a]

Emissions Component	No-Action	HDPUV4	HDPUV10	HDPUV14
Acetaldehyde				
Heavy-duty trucks and vans tailpipe	527	527	526	524
Heavy-duty trucks and vans upstream	8	8	8	8
Total	535	535	534	532
Acrolein				
Heavy-duty trucks and vans tailpipe	56	56	55	55
Heavy-duty trucks and vans upstream	1	1	1	1
Total	57	57	57	56
Benzene				
Heavy-duty trucks and vans tailpipe	1,128	1,128	1,125	1,115
Heavy-duty trucks and vans upstream	101	101	101	98
Total	1,229	1,229	1,226	1,213
1,3-Butadiene				
Heavy-duty trucks and vans tailpipe	118	118	118	117
Heavy-duty trucks and vans upstream	0	0	0	0
Total	118	118	118	117
Diesel particulate matter (DPM)				
Heavy-duty trucks and vans tailpipe	1,595	1,595	1,595	1,597
Heavy-duty trucks and vans upstream	4,378	4,378	4,373	4,355
Total	5,973	5,973	5,969	5,951
Formaldehyde				
Heavy-duty trucks and vans tailpipe	639	639	639	637
Heavy-duty trucks and vans upstream	56	56	56	55
Total	696	696	695	692

Notes:
[a] Impacts have been rounded to the nearest whole number.

Table 4.2.1-16. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans by HDPUV FE Standard Alternative, Direct and Indirect Impacts [a,b]

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Acetaldehyde				
2035	0	0	-1	-3
2050	0	0	-4	-14
Acrolein				
2035	0	0	0	0
2050	0	0	0	-1
1,3-Butadiene				
2035	0	0	-3	-16

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
2050	0	-1	-17	-60
Benzene				
2035	0	0	0	-1
2050	0	0	-1	-5
Diesel particulate matter (DPM)				
2035	0	0	-4	-21
2050	0	0	-16	-79
Formaldehyde				
2035	0	0	-1	-3
2050	0	0	-4	-14

Notes:

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

[b] Impacts have been rounded to the nearest whole number.

The differences in national emissions of toxic air pollutants among the HDPUV FE standard action alternatives compared to the HDPUV No-Action Alternative would range from less than 1 percent to almost 7 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.

Nonattainment Areas

EPA has not designated nonattainment areas for toxic air pollutants. To provide a regional perspective, changes in toxic air pollutant emissions were evaluated for areas that are in nonattainment for criteria pollutants. For each pollutant, Table 4.2.1-17 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur.[38] Appendix D, *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 2035 and 2050, emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde would decrease under all HDPUV FE standard action alternatives in all nonattainment areas compared to the HDPUV No-Action Alternative. For DPM in 2035, emissions would increase in the majority of nonattainment areas compared to the No-Action Alternative. For DPM in 2050, emissions would decrease in all nonattainment areas compared to the No-Action Alternative.

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

Table 4.2.1-17. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Heavy-Duty Pickup Trucks and Vans across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Air Toxic	Maximum Increase/ Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.5	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]
Acrolein	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.04	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]
Benzene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-2	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]
1,3-Butadiene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.2	2050	HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour); Ozone (2008 and 2015 8-hour)]
Diesel particulate matter (DPM)	Maximum increase	0.04	2035	HDPUV14	Atlanta, GA [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-11	2050	HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Formaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.4	2050	HDPUV14	Dallas-Fort Worth, TX [Ozone (2008 and 2015 8-hour)]

Health Impacts

Adverse health impacts from criteria pollutant emissions are expected to remain the same or decrease nationwide in 2035 and 2050 under all HDPUV FE standard action alternatives. This is due to decreases in the downstream emissions of NO_X, SO_2, and particularly PM2.5 in these years under each action alternative relative to the No-Action Alternative. As discussed in Section 4.1.2.6, *Health Impacts*, the health impacts per ton of emissions are substantially larger for downstream emissions than upstream emissions, and substantially larger for PM2.5 emissions than NO_X and SO_2 emissions. Though there are increases in upstream emissions for some years and action alternatives, and though the PM2.5 emissions changes sometimes are smaller than the emissions changes for NO_X and SO_2, the decreases in downstream emissions, particularly for PM2.5, lead to decreases (or no changes) in adverse health impacts. The decreases in impacts from downstream PM2.5 emissions are larger than the increases in impacts from upstream emissions.

The improvements to health impacts (or decreases in health incidences) would get larger from Alternative HDPUV4 to Alternative HDPUV14 in 2035 and 2050. These improvements reflect the generally increasing stringency of the action alternatives as they become implemented. As discussed in Appendix C, Section C.5.7, *Health Impacts*, the values in Table 4.2.1-18 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. As discussed in Appendix C, Section C.5.7, *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 2013b).

Table 4.2.1-18. Nationwide Changes in Health Impacts (cases per year) from Criteria Pollutant Emissions from U.S. Heavy-Duty Pickup Trucks and Vans by Alternative, Direct and Indirect Impacts [a,b,c]

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Premature mortality (Krewski et al. 2009)				
2035	0	0	0	0
2050	0	0	-1	-5
Emergency room visits: respiratory				
2035	0	0	0	0
2050	0	0	-1	-3
Acute bronchitis				
2035	0	0	0	-1
2050	0	0	-2	-9
Lower respiratory symptoms				
2035	0	0	-2	-14
2050	0	-1	-31	-113
Upper respiratory symptoms				
2035	0	0	-3	-21
2050	0	-2	-45	-162
Minor restricted activity days				
2035	0	-7	-145	-908
2050	0	-72	-1,523	-5,465

Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Work-loss days				
2035	0	-1	-22	-141
2050	0	-12	-247	-891
Asthma exacerbation				
2035	0	0	-4	-25
2050	0	-3	-53	-192
Hospital admissions: cardiovascular				
2035	0	0	0	0
2050	0	0	0	-1
Hospital admissions: respiratory				
2035	0	0	0	0
2050	0	0	0	-1
Non-fatal heart attacks (Peters et al. 2001)				
2035	0	0	0	0
2050	0	0	-1	-5
Non-fatal heart attacks (All others)				
2035	0	0	0	0
2050	0	0	0	-1

Notes:

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

[b] Changes for the HDPUV No-Action Alternative are shown as zero because the No-Action Alternative is the baseline to which the HDPUV FE standard action alternatives are compared.

[c] Impacts have been rounded to the nearest whole number.

Under any HDPUV FE standard action alternative, total emissions from HDPUVs are expected to decrease over time compared to existing (2022) 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 HDPUVs are expected to decrease over time compared to existing conditions.

4.2.2 Cumulative Impacts

This section examines cumulative air quality impacts. Cumulative effects are effects on the environment that result from the incremental effects of the action when added to the effects of other past, present, and reasonably foreseeable actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time. Section 4.2.2.1, *Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards*, presents the cumulative impacts of the two sets of standards that are being proposed by NHTSA in its proposed rule. Section 4.2.2.2, *Other Past, Present, and Reasonably Foreseeable Future Actions*, addresses the cumulative impacts of NHTSA's Proposed Action and alternatives in combination with other past, present, and reasonably foreseeable future actions. For both CAFE and HDPUV FE standards, the analysis shows that the action alternatives would result in different levels of emissions from vehicles when measured against projected trends under the respective 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 relevant No-Action Alternative.

4.2.2.1 Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards

Criteria Pollutants

Emissions Levels

Table 4.2.2-1 summarizes the total upstream and downstream[39] national emissions by CAFE and HDPUV FE alternative combination for each of the criteria pollutants and analysis years. Figure 4.2.2-1 compares the percentage differences in emissions among the alternatives for 2035, a near-term forecast year for passenger cars, light trucks, and HDPUVs. Figure 4.2.2-2 illustrates this information in the context of the total emissions for each alternative.

Figure 4.2.2-3 shows the changes over time in total national emissions of criteria pollutants under Alternatives PC1LT3 and HDPUV4 (the least stringent and highest fuel-use CAFE and HDPUV FE standard action alternatives) and Alternatives PC6LT8 and HDPUV14 (the most stringent and lowest fuel-use CAFE and HDPUV FE standard action alternatives) to show the highest and lowest ends of the range of cumulative emissions impacts over time across action alternatives. Figure 4.2.2-3 shows a consistent time trend among the criteria pollutants except for SO_2. Emissions of CO, NO_X, PM2.5, and VOC decrease from 2035 to 2050 because of increasingly stringent EPA regulation of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*), despite a growth in total VMT from 2035 to 2050.[40] Those decreases in CO, NO_X, and PM2.5 emissions occur also despite a growth in their upstream emissions due to 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. However, upstream VOC emissions decrease from 2035 to 2050. Emissions of SO_2 increase from 2035 to 2050 under all combinations of CAFE and HDPUV FE standard action alternatives, where emissions from vehicles decrease but upstream power-plant emissions from EV charging increase at a greater rate.

Total emissions consist of six components: two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the rule (passenger cars, light trucks, and HDPUVs). Table 4.2.2-2 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

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

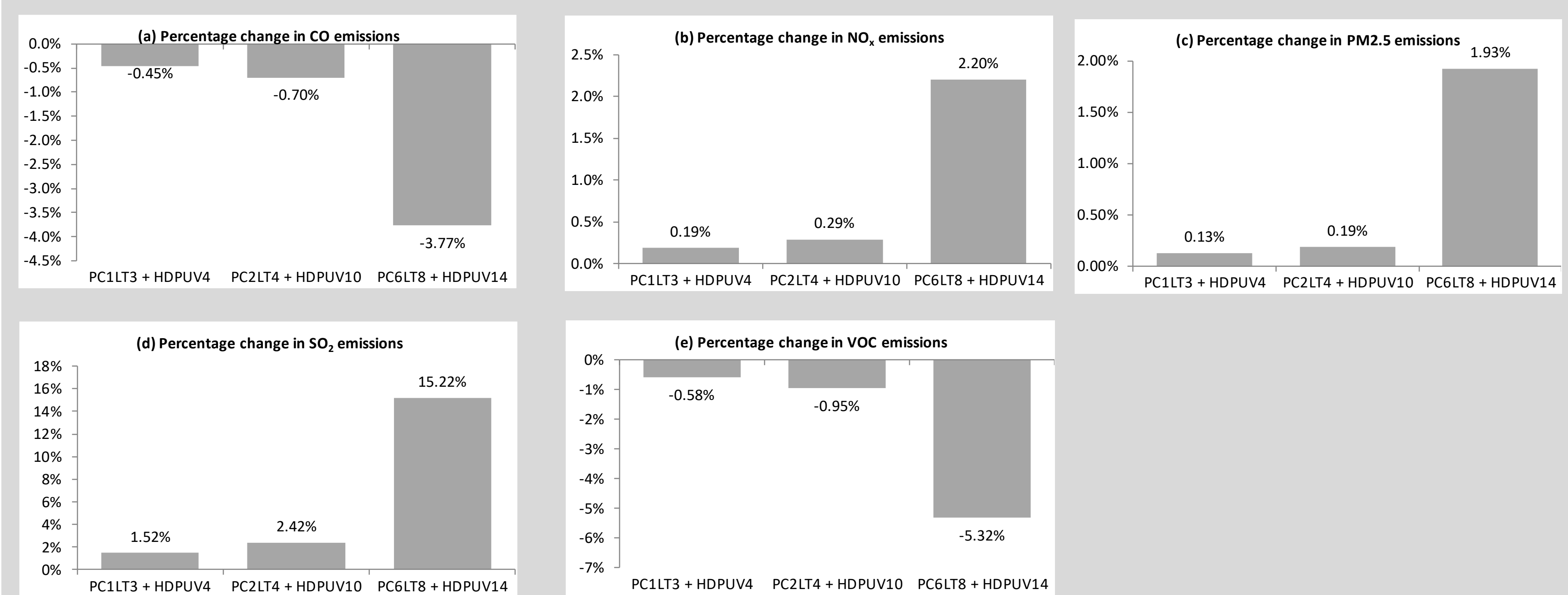
[40] Continued growth in VMT is projected to occur under all alternatives until 2046; a slight decline is projected to occur from 2047 to 2050.

III of the proposed rule preamble, TSD Chapter 2, and PRIA Chapter 3.2 issued concurrently with this EIS, including the rate at which new vehicles are sold, will also affect these air quality impact estimates.

Table 4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Carbon monoxide (CO)				
2035	6,371,057	6,342,334	6,326,669	6,130,999
2050	2,227,540	2,210,860	2,157,810	1,666,068
Nitrogen oxides (NO_X)				
2035	378,036	378,751	379,146	386,369
2050	259,656	259,055	259,077	264,976
Particulate matter (PM2.5)				
2035	26,681	26,716	26,732	27,195
2050	22,953	22,880	22,813	22,744
Sulfur oxides (SO_2)				
2035	97,268	98,750	99,620	112,076
2050	136,782	136,572	137,804	152,174
Volatile organic compounds (VOCs)				
2035	790,119	785,512	782,584	748,094
2050	409,889	407,642	399,547	330,087

Figure 4.2.2-1. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs for 2035 by CAFE and HDPUV FE Alternative Combination Compared to the No-Action Alternatives, Cumulative Impacts



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

Notes:

The vertical (percentage) scale differs by pollutant.

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 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs for 2035 by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts

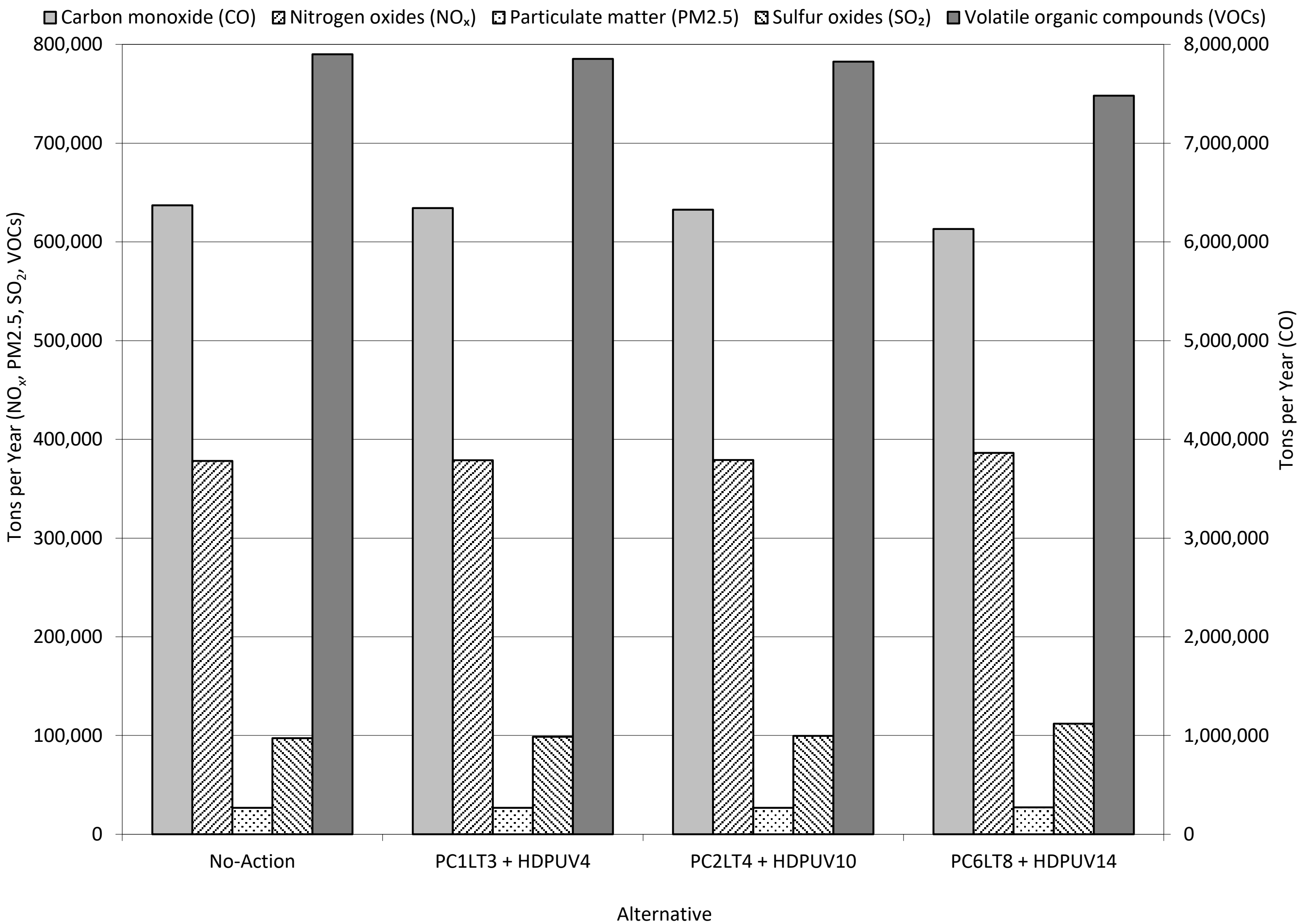


Figure 4.2.2-3. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs under Alternatives PC1LT3 + HDPUV4 and Alternatives PC6LT8 + HDPUV14, Providing the Lowest and Highest Range in Cumulative Impacts

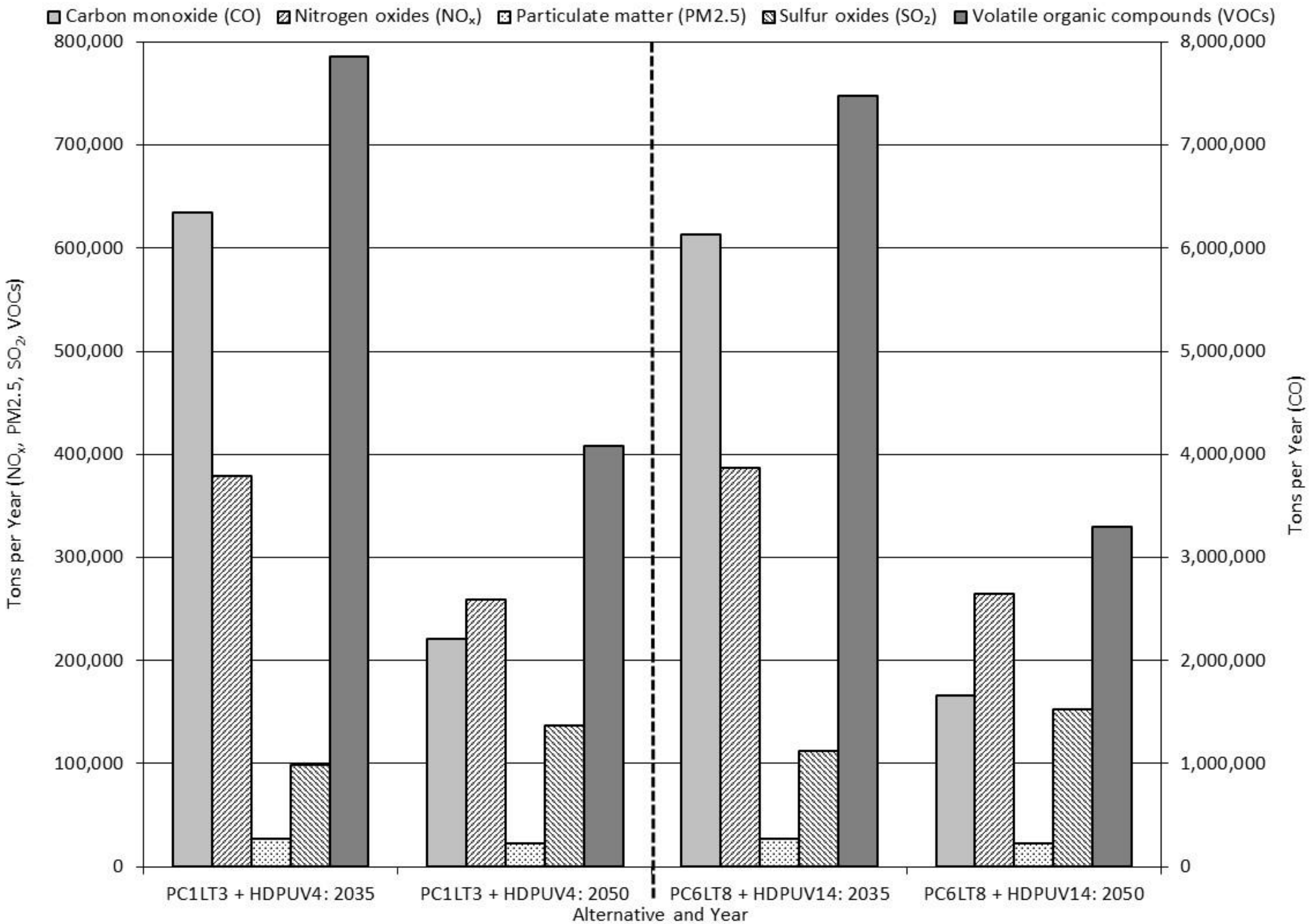


Table 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by Emissions Component and CAFE and HDPUV FE Alternative Combination, Cumulative Impacts

Emissions Component	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Carbon monoxide (CO)				
Passenger cars tailpipe	2,056,457	2,046,328	2,049,142	2,006,512
Passenger cars upstream	24,305	24,504	24,435	25,778
Light-duty trucks tailpipe	3,713,889	3,694,404	3,676,015	3,517,890
Light-duty trucks upstream	55,171	55,892	56,431	62,767
Heavy-duty trucks and vans tailpipe	510,701	510,671	510,052	507,214
Heavy-duty trucks and vans upstream	10,532	10,535	10,594	10,838
Total	6,371,057	6,342,334	6,326,669	6,130,999
Nitrogen oxides (NO_x)				
Passenger cars tailpipe	39,052	38,839	38,888	37,927
Passenger cars upstream	46,019	46,281	46,167	48,152
Light-duty trucks tailpipe	90,367	89,970	89,590	86,241
Light-duty trucks upstream	107,390	108,452	109,223	118,518
Heavy-duty trucks and vans tailpipe	74,950	74,948	74,930	74,824
Heavy-duty trucks and vans upstream	20,257	20,261	20,349	20,707
Total	378,036	378,751	379,146	386,369
Particulate matter (PM2.5)				
Passenger cars tailpipe	3,357	3,328	3,333	3,200
Passenger cars upstream	3,372	3,399	3,390	3,570
Light-duty trucks tailpipe	7,487	7,427	7,372	6,930
Light-duty trucks upstream	7,660	7,757	7,829	8,680
Heavy-duty trucks and vans tailpipe	3,350	3,350	3,344	3,319
Heavy-duty trucks and vans upstream	1,455	1,456	1,464	1,496
Total	26,681	26,716	26,732	27,195
Sulfur oxides (SO_2)				
Passenger cars tailpipe	1,320	1,299	1,299	1,214
Passenger cars upstream	25,865	26,233	26,138	28,326
Light-duty trucks tailpipe	3,865	3,818	3,777	3,355
Light-duty trucks upstream	54,539	55,717	56,631	67,032
Heavy-duty trucks and vans tailpipe	707	707	703	689
Heavy-duty trucks and vans upstream	10,972	10,976	11,071	11,460
Total	97,268	98,750	99,620	112,076
Volatile organic compounds (VOCs)				
Passenger cars tailpipe	170,161	169,586	169,805	167,609
Passenger cars upstream	68,777	67,814	67,831	64,207
Light-duty trucks tailpipe	259,652	258,583	257,543	248,153
Light-duty trucks upstream	196,354	194,369	192,563	174,625
Heavy-duty trucks and vans tailpipe	64,050	64,043	63,878	63,159
Heavy-duty trucks and vans upstream	31,124	31,118	30,966	30,341
Total	790,119	785,512	782,584	748,094

Table 4.2.2-2 shows that, cumulative across the three vehicle classes, tailpipe emissions in 2035 of CO, NO_X, PM2.5, SO_2, and VOC decrease under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives.[41] The decreases get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14. These decreases suggest that declines in tailpipe emissions rates (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline, and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). 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.

Table 4.2.2-2 shows that, cumulative across the three vehicle classes, upstream emissions of CO, NO_X, PM2.5, and SO_2 increase under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives, while VOC emissions decrease. The changes in emissions get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14. The increases in CO, NO_X, PM2.5, and SO_2 emissions reflect the projected increase in EV use, 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 over time. Table 4.2.2-3 lists the net changes in nationwide criteria pollutant emissions for each CAFE and HDPUV FE alternative combination for each criteria pollutant and analysis year compared to the No-Action Alternatives in the same year. Figure 4.2.2-1 shows these changes in percentages for 2035.

- In 2035, emissions of NO_X, PM2.5, and SO_2 do not increase substantially under any of the CAFE and HDPUV FE standard action alternative combinations. Further, modeled increases are very small relative to reductions from the historical levels represented in the current CAFE and HDPUV FE standards. Relative to the No-Action Alternatives, the modeling results suggest NO_X, PM2.5, and SO_2 emissions increases in 2035 that get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14 (the combination of the most stringent CAFE and HDPUV FE standard alternatives). The increases in NO_X, PM2.5, and 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. For CO and VOCs, the emissions decreases in 2035 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14, relative to the No-Action Alternatives.
- In 2050, emissions of NO_X decrease under Alternatives PC1LT3 and HDPUV4 and Alternatives PC2LT4 and HDPUV10 but marginally increase under Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives. Emissions of SO_2 decrease under Alternatives PC1LT3 and HDPUV4 but increase under Alternatives PC2LT4 and HDPUV10 and Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives. In 2050, as in 2035, the increases in NO_X and 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. Emissions of CO, PM2.5, and VOCs

[41] No-Action Alternatives (plural) refers to the CAFE No-Action Alternative and the HDPUV No-Action Alternative combined into a single dataset.

decrease under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives, and the decreases get larger from Alternatives PC1LT3 and HDPUV4 through Alternatives PC6LT8 and HDPUV14 for CO and VOCs, while the decreases for PM2.5 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10, and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14, compared to the No-Action Alternatives.

Table 4.2.2-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts [a]

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Carbon monoxide (CO)				
2035	0	-28,722	-44,388	-240,057
2050	0	-16,680	-69,730	-561,472
Nitrogen oxides (NO_X)				
2035	0	716	1,111	8,334
2050	0	-601	-578	5,320
Particulate matter (PM2.5)				
2035	0	35	51	514
2050	0	-73	-140	-209
Sulfur oxides (SO_2)				
2035	0	1,481	2,352	14,807
2050	0	-210	1,022	15,392
Volatile organic compounds (VOCs)				
2035	0	-4,607	-7,535	-42,025
2050	0	-2,246	-10,341	-79,801

Notes:
[a] Changes for the No-Action Alternatives are shown as zero because the combination of the CAFE No-Action Alternative and the HDPUV No-Action Alternative is the baseline to which the CAFE and HDPUV FE alternative combinations are compared.

Under each CAFE and HDPUV FE alternative combination compared to the No-Action Alternatives, the largest relative increases in emissions among the criteria pollutants would occur for SO_2, for which emissions would increase by as much as 15.2 percent under Alternatives PC6LT8 and HDPUV14 in 2035 compared to the No-Action Alternatives. The largest relative decreases in emissions would occur for CO, for which emissions would decrease by as much as 25.2 percent under Alternatives PC6LT8 and HDPUV14 in 2050 compared to the No-Action Alternatives (Table 4.2.2-3). Percentage increases and decreases in emissions of NO_X and PM2.5 would be less.

The differences in national emissions of criteria air pollutants among the CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives would range from less than 1 percent to about 25 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.

Nonattainment Areas

Table 4.2.2-4 summarizes the criteria air pollutant analysis results by nonattainment area.[42] For each pollutant, Table 4.2.2-4 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur. Appendix D, *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 D indicates that for CO, NO_X, PM2.5, and SO_2 in 2035, the majority of nonattainment areas would experience decreases in emissions across all CAFE and HDPUV FE alternative combinations, compared to the No-Action Alternatives. For CO, NO_X, PM2.5, and SO_2 in 2050, under Alternatives PC1LT3 and HDPUV4, all nonattainment areas would experience decreases in emissions, while under Alternatives PC2LT4 and HDPUV10 and Alternatives PC6LT8 and HDPUV14, the majority of nonattainment areas would experience decreases in emissions, compared to the No-Action Alternatives. For VOCs, across all CAFE and HDPUV FE alternative combinations, all nonattainment areas would experience decreases in emissions in 2035 and 2050, compared to the No-Action Alternatives.

Table 4.2.2-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs, Across All Nonattainment or Maintenance Areas, CAFE and HDPUV FE Alternative Combinations, and Years, Cumulative Impacts

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Carbon monoxide (CO)	Maximum increase	212	2050	PC6LT8 + HDPUV14	Archuleta County; Pagosa Springs, CO [PM10 (1987 24-hour)]
	Maximum decrease	-25,934	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin, CA [NO_2 (1971 Annual)]
Nitrogen oxides (NO_X)	Maximum increase	715	2035	PC6LT8 + HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
	Maximum decrease	-278	2050	PC6LT8 + HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]
Particulate matter (PM2.5)	Maximum increase	167	2050	PC6LT8 + HDPUV14	Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE [Ozone (2015 8-hour)]
	Maximum decrease	-46	2050	PC6LT8 + HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]
Sulfur oxides (SO_2)	Maximum increase	2,342	2050	PC6LT8 + HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-29	2050	PC1LT3 + HDPUV4	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Volatile organic compounds (VOCs)	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-3,265	2050	PC6LT8 + HDPUV14	New York-N. New Jersey-Long Island, NY-NJ-CT [PM2.5 (2006 24-hour)]

[42] In the *Nonattainment Areas* subsections of Section 4.2.1.1, *CAFE Standards,* Section 4.2.1.2, *HDPUV FE Standards*, and Section 4.2.2.1, *Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards*, the term *nonattainment* refers to both nonattainment areas and maintenance areas.

Each nonattainment area implements emissions controls and other requirements, in accordance with its SIP, that aim to reduce emissions so 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 a CAFE and HDPUV FE alternative combination, the increase would represent a slight decrease in the rate of reduction projected in the SIP.

Toxic Air Pollutants

Emissions Levels

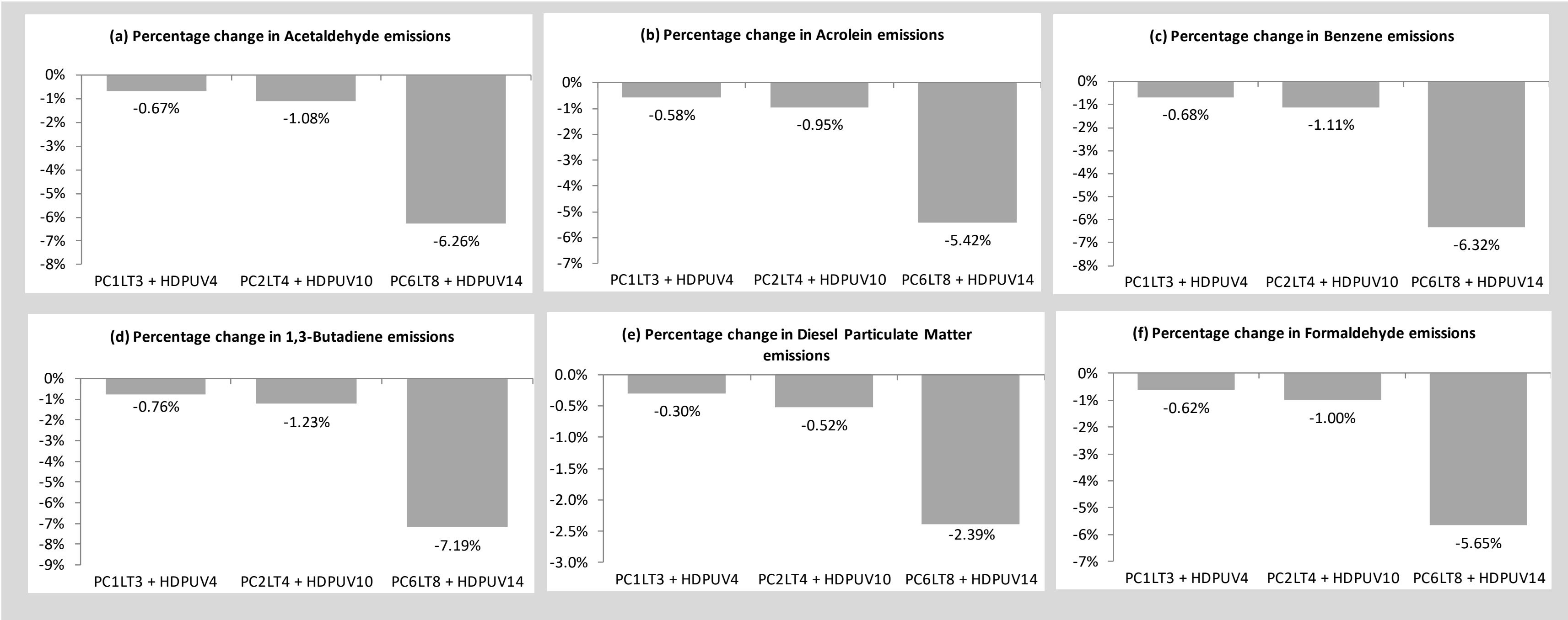
Table 4.2.2-5 summarizes the total upstream and downstream[43] emissions of toxic air pollutants by CAFE and HDPUV FE alternative combination for each of the toxic air pollutants and analysis years. Figure 4.2.2-4 compares the percentage differences in toxic air pollutant emissions for each CAFE and HDPUV FE alternative combination in 2035.

Table 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Acetaldehyde				
2035	2,379	2,363	2,353	2,230
2050	881	876	850	638
Acrolein				
2035	180	179	178	170
2050	60	60	58	44
Benzene				
2035	8,487	8,430	8,393	7,951
2050	3,687	3,666	3,567	2,750
1,3-Butadiene				
2035	859	852	848	797
2050	342	340	330	244
Diesel particulate matter (DPM)				
2035	40,609	40,488	40,398	39,637
2050	33,354	33,280	33,073	31,810
Formaldehyde				
2035	2,192	2,179	2,170	2,069
2050	751	748	726	546

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

Figure 4.2.2-4. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs for 2035 by CAFE and HDPUV FE Alternative Combination Compared to the No-Action Alternatives, Cumulative Impacts



Notes:

The vertical (percentage) scale differs by pollutant.

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

Figure 4.2.2-5 summarizes the changes over time in total national emissions of toxic air pollutants under Alternatives PC1LT3 and HDPUV4 (the least stringent and highest fuel-use CAFE and HDPUV FE standard action alternatives) and Alternatives PC6LT8 and HDPUV14 (the most stringent and lowest fuel-use CAFE and HDPUV FE standard action alternatives) to show the highest and lowest ends of the range of cumulative emissions impacts over time across action alternatives. This figure indicates a consistent time trend among the toxic air pollutants, where emissions decrease from 2035 to 2050 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.[44]

Total toxic pollutant emissions consist of six components: two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the rule (passenger cars, light trucks, and HDPUVs). Table 4.2.2-6 shows the total emissions of air toxic pollutants by component for calendar year 2035, indicating that tailpipe emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde, cumulative across the three vehicle classes, decrease under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives, suggesting that declines in tailpipe emissions rates (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline, and that these decreases are greater than the tailpipe emissions increases due to the rebound effect (from greater VMT resulting from greater vehicle fuel economy). Tailpipe DPM emissions in 2035 stay the same or increase under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives. Upstream emissions of all toxic pollutants, cumulative across the three vehicle classes, decrease or remain the same under all CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives. 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.

Table 4.2.2-7 lists the net change in nationwide emissions for each of the toxic air pollutants and analysis years under the CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives in the same year. Figure 4.2.2-4 shows these changes in percentages for 2035. Toxic air pollutant emissions across the CAFE and HDPUV FE alternative combinations remain the same or decrease in 2035 and 2050 relative to the No-Action Alternatives for the same reasons as for criteria pollutants. The decreases in 2035 get smaller from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10 and then larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14; the decreases in 2050 get larger from Alternatives PC1LT3 and HDPUV4 through Alternatives PC6LT8 and HDPUV14.

The largest relative decreases in emissions generally would occur for acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde for which emissions would decrease by as much as 29 percent under Alternatives PC6LT8 and HDPUV14 in 2050, compared to the No-Action Alternatives (Table 4.2.2-7). Percentage decreases in emissions of 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 CAFE and HDPUV FE requirements.

[44] Continued growth in VMT is projected to occur under all alternatives until 2046; a slight decline is projected to occur from 2047 to 2050.

Figure 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs under Alternatives PC1LT3 + HDPUV4 and Alternatives PC6LT8 + HDPUV14, Providing the Lowest and Highest Range in Cumulative Impacts

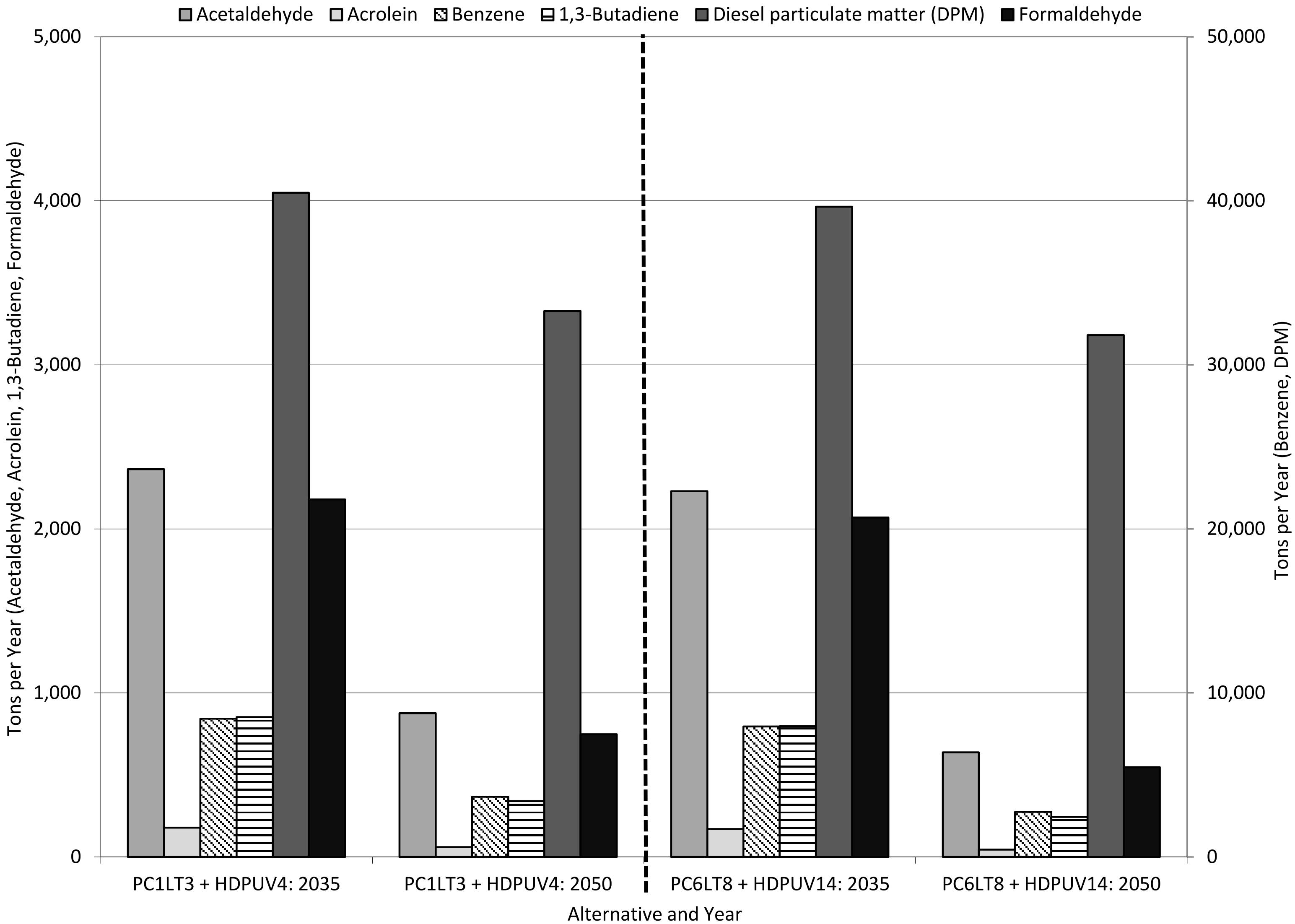


Table 4.2.2-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs, by Emissions Component and CAFE and HDPUV FE Alternative Combination, Cumulative Impacts [a]

Emissions Component	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Acetaldehyde				
Passenger cars tailpipe	576	571	572	545
Passenger cars upstream	13	13	13	12
Light-duty trucks tailpipe	1,216	1,206	1,196	1,107
Light-duty trucks upstream	39	38	38	34
Heavy-duty trucks and vans tailpipe	527	527	526	524
Heavy-duty trucks and vans upstream	8	8	8	8
Total	2,379	2,363	2,353	2,230
Acrolein				
Passenger cars tailpipe	38	37	37	36
Passenger cars upstream	2	2	2	2
Light-duty trucks tailpipe	79	78	78	72
Light-duty trucks upstream	5	5	5	4
Heavy-duty trucks and vans tailpipe	56	56	55	55
Heavy-duty trucks and vans upstream	1	1	1	1
Total	180	179	178	170
Benzene				
Passenger cars tailpipe	2,177	2,161	2,164	2,087
Passenger cars upstream	225	221	221	207
Light-duty trucks tailpipe	4,199	4,170	4,140	3,874
Light-duty trucks upstream	657	649	642	570
Heavy-duty trucks and vans tailpipe	1,128	1,128	1,125	1,115
Heavy-duty trucks and vans upstream	101	101	101	98
Total	8,487	8,430	8,393	7,951
1,3-Butadiene				
Passenger cars tailpipe	238	236	236	225
Passenger cars upstream	0	0	0	0
Light-duty trucks tailpipe	501	497	493	455
Light-duty trucks upstream	1	1	1	1
Heavy-duty trucks and vans tailpipe	118	118	118	117
Heavy-duty trucks and vans upstream	0	0	0	0
Total	859	852	848	797
Diesel particulate matter (DPM)				
Passenger cars tailpipe	8	8	8	8
Passenger cars upstream	9,514	9,460	9,452	9,334
Light-duty trucks tailpipe	31	31	31	31
Light-duty trucks upstream	25,083	25,016	24,939	24,312

Emissions Component	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Heavy-duty trucks and vans tailpipe	1,595	1,595	1,595	1,597
Heavy-duty trucks and vans upstream	4,378	4,378	4,373	4,355
Total	40,609	40,488	40,398	39,637
Formaldehyde				
Passenger cars tailpipe	366	362	363	349
Passenger cars upstream	94	93	93	86
Light-duty trucks tailpipe	761	756	750	702
Light-duty trucks upstream	276	272	269	239
Heavy-duty trucks and vans tailpipe	639	639	639	637
Heavy-duty trucks and vans upstream	56	56	56	55
Total	2,192	2,179	2,170	2,069

Note:

[a] Impacts have been rounded to the nearest whole number.

Table 4.2.2-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts [a,b]

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Acetaldehyde				
2035	0	-16	-26	-149
2050	0	-5	-31	-243
Acrolein				
2035	0	-1	-2	-10
2050	0	0	-2	-16
1,3-Butadiene				
2035	0	-58	-94	-536
2050	0	-21	-120	-937
Benzene				
2035	0	-7	-11	-62
2050	0	-2	-12	-98
Diesel particulate matter (DPM)				
2035	0	-121	-211	-972
2050	0	-74	-280	-1,544
Formaldehyde				
2035	0	-14	-22	-124
2050	0	-4	-26	-205

Notes:

[a] Changes for the No-Action Alternatives are shown as zero because the combination of the CAFE No-Action Alternative and the HDPUV No-Action Alternative is the baseline to which the CAFE and HDPUV FE action alternatives are compared.

[b] Impacts have been rounded to the nearest whole number.

The differences in national emissions of toxic air pollutants among the CAFE and HDPUV FE alternative combinations compared to the No-Action Alternatives would range from less than 1 percent to almost 29 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.

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 designated nonattainment for criteria pollutants. For each pollutant, Table 4.2.2-8 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur.[45] Appendix D, *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 2035 and 2050, emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde would decrease under all CAFE and HDPUV FE alternative combinations in all nonattainment areas compared to the No-Action Alternatives. For DPM in 2035, emissions would decrease in the majority of nonattainment areas compared to the No-Action Alternatives. For DPM in 2050, emissions would decrease in all nonattainment areas compared to the No-Action Alternatives.

Table 4.2.2-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs across All Nonattainment or Maintenance Areas, CAFE and HDPUV FE Alternative Combinations, and Years, Cumulative Impacts

Air Toxic	Maximum Increase/ Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-11	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
Acrolein	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-0.7	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]

[45] 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	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Benzene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-37	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
1,3-Butadiene	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-4	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
Diesel particulate matter (DPM)	Maximum increase	0.02	2035	PC6LT8 + HDPUV14	Phoenix, AZ [CO (1971 8-hour); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]
	Maximum decrease	-213	2050	PC6LT8 + HDPUV14	Houston-Galveston-Brazoria, TX [Ozone (2008 and 2015 8-hour)]
Formaldehyde	Maximum increase	0	No increases are predicted for any years or alternatives		
	Maximum decrease	-7	2050	PC6LT8 + HDPUV14	Los Angeles-South Coast Air Basin Area, CA [CO (1971 8-hour); NO_2 (1971 Annual); PM2.5 (2006 24-hour; 2012 Annual); PM10 (1987 24-hour); Ozone (2008 and 2015 8-hour)]

Health Impacts

Adverse health impacts from criteria pollutant emissions are expected to remain the same or decrease nationwide in 2035 and 2050 under all CAFE and HDPUV FE alternative combinations. This is due to decreases in the downstream emissions of NO_X, SO_2, and particularly PM2.5 in these years under each alternative combination relative to the No-Action Alternatives. As discussed in Section 4.1.2.6, *Health Impacts*, the health impacts per ton of emissions are substantially larger for downstream emissions than upstream emissions, and substantially larger for PM2.5 emissions than NO_X and SO_2 emissions. Though there are increases in upstream emissions for some years and alternative combinations, and though the PM2.5 emissions changes sometimes are smaller than the emissions changes for NO_X and SO_2, the decreases in downstream emissions, particularly for PM2.5, lead to decreases (or no changes) in adverse health impacts. The decreases in impacts from downstream PM2.5 emissions are larger than the increases in impacts from upstream emissions.

The improvements to health impacts (or decreases in health incidences) in 2035 would get smaller or stay the same from Alternatives PC1LT3 and HDPUV4 to Alternatives PC2LT4 and HDPUV10 and then get larger from Alternatives PC2LT4 and HDPUV10 to Alternatives PC6LT8 and HDPUV14; in 2050, the improvements would get larger from Alternatives PC1LT3 and HDPUV4 to Alternatives PC6LT8 and HDPUV14. These improvements reflect the generally increasing stringency of the CAFE and HDPUV FE standard action alternatives as they become implemented. As discussed in Appendix C, Section C.5.7, *Health Impacts*, the values in Table 4.2.2-9 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. As discussed in Appendix C, Section C.5.7, *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 2013b).

Under any CAFE and HDPUV FE alternative combination, total emissions from passenger cars, LD trucks, and HDPUVs are expected to decrease over time compared to existing (2022) 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 CAFE and HDPUV FE alternative combination the total health effects of emissions from passenger cars, LD trucks, and HDPUVs are expected to decrease over time compared to existing conditions.

Table 4.2.2-9. Nationwide Changes in Health Impacts (cases per year) from Criteria Pollutant Emissions from U.S. Combined Passenger Cars, Light Trucks, and HDPUVs by CAFE and HDPUV FE Alternative Combination, Cumulative Impacts [a,b,c]

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Premature mortality (Krewski et al. 2009)				
2035	0	-4	-7	-28
2050	0	-7	-22	-119
Emergency room visits: respiratory				
2035	0	-3	-6	-27
2050	0	-4	-14	-80
Acute bronchitis				
2035	0	-8	-15	-69
2050	0	-10	-35	-207
Lower respiratory symptoms				
2035	0	-107	-183	-869
2050	0	-129	-446	-2,622
Upper respiratory symptoms				
2035	0	-156	-267	-1,273
2050	0	-183	-637	-3,768
Minor restricted activity days				
2035	0	-5,374	-9,107	-45,054
2050	0	-5,403	-19,707	-120,890

Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Work-loss days				
2035	0	-903	-1,529	-7,541
2050	0	-921	-3,336	-20,415
Asthma exacerbation				
2035	0	-185	-315	-1,505
2050	0	-215	-750	-4,444
Hospital admissions: cardiovascular				
2035	0	-1	-2	-7
2050	0	-2	-6	-31
Hospital admissions: respiratory				
2035	0	-1	-2	-6
2050	0	-2	-6	-29
Non-fatal heart attacks (Peters et al. 2001)				
2035	0	-4	-7	-29
2050	0	-7	-23	-124
Non-fatal heart attacks (All others)				
2035	0	0	-1	-3
2050	0	-1	-2	-13

Notes:

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

[b] Changes for the No-Action Alternatives are shown as zero because the combination of the CAFE No-Action Alternative and the HDPUV No-Action Alternative is the baseline to which the action alternatives are compared.

[c] Impacts have been rounded to the nearest whole number.

4.2.2.2 Other Past, Present, and Reasonably Foreseeable Future Actions

As discussed in Appendix C, Section C.4, *Vehicle Emissions Standards,* aggregate emissions associated with vehicles have decreased substantially since 1970, even as VMT has nearly doubled (Davis and Boundy 2022; EPA 2021c). The primary actions that have resulted in tailpipe 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) because 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 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 SIPs.

In January 2023, EPA issued more stringent standards for tailpipe emissions from HD engines and vehicles.[46] The new emissions standards will take effect for MY 2027 HD vehicles, will cover a wider range of HD engine operating conditions compared to today's standards, and will require the new emissions standards to be met for a longer period of the operational life of HD engines than under current standards. EPA has projected that in 2045 the new standards will reduce NO_X emissions from HD engines by 48 percent, PM2.5 by 8 percent, VOC by 23 percent, and CO by 18 percent, and will also reduce associated emissions of toxic air pollutants.

Growth in VMT is expected to continue. FHWA (2022) has projected that between 2019 and 2049, VMT by LD vehicles will increase by 17 percent, VMT by single-unit trucks will increase by 101 percent, and VMT by combination trucks will increase by 57 percent, for an overall increase of 22 percent. LD vehicles account for 90 percent of total VMT and, thus, are the major influence on overall VMT growth, while single-unit trucks and combination trucks account for 4 percent and 5 percent of VMT, respectively. As discussed above, tailpipe emissions from passenger cars, light trucks, and HDPUVs combined are expected to generally decrease with time through 2050 under the Proposed Action and alternatives.

In addition to changes in VMT and emissions, climate change is expected to influence air quality and associated health effects. For example, Fann et al. (2021) modeled projected changes in climate and emissions, the resulting concentrations of ozone and PM2.5, and associated mortality through 2095. The amount of mortality attributable to air pollution was predicted to increase substantially due to climate change. The increases in mortality attributable to air pollution associated with climate change were projected to decline if air pollutant emissions were reduced.

As discussed in Chapter 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.

Overall emissions of any specific criteria or 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 LD 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,[47] would affect the size of these emissions changes.

[46] Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards; Final Rule, 88 FR 4296 (Jan. 24, 2023).

[47] 43 CFR Parts 3160 and 3170.

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 electricity 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 in favor of renewable energy sources from fossil fuels. Continuation of either of these economic trends likely would lead to lower total emissions from EV charging. However, recent National Renewable Energy Laboratory (NREL) modeling suggests that implementation of the Inflation Reduction Act of 2022 (IRA) and the Infrastructure Investment and Jobs Act of 2021 (known as the Bipartisan Infrastructure Law [BIL]) would increase the total share of clean electricity sources to around 80 percent of total generation by 2030, up from around 50 percent in a case without the IRA and BIL (NREL 2023).

There also have been efforts across the country to improve the efficiency of grids and charging infrastructure. As these technologies improve, they can help minimize emissions and grid impacts as EVs comprise a larger share of total vehicles. The increase in clean electricity sources under the IRA and BIL, and grid efficiency efforts, are estimated to reduce NO_X and SO_2 emissions from the energy sector by about 60 percent from 2022 to 2030. Lower NO_X and SO_2 emissions also mean reduced PM formation, such that 4,200–18,000 premature deaths in total (depending on which study is used) will be avoided in the 2023–2030 period (NREL 2023). To the extent that these trends do not come to pass, these benefits would not be realized.

The Energy Information Administration's Annual Energy Outlook forecasts of power generation used in the CAFE Model account for existing legislation and other regulatory actions that affect power plant emissions. To the extent that these requirements may be amended in future years when the EV percentage of LD 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 bring nonattainment areas into attainment. To the extent that the trend toward more stringent emissions standards could change in the future, total nationwide emissions from vehicles and industrial processes could change accordingly.

Cumulative changes in health impacts due to air pollution are expected to be consistent with trends in emissions and population exposure. Higher emissions in a geographic area would be expected to lead to an increase in overall health impacts in that area, while lower emissions would be expected to lead to a decrease in health impacts in that area, compared to conditions in the absence of cumulative impacts. Population distribution varies geographically, and as a result, a given amount of emissions would have greater health impacts in an area with greater population than in an area with less population. The level of population exposure in an area also is affected by the meteorological and topographical conditions in that area because these factors affect the dispersion and transport of emissions in the atmosphere. In addition, populations living or working near roadways could experience relatively greater exposure to tailpipe emissions, while populations living or working near upstream facilities (e.g., refineries) could experience relatively greater exposure to upstream emissions. An individual geographic area could experience either an increase or decrease in cumulative impacts under the proposed CAFE and HDPUV FE standards, depending on the relative magnitudes of effects from tailpipe versus upstream emissions that would affect that area.

CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This chapter 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 EIS, 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 direct and indirect effects 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) separately for the two components of NHTSA's Proposed Action: CAFE standards and heavy-duty pickup truck and van (HDPUV) fuel efficiency (FE) standards. For purposes of this analysis, the CAFE standards are assumed to remain in place for MY 2032 and beyond passenger cars and light trucks at the level of the MY 2032 CAFE standards set forth by the agency. Similarly, this analysis assumes that the HDPUV FE standards will remain in place for MY 2035 and beyond HDPUVs at the level of the MY 2035 FE standard set forth by NHTSA. This chapter presents results through 2100.

The cumulative impacts of the Proposed Action are discussed in detail in Section 5.4.2, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*. This section 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 and HDPUV 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 EIS draws primarily on panel-reviewed synthesis and assessment reports from the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Global Change Research Program (GCRP), supplemented with past reports from the U.S. Climate Change Science Program (CCSP), the National Research Council (NRC), and the Arctic Council. It also cites EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act* (EPA 2009), which relied heavily on past major international or national scientific assessment reports. NHTSA relies on assessment reports because these reports assess numerous individual studies to draw general conclusions about the state of climate science and potential impacts of climate change, as summarized or found in peer-reviewed reports. U.S. government agencies and individual government scientists review and formally accept, commission, or in some cases author these reports. In many cases, these reports 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, uncertainty still exists, as with all assessments of environmental impacts. See Appendix E, *Greenhouse Gas Emissions and Climate*

[1] On January 9, 2023, CEQ published interim guidance for assessing greenhouse gas (GHG) emissions and climate change impacts in documents prepared for compliance with NEPA. National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change; Notice of Interim Guidance; Request for Comments, 88 FR 1196 (Jan. 9, 2023). The interim guidance advises "agencies that the 'rule of reason' inherent in NEPA and the CEQ [r]egulations should guide agencies in determining, based on their expertise and experience, how to consider an environmental effect and prepare an analysis based on the available information." *Id.* at 1198.

Change, Section E.1.1, *Uncertainty in the IPCC Framework*, for a detailed discussion 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 EIS additionally draws on peer-reviewed literature that has been published since the release of the latest IPCC and 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 EIS, as well as NHTSA's consideration of other studies that demonstrate the potential impacts of climate change on health, society, and the environment, are provided to help inform the public and 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 heavy-duty (HD) standards, MY 2017–2025 CAFE standards, Phase 2 HD standards, SAFE Vehicles MY 2021–2026 Rule, and the Final Supplemental MY 2024–2026 CAFE standards EIS.[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 evaluate 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 EIS, NHTSA uses the system developed by IPCC to describe uncertainty associated with various climate change impacts.

To reflect the likelihood of climate change impacts accurately for each sector, NHTSA references and uses the IPCC uncertainty guidelines (IPCC 2021a). IPCC notes two primary uncertainties with climate modeling: (1) *model uncertainties*, which occur when a climate model might not accurately represent complex phenomena in the climate system, and (2) *scenario uncertainties*, which arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings. These types of uncertainties are described by using two metrics for communicating the degree of certainty—the confidence in the validity of findings (expressed qualitatively) and quantified measures of uncertainties (expressed probabilistically). This approach provides a consistent method to define confidence levels

[2] Working Group reports of IPCC's Sixth Assessment Report were released in 2021 and 2022. This EIS 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 Technical Support Document. 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 1502.21.

and percent probability of a projected outcome or impact and was applied to key IPCC and GCRP findings where IPCC or GCRP has defined the associated uncertainty with the finding. For a more detailed discussion on this topic See Appendix E, Section E.1.1, *Uncertainty in the IPCC Framework.*

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 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 climate 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).

IPCC's *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 WGI AR6) identified the following drivers of climate change: GHGs, aerosols, clouds, ozone, solar radiation and surface changes (e.g., changes in vegetation, snow or ice cover, ocean color) (IPCC 2021b). For a more detailed discussion on drivers of climate change, see Appendix E, Section E.1.2, *Climate Change and Its Causes.*

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 2021a; GCRP 2017).

This section briefly discusses trends in 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. For a more detailed discussion on these topics, see Appendix E, Section E.2, *Greenhouse Gas Emissions and Aerosols—Historical and Current Trends*, and Section E.3*, Climate Change Trends.*

5.2.1 Greenhouse Gas Emissions and Aerosols—Historical and Current Trends

GHGs are gaseous constituents in the atmosphere, both natural and anthropogenic, that absorb and re-emit terrestrial infrared radiation. Primary GHGs in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone. GHGs are emitted from a wide variety of sectors, including energy, industrial processes, waste, agriculture, and forestry. In general, global GHG emissions continue to increase, although annual increases vary according to factors such as weather, energy prices, and economics. 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 (World Resources Institute [WRI] 2023). For a detailed discussion of global trends in GHG emissions, see Appendix E, Section E.2.1, *Global Greenhouse Gas Emissions.* For U.S. trends, see Section E.2.2, *U.S. Greenhouse Gas Emissions.*

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 2021b; CCSP 2009). 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. For more details on aerosols and their impacts, see Appendix E, Section E.2.3, *Black Carbon and Other Aerosols.*

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 2021b). 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.

At continental and global scales, significant trends have been observed over the 20th century. 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; cold-dependent habitats are shifting to higher altitudes and latitudes; sea level is rising and oceans are becoming more acidic because of increasing absorption of CO_2 by seawater; more frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (IPCC 2021b; GCRP 2017). If emissions from both developed and developing countries are not reduced dramatically in the coming decades, the elevation in atmospheric CO_2 concentrations is likely to persist for many centuries, with the potential for temperature anomalies continuing much longer (IPCC 2021b). For a more detailed discussion of trends in key climate change attributes (temperature, precipitation, sea-level rise, and ocean pH), see Appendix E, Section E.3, *Climate Change Trends.*

5.3 Analysis Methods

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

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

gas. By multiplying the emissions reductions of each gas by estimates of their social cost, NHTSA derived a monetized estimate of the benefits associated with the emissions reductions projected under each action alternative. NHTSA has estimated the monetized benefits associated with GHG emissions reductions in its Preliminary Regulatory Impact Analysis (PRIA), Chapter 8.2.4.1. 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.[5] NHTSA translated the changes in GHG emissions associated with each action alternative to changes in temperature, precipitation, sea level, and ocean pH in relation to projections of these climatic parameters under the No-Action Alternative.

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

NHTSA's analysis of the impacts of the proposed rule on GHG emissions involved modeling emissions resulting from both the proposed CAFE standard action alternatives and the proposed HDPUV FE standard action alternatives. NHTSA then generated combined alternatives using additive emissions from the separate action alternatives to model the impacts of the proposed rule under a more moderate climate scenario. Under the moderate climate scenario, which assumes worldwide initiatives to reduce emissions, the impacts of CAFE and HDPUV FE standards should be integrated, as their enforcement periods will concurrently intersect, resulting in a cumulative effect. NHTSA determined the set of combined action alternatives by using the low, high, and moderate emissions alternatives from the CAFE and HDPUV set of alternatives.

Comparisons between the relevant No-Action Alternative and each action alternative for the CAFE standards, HDPUV FE standards, and combined standards are presented to illustrate the different environmental impacts of each action 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 relevant 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 between emissions under the relevant No-Action Alternative and emissions under that alternative.

For more information on the methods NHTSA used to characterize the effects of the alternatives on climate, see below and Appendix E, Section E.4, *Analysis Methods*.

5.3.1 Methods for Modeling Greenhouse Gas Emissions

This EIS compares GHG emissions under different alternatives, including a separate No-Action Alternative for light-duty (LD) passenger vehicles, HDPUVs, and the combined CAFE and HDPUV FE alternatives. GHG emissions under each alternative were estimated using the methods described in Chapter 2, Section 2.3, *Standard-Setting and EIS Methods and Assumptions*. For years 2022 through

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

2050, the emissions estimates in this EIS include tailpipe emissions from fuel combustion and upstream emissions from the production and distribution of fuel for LD passenger vehicles and HDPUVs. 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 Chapter 2, Section 2.3.1, *CAFE Model*.

For the climate analysis, GHG emissions trajectories are projected through the year 2100. In order to estimate GHG emissions for the LD and HD fleets for 2051 to 2100, NHTSA extrapolated from the CAFE Model results by applying the projected rate of change in U.S. transportation fuel consumption over this period from the intermediate global climate scenario Shared Socioeconomic Pathway (SSP)2-4.5 used in the analysis.[6,7] For 2051 through 2100, the SSP2-4.5 scenario projects that U.S. road transportation fuel consumption will decline slightly because of assumed improvements in efficiency of internal combustion engine (ICE)-powered vehicles and increased deployment of non-ICE 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.[8] The assumptions and methods used to extrapolate GHG emissions estimates beyond 2050 for this EIS are broadly consistent with those used in the *MY 2011–2015 CAFE Final EIS* (NHTSA 2008), 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 2016b), the *MY 2021–2026 Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Final EIS* (NHTSA 2020), and the Draft and Final *Supplemental Environmental Impact Statement for Model Year 2024–2026 Corporate Average Fuel Economy Standards* (NHTSA 2021, 2022).

The emissions estimates include CO_2, CH_4, and N_2O emissions from both direct fuel combustion and the production and distribution of fuel and electricity (upstream emissions). The MOVES model also estimated non-GHG emissions, both criteria pollutants and air toxics.

Fuel savings from more stringent CAFE and HDPUV FE standards would result in lower overall emissions of CO_2 (the main GHG emitted) because lower fuel consumption and greater fuel efficiency reduce CO_2 emissions. Reduced fuel consumption also lowers CO_2 emissions from fuel production and distribution. However, new CAFE and HDPUV FE standards could also lead to increased CO_2 emissions from processes involved in producing and delivering alternative energy sources, such as electricity generation. For more information, see Appendix E, Section E.4.2, *Methods for Modeling Greenhouse Gas Emissions.*

NHTSA estimated the CO_2 emissions during each phase of fuel and electricity production and distribution using CO_2 emissions rates from the GREET model, including previous assumptions about how fuel savings are reflected in reductions in activity during each phase of fuel production and distribution. The total reduction in CO_2 emissions from improving fuel economy under each alternative is the sum of the reductions in motor vehicle emissions from reduced fuel combustion compared to the relevant No-

[6] More information regarding global emissions scenarios can be found in Appendix E, Section E.4.3.4, *Global Emissions Scenarios*.

[7] 2050 is the last year for which the CAFE Model provides estimates of fleet CO_2 emissions for this analysis.

[8] NHTSA anticipates a larger post-2050 decline in passenger car and light truck energy consumption than what is projected in the SSP3-7.0 scenario due to updated projections around technology availability and adoption, as well as other factors that affect fuel consumption. However, the EIS 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.

Action Alternative plus the reduction in upstream emissions from a lower volume of fuel production and distribution than is projected under the relevant No-Action Alternative (minus the increase in upstream emissions resulting from increased electricity generation).

For more information on the methods NHTSA used for modeling GHG emissions, see Appendix E, Section E.4.2, *Methods for Modeling Greenhouse Gas Emissions*.

5.3.2 Social Cost of Greenhouse Gas Emissions

This EIS 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. Chapters 8.2.4.1 and 8.3.4.1 of the PRIA characterize 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 may consult Section V.D of the preamble to the proposed rule for a description of how the monetized cost-benefit analysis factors into its decision-making process. The proposed rule preamble and PRIA are both available for public review.

5.3.3 Methods for Estimating Climate Effects

This EIS estimates and reports the projected reductions in GHG emissions, particularly CO_2, that would result from the action alternatives for CAFE standards, HDPUV FE standards, and the combined set of alternatives. The reduction in GHG emissions is a direct effect of the increased stringency in fuel economy and fuel efficiency 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. For a more detailed description of the methods NHTSA used to estimate climate effects, see Appendix E, Section E.4.3, *Methods for Estimating Climate Effects*.

5.3.3.1 MAGICC Modeling

To estimate changes in CO_2 concentrations and global mean surface temperature, NHTSA used a reduced-complexity climate model (MAGICC). To estimate changes in global precipitation and sea-level rise, NHTSA used increases in global mean surface temperature combined with an approach and coefficients from IPCC WGI AR6 (IPCC 2021b). NHTSA used publicly available modeling software[9] MAGICC7 (Meinshausen et al. 2020) to estimate changes in key direct and indirect effects, incorporating the estimated reductions in emissions of CO_2, CH_4, N_2O, carbon monoxide (CO), nitrogen oxides, sulfur dioxide, and volatile organic compounds 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 CAFE standard and HDPUV FE standard action alternatives under different assumptions about the sensitivity of climate

[9] MAGICC7, accessible for general use, is distributed under the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) license, which forbids commercial application. NHSTA has entered into a direct agreement with ClimateResource, the creators of MAGICC, to incorporate MAGICC7 modeling in this analysis.

to GHG concentrations in the atmosphere. For more information on the selection of MAGICC for this analysis, please see Appendix E, Section E.4.3.1, *MAGICC Modeling*.

5.3.3.2 Sea-Level Rise

NHTSA estimated the projected changes in global mean sea level based on data from the IPCC WGI AR6 (IPCC 2021b),[10,11] using global mean surface temperature data and projections from 1950 to 2100, global mean sea-level rise data from 1950 to 2019, and projections from 2020 to 2100 under various SSP scenarios. Regression models relating projected changes in sea level to projected changes in temperature are developed for each SSP scenario, using temperature outputs from MAGICC as inputs. The temperature outputs of the MAGICC simulations are used as input to these regression models to project sea-level rise for each SSP scenario.[12]

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 by translating atmospheric CO_2 levels into changes in ocean pH. A lower ocean pH indicates higher ocean acidity, while a higher pH indicates lower acidity.[13] NHTSA used the CO2SYS model to estimate the pH of ocean water in the years 2040, 2060, and 2100 under the relevant No-Action Alternative and each of the CAFE and HDPUV FE standard action alternatives, with total alkalinity and partial pressure of CO_2 selected as inputs for each. The total alkalinity input was held constant at 2,345 micromoles per kilogram of seawater and the projected atmospheric CO_2 concentration (parts per million [ppm]) data was obtained from MAGICC model runs using each action alternative. NHTSA then compared the pH values calculated from each action alternative to the relevant No-Action Alternative to determine the impact of the Proposed Action and alternatives on ocean pH.

5.3.3.4 Global Emissions Scenarios

MAGICC uses long-term emissions scenarios that represent different assumptions about key drivers of GHG emissions. The reference scenario used in the direct and indirect analysis is the SSP3-7.0 scenario, which IPCC describes as a high emissions scenario that assumes no successful, comprehensive global actions to mitigate GHG emissions and yields atmospheric CO_2 levels of 800 ppm and an effective radiative forcing (ERF) of 7.0 watts per square meter (W/m^2) in 2100.[14] IPCC often refers to SSP3-7.0 as a

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[10] Sea-level rise outputs from MAGICC7 were not used because this component of the model is still under development.

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

[12] 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.

[13] 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 2021b).

[14] "Radiative forcing (RF) describes the change in the net downward radiative flux from the top of the atmosphere after allowing for atmospheric temperatures, water vapor and clouds to adjust, but with surface temperature or a portion of surface conditions unchanged. All surface and tropospheric conditions are kept fixed for RF, whereas effective radiative forcing (ERF) allows all physical variables to respond to perturbations, except for those concerning the ocean and sea ice" (IPCC 2021b). The SSP scenarios model ERF, while previous RCP scenarios modeled RF.

high emissions scenario, where CO_2 concentrations increase to 2100, but less rapidly than SSP5-8.5, the most extreme scenario.

NHTSA adjusted the reference datasets to use these SSP scenarios in place of the previous Representative Concentration Pathway (RCP) scenarios, which explore the effects of different emissions trajectories, resulting in various radiative forcing values. However, unlike in SSPs, the socioeconomic characteristics that define RCPs are not standardized, making it difficult to map societal changes.

The impact of each action alternative was simulated by calculating the difference between annual GHG emissions under the relevant No-Action Alternative and emissions under the CAFE or HDPUV FE 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.

The reference scenario used in the cumulative impacts analysis is the SSP2-4.5 scenario, which assumes moderate success of global actions taken to address climate change and yields atmospheric CO_2 levels of 568 ppm and an ERF of approximately 4.5 W/m^2 in the year 2100. IPCC refers to SSP2-4.5 as an intermediate emissions scenario. This scenario was chosen because regional, national, and international initiatives and programs being planned or already underway indicate that a moderate reduction in the growth rate of global GHG emissions is reasonably foreseeable in the future. The methods and assumptions for the cumulative analysis are largely the same as those used in the direct and indirect impacts analysis. For this analysis, NHTSA calculated the difference in annual GHG emissions under the CAFE and HDPUV FE standard action alternatives compared to the relevant No-Action Alternative. To evaluate the sensitivity of the results, NHTSA used the SSP1-2.6 and SSP3-7.0 scenarios. The SSP1-2.6 scenario assumes low challenges to adaptation and mitigation and yields atmospheric CO_2 levels of 437.66 ppm and an ERF of approximately 2.6 W/m^2 in the year 2100.

The modeling runs and sensitivity analysis simulate relative changes in atmospheric CO_2 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 CAFE and HDPUV FE action alternatives compared to projected emissions under the relevant No-Action Alternative. They assume a climate sensitivity of 3 degrees Celsius (°C) (5.4 degrees Fahrenheit [°F]) for a doubling of CO_2 concentrations in the atmosphere. Section 5.4, *Environmental Consequences*, presents the results of the model runs for the alternatives.

The sensitivity analyses examine the relationship between the alternatives, likely climate sensitivities, and scenarios of global emissions paths and the associated direct and indirect impacts for each combination. NHTSA assessed climate sensitivities of 1.9, 3.0, and 4.8°C (3.4, 5.4, and 8.6°F) for a doubling of CO_2 concentrations in the atmosphere and performed the sensitivity analysis around three of the CAFE alternatives—the No-Action Alternative, Alternative PC1LT3, and Alternative PC6LT8, and three of the HDPUV FE alternatives—the No-Action Alternative, Alternative HDPUV4, and Alternative HDPUV14. For the direct and indirect impacts analysis, the sensitivity analysis was performed against the SSP3-7.0 scenario and for the cumulative impact analysis, the sensitivity analysis was performed against the SSP2-4.5, SSP1-2.6, and SSP3-7.0 scenarios.

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: IPCC WGI AR6 (IPCC 2021b) and IPCC WGI AR5 (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* (NCA4) (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 quantifying how reduced emissions from a specific policy or action might affect the probability and timing of abrupt climate change. This area of climate science is one of the most complex and scientifically challenging. Given the difficulty of simulating the large-scale processes involved in these tipping points, or inferring their characteristics from paleoclimatology, considerable uncertainties remain on tipping points and the rate of change. Despite the lack of a precise quantitative methodological approach, NHTSA has provided a qualitative and comparative analysis of tipping points and abrupt climate change in Appendix E, Section E.5.2.11, *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 CAFE and HDPUV FE standard action alternatives relative to the relevant No-Action Alternative. Using the methods described in Section 5.3, *Analysis Methods*, NHTSA modeled the direct, indirect, and cumulative impacts of the alternatives on atmospheric CO_2 concentrations, temperature, precipitation, sea level, and ocean pH.[15]

This section is organized into Section 5.4.1, *Direct and Indirect Impacts on Greenhouse Gas Emissions and Climate Change*, and Section 5.4.2, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*. The analysis of direct and indirect impacts in Section 5.4.1 is based on a scenario under which there are no other major global actions to reduce GHGs. The presentation of direct and indirect impacts is shown for the Proposed Action and alternatives. This analysis assumes that there is some growth in vehicle fuel efficiency in the absence of this rulemaking. The analysis of cumulative impacts in Section 5.4.2 measures the combined impacts of market, regulatory, and policy incentives and electric vehicle (EV) penetration for improving vehicle fuel efficiency and the vehicle fuel efficiency improvements resulting from the Proposed Action and alternatives. Appendix A, *Modeling Results Reported Separately by Vehicle Class*, presents the *Direct and Indirect Impacts* modeling results for passenger vehicles and

[15] 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.

light trucks separately. Appendix A also presents the *Cumulative Impacts* modeling results separately for CAFE and HDPUV FE standard action alternatives.

Each of the CAFE and HDPUV FE standard action alternatives would result in reduced GHG emissions compared with the relevant No-Action Alternative. The more an alternative would decrease GHG emissions, the more it would be expected to decrease the climate change impacts associated with such emissions.

5.4.1 Direct and Indirect Impacts on Greenhouse Gas Emissions and Climate Change

5.4.1.1 Greenhouse Gas Emissions

Using the methods described in Section 5.3, *Analysis Methods*, NHTSA estimated projected emissions reductions under the CAFE and HDPUV FE standard action alternatives for 2027 through 2100. These emissions reductions represent the differences in total annual emissions in future years of U.S. passenger cars and light trucks and HDPUVs in use under the relevant 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, determines 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 global warming potentials 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 5.4.1.2, *Direct and Indirect Impacts on Climate Change Indicators*, and Section 5.4.2.2, *Cumulative Impacts on Climate Change Indicators*), 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 Table 5.4.1-2 (as well as Figure 5.4.1-1 and Figure 5.4.1-2) show total U.S. LD vehicle and HDPUV CO_2 emissions under the relevant No-Action Alternative and emissions reductions that would result from the Proposed Action and alternatives from 2027 to 2100. All action alternatives would result in lower CO_2 emissions than the relevant No-Action Alternative because all action alternatives involve more stringent CAFE and HDPUV FE standards than the No-Action Alternative. U.S. passenger car and light truck emissions from 2027 to 2100 would range from a low of 44,200 million metric tons of carbon dioxide ($MMTCO_2$) under Alternative PC6LT8 to a high of 52,800 $MMTCO_2$ under the CAFE No-Action Alternative. Compared to the No-Action Alternative, projected emissions reductions from 2027 to 2100 under the CAFE action alternatives would range from 300 to 8,600 $MMTCO_2$. HDPUV emissions range from a low of 9,300 $MMTCO_2$ under Alternative HDPUV14 to a high of 9,800 $MMTCO_2$ under the HDPUV No-Action Alternative and projected emissions reductions from 2027 to 2100 range from 100 to 400 $MMTCO_2$. Compared to the SSP3-7.0[16] total global emissions projection of 4,991,547 $MMTCO_2$ over this period, reductions from the CAFE standards would range from approximately 0.01 to 0.17 percent from projected levels. HDPUV FE standards would reduce emissions by a range of approximately less than 0.002 to 0.008 percent from projected levels.

[16] SSP3-7.0 is the reference scenario for the analysis of direct and indirect impacts and represents a high scenario of global emissions.

Table 5.4.1-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All Passenger Cars and Light Trucks, 2027 to 2100, by Alternative [a]

Alternative	Total Emissions	Emissions Reductions Compared to No-Action	Percent (%) Emissions Reductions Compared to No-Action Alternative Emissions
No-Action	52,800	--	--
PC1LT3	52,500	300	0.6%
PC2LT4	51,700	1,100	2.1%
PC3LT5	50,000	2,800	5.3%
PC6LT8	44,200	8,600	16.3%

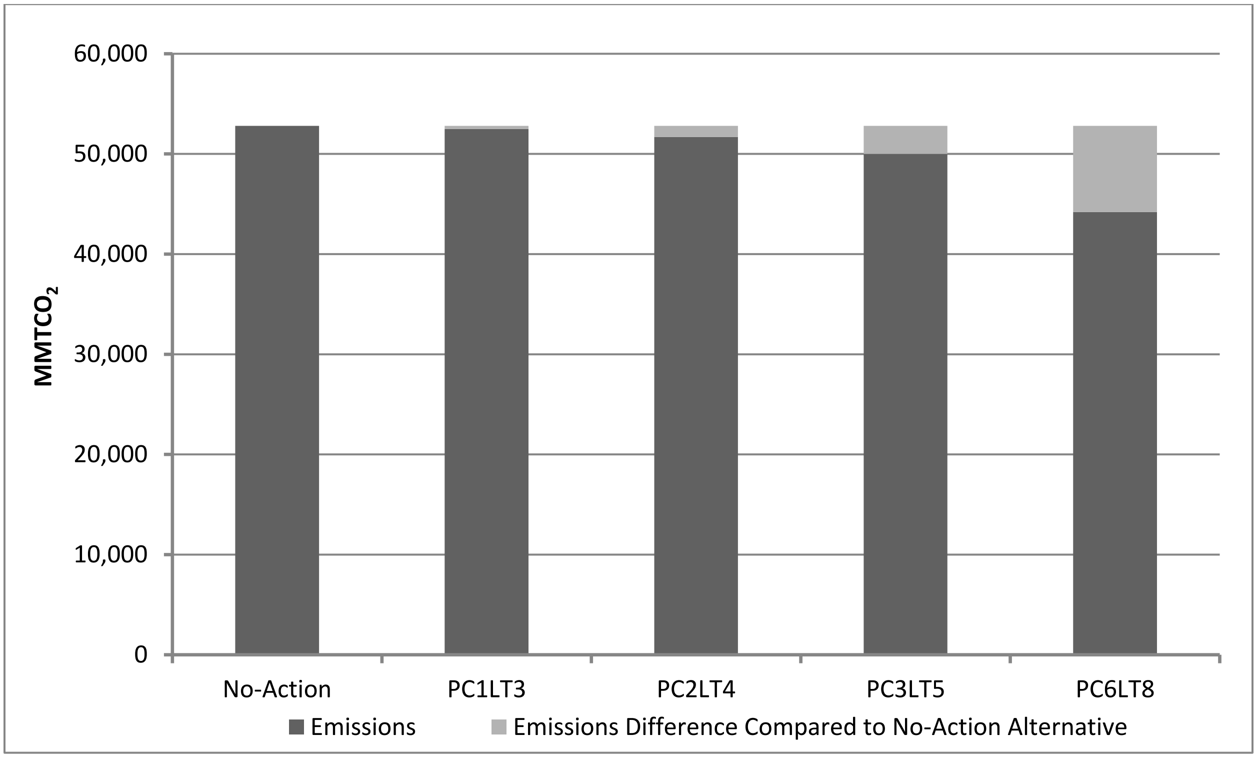
Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.
$MMTCO_2$ = million metric tons of carbon dioxide

Table 5.4.1-2. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All HDPUVs, 2027 to 2100, by Alternative [a]

Alternative	Total Emissions	Emissions Reductions Compared to No-Action	Percent (%) Emissions Reductions Compared to No-Action Alternative Emissions
No-Action	9,800	--	0.0%
HDPUV4	9,800	--	0.0%
HDPUV10	9,600	100	1.0%
HDPUV14	9,300	400	4.1%

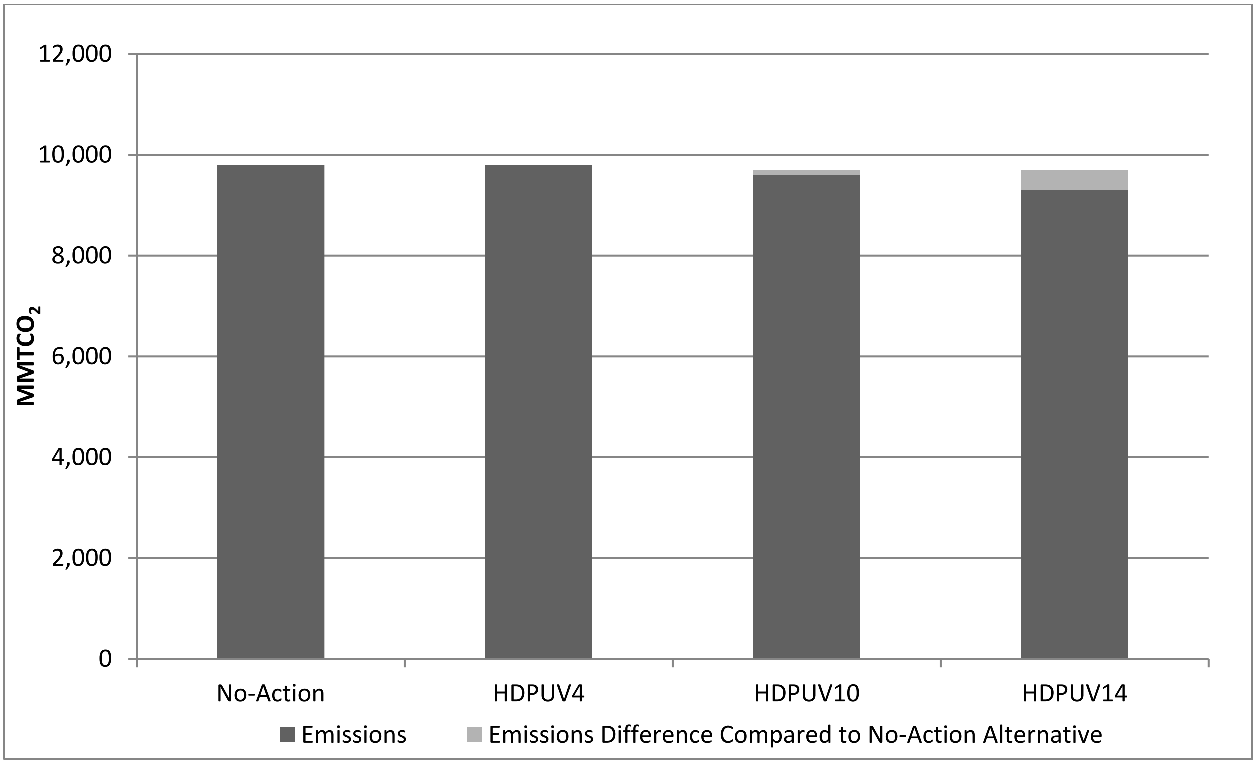
Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.
$MMTCO_2$ = million metric tons of carbon dioxide

Figure 5.4.1-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All Passenger Cars and Light Trucks, 2027 to 2100, by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

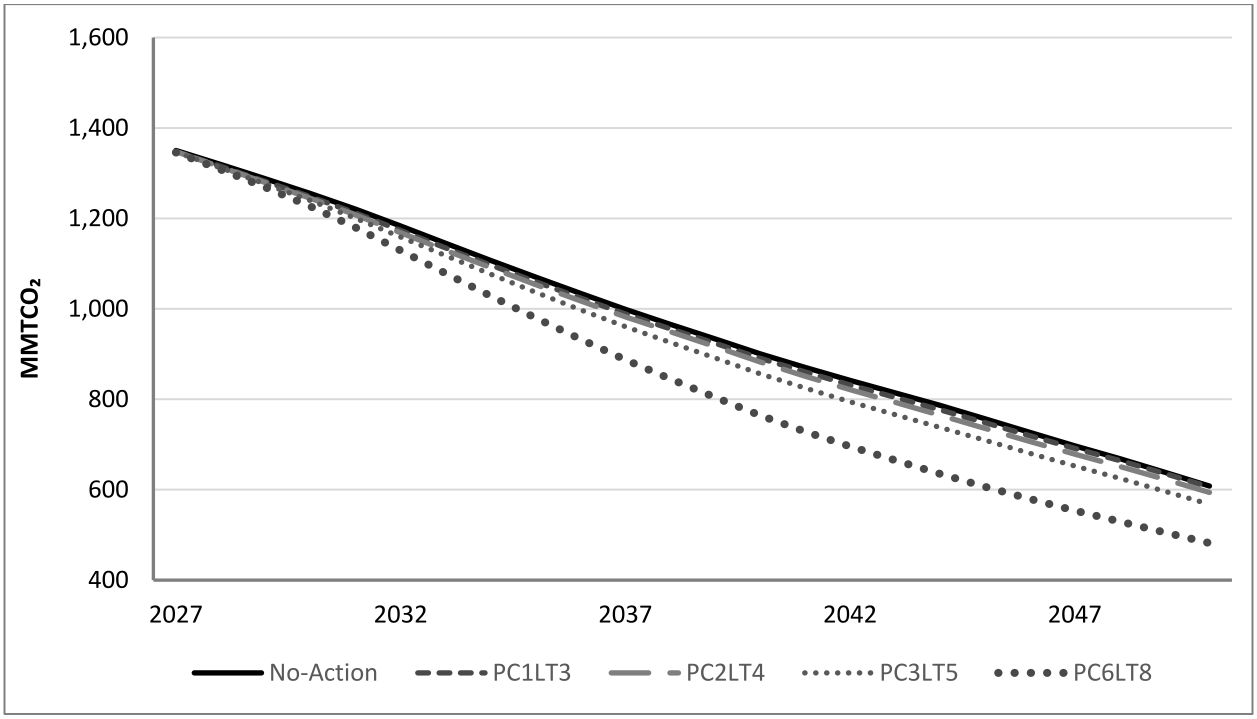
Figure 5.4.1-2. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All HDPUVs, 2027 to 2100, by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

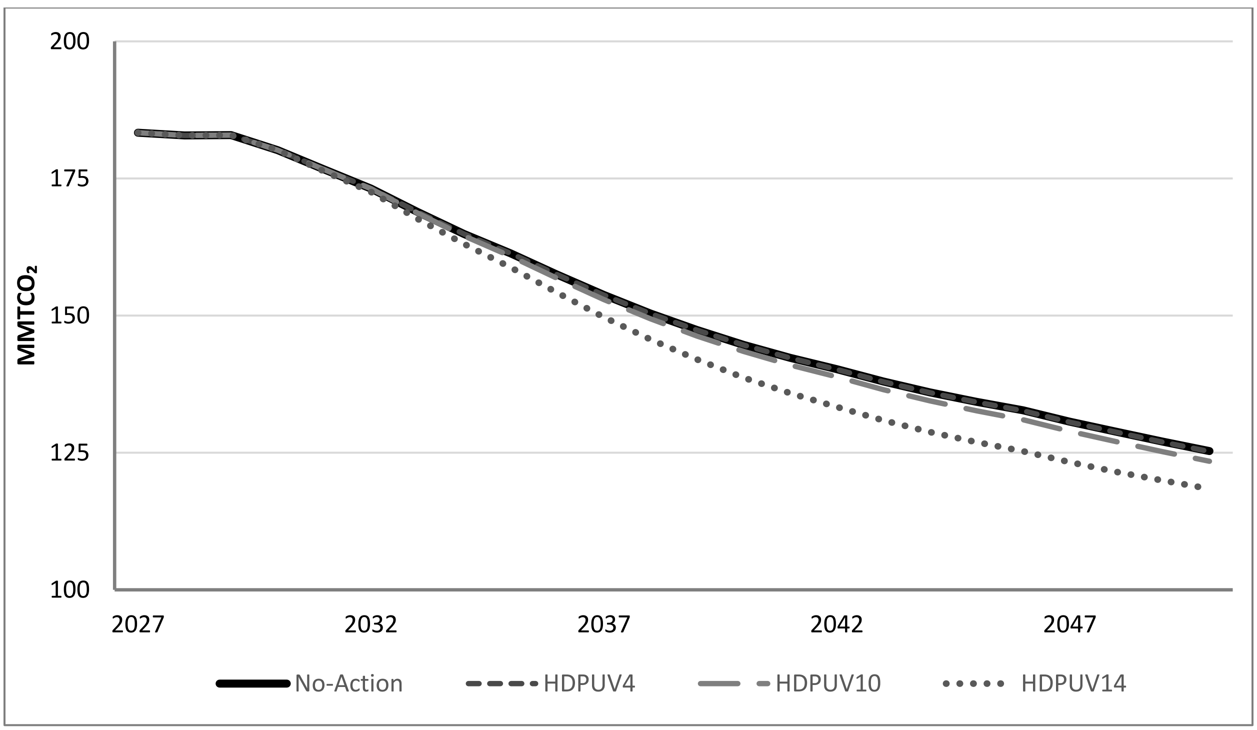
To get a sense of the relative magnitude of these reductions, it can be helpful to consider emissions from vehicles in the context of emissions projections from the transportation sector. Passenger cars and light trucks currently account for 20 percent of CO_2 emissions in the United States. The CAFE action alternatives would reduce total CO_2 emissions from U.S. passenger cars and light trucks by a range of 0.6 to 16.3 percent from 2027 to 2100 compared to the CAFE No-Action Alternative. The HDPUV FE standard action alternatives would reduce total CO_2 emissions from HDPUVs by a range of less than 0.1 to 4.1 percent from 2027 to 2100 compared to the HDPUV No-Action Alternative. Compared to annual U.S. CO_2 emissions of 9,477 $MMTCO_2$ from all sources at the end of the century projected by the SSP3-7.0 baseline scenario, the CAFE and HDPUV FE standard action alternatives would reduce total U.S. CO_2 emissions in the year 2100 by a range of 0.02 to 1.2 percent. Figure 5.4.1-3 and Figure 5.4.1-4 show the projected annual emissions from LD vehicles and HDPUVs under the alternatives.

Figure 5.4.1-3. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All Passenger Cars and Light Trucks by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Figure 5.4.1-4. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All HDPUVs by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Table 5.4.1-3 and Table 5.4.1-4 illustrate that the Proposed Action and alternatives would reduce emissions of CO_2 from their projected levels under the No-Action Alternative for both LD vehicles and HDPUVs. Similarly, under the Proposed Action and alternatives for CAFE and HDPUV FE standards, CH_4 and N_2O emissions in future years are projected to decline from their projected levels under the relevant No-Action Alternative. These reductions are presented in million metric tons of carbon dioxide equivalent ($MMTCO_2e$) in the table below. All CAFE and HDPUV FE standard action alternatives would result in emissions reductions compared to the relevant No-Action Alternative. Of the CAFE standard action alternatives, Alternative PC6LT8 would result in the greatest emissions reductions. For HDPUV FE standard action alternatives, Alternative HDPUV14 would result in the greatest emissions reductions.

Table 5.4.1-3. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All Passenger Cars and Light Trucks by Alternative [a]

GHG and Year	No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Carbon dioxide (CO_2)					
2020	1,531	1,531	1,531	1,531	1,531
2040	901	891	883	856	764
2060	605	603	591	565	479
2080	601	599	587	561	476
2100	559	557	546	522	443
Methane (CH_4)					
2020	52	52	52	52	52
2040	34	33	33	32	30
2060	25	25	25	24	22
2080	25	25	25	24	21
2100	23	23	23	22	20
Nitrous oxide (N_2O)					
2020	19	19	19	19	19
2040	9	9	9	9	8
2060	6	6	6	5	4
2080	6	6	5	5	4
2100	5	5	5	5	4
Total (all GHGs)					
2020	1,602	1,602	1,602	1,602	1,602
2040	944	933	925	897	802
2060	636	634	621	594	505
2080	631	629	617	590	502
2100	587	585	574	549	467

Notes:
[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the SSP3-7.0 scenario. These assumptions project a slight decline over this period.
$MMTCO_2e$ = million metric tons of carbon dioxide equivalent

Table 5.4.1-4. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All HDPUVs by Alternative [a]

GHG and Year	No-Action	HDPUV4	HDPUV10	HDPUV14
Carbon dioxide (CO_2)				
2020	189	189	189	189
2040	145	145	143	139
2060	125	125	123	118
2080	124	124	122	117
2100	115	115	113	109
Methane (CH_4)				
2020	6	6	6	6
2040	5	5	5	5
2060	5	5	5	5
2080	5	5	5	5
2100	5	5	4	4
Nitrous oxide (N_2O)				
2020	2	2	2	2
2040	2	2	2	2
2060	1	1	1	1
2080	1	1	1	1
2100	1	1	1	1
Total (all GHGs)				
2020	198	198	198	198
2040	152	152	150	145
2060	131	131	129	124
2080	130	130	128	123
2100	121	121	119	114

Notes:
[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the SSP3-7.0 scenario. These assumptions project a slight decline over this period.
$MMTCO_2e$ = million metric tons of carbon dioxide equivalent

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

CEQ recommends including an explanation of how the Proposed Action and alternatives would help meet or detract from achieving relevant climate action goals and commitments. Therefore, 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 to 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.[17] In November 2021, the United States submitted its long-term strategy to the UNFCCC communicating a goal of net zero emissions by 2050, which included the "five key transformations" as pathways to achieving this goal.

Total GHG emissions from both U.S. LD vehicles and HDPUVs in 2030 are projected to be below 2005 levels for the relevant No-Action and action alternatives. For passenger cars and light trucks, the percentage decreases range from a 35.5 percent reduction for the No-Action Alternative to a 37.0 percent reduction for the most stringent alternative (Alternative PC6LT8). HDPUV FE standard action alternatives vary less than 0.01 percent from the No-Action Alternative reduction of 15.8 percent. These reductions in emissions alone would not reduce total emissions from passenger cars and light trucks and HDPUVs enough to reach a 50 to 52 percent reduction from 2005 levels by 2030 or achieve net zero emissions by 2050.

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 future model years, 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 and HDPUV FE standards does not allow the agency to regulate other mobile sources of GHG emissions (e.g., hydrofluorocarbon emissions from vehicle air conditioners) or other factors affecting transportation emissions, such as driving habits or use trends; NHTSA cannot, for example, control vehicle miles traveled (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 growth and a variety of other factors, is projected to result in growth in passenger car and light truck VMT, peaking in 2044 and declining gradually in the following years. Alternatively, HDPUV VMT continually increases under all alternatives between 2022 and 2050. 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 2022 and 2044 offsets some of the effect of increased passenger car and light truck and HDPUV FE 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 and HDPUVs in use resulting from older, less-efficient vehicles being replaced by newer, more-efficient models over time and due to increasing percentages of EVs, which have zero tailpipe emissions and produce lower emissions from a life-cycle perspective.

[17] 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.

Comparison to Annual Emissions from Passenger Cars and Light Trucks and HDPUVs

As an illustration of the fuel use projected under the Proposed Action and alternatives, Figure 5.4.1-5 and Figure 5.4.1-6 express the CO_2 reductions under each action alternative in 2035 as the equivalent number of passenger cars and light trucks, as well as HDPUVs, that would produce those emissions in that year.

The emissions reductions under the CAFE standard action alternatives would be equivalent to the annual emissions from 2,481,083 passenger cars and light trucks (Alternative PC1LT3) to 21,921,146 passenger cars and light trucks (Alternative PC6LT8) in 2035, compared to the annual emissions under the No-Action Alternative. A total of 260,514,221 passenger cars and light trucks are projected to be on the road in 2035 under the No-Action Alternative.[18,19]

The emissions reductions under the HDPUV FE standard action alternatives would be equivalent to the annual emissions from 2,325 HDPUVs (Alternative HDPUV4) to 297,812 HDPUVs (Alternative HDPUV14) in 2035, compared to the annual emissions under the No-Action Alternative. A total of 18,601,101 HDPUVs are projected to be on the road in 2035 under the No-Action Alternative.[20,21]

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 WGI AR6 estimates that for a 66 percent chance of limiting warming to 2°C, the remaining carbon budget is 300 gigatons (Gt) carbon (1,100 Gt CO_2) from January 2021, equivalent to 26 years of emissions assuming annual global emissions at 2020 emissions levels (IPCC 2021b). The most recent Global Carbon Budget (Friedlingstein et al. 2022) estimates emissions in 2021 were approximately 9.9 Gt carbon (36.3 Gt CO_2), bringing the IPCC WGI AR6 carbon budget to 290.1 Gt carbon (1,063.7 Gt CO_2) from January 2022. Because estimates vary depending on a range of factors, such as the assumed conditions and the climate model used (Rogelj et al. 2019), no one number for the remaining global carbon budget can be considered definite.

[18] Values for vehicle totals have been rounded.

[19] 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 4.11 metric tons of CO_2 emissions in 2035 based on MOVES, the GREET model, and EPA analysis.

[20] Values for vehicle totals have been rounded.

[21] The average HDPUV is projected to account for 8.67 metric tons of CO_2 emissions in 2035 based on MOVES, the GREET model, and EPA analysis.

Figure 5.4.1-5. Number of Passenger Cars and Light Trucks Equivalent to Carbon Dioxide Reductions in 2035 Compared to the CAFE No-Action Alternative

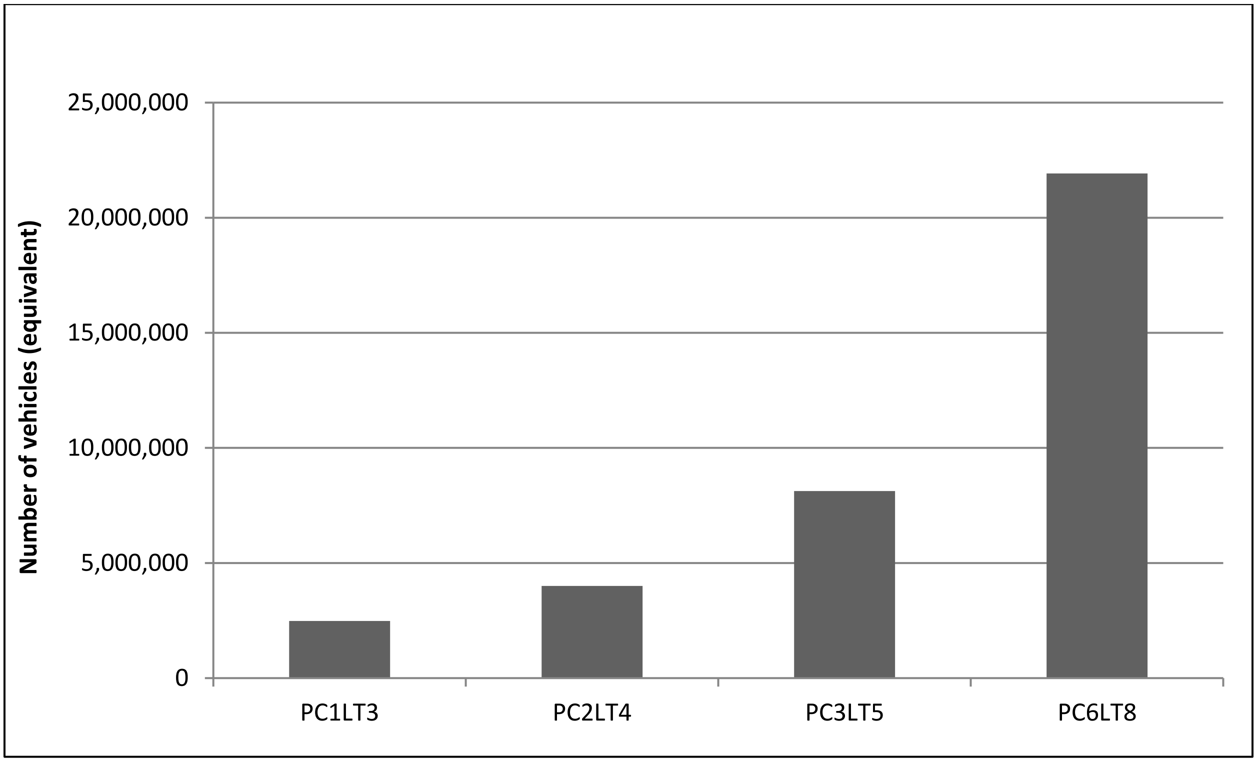
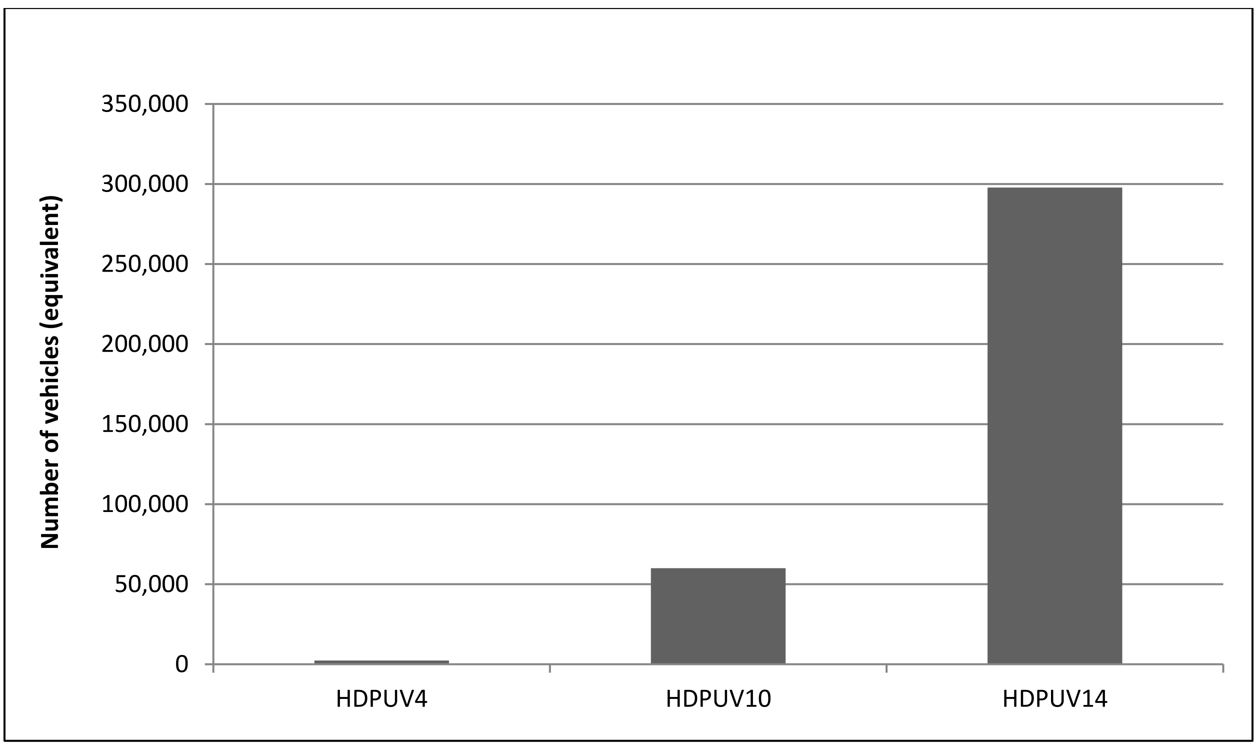


Figure 5.4.1-6. Number of HDPUVs Equivalent to Carbon Dioxide Reductions in 2035 Compared to the HDPUV No-Action Alternative



U.S. passenger cars and light trucks under the CAFE No-Action Alternative are projected to emit 16.3 Gt carbon (60 Gt CO_2) from 2022 to 2100, or 5.6 percent of the remaining global carbon budget according to the IPCC WGI AR6 estimate. Under Alternative PC2LT4, this projection decreases to 16.0 Gt carbon (59 Gt CO_2) or 5.5 percent of the remaining budget. U.S. HDPUVs under the HDPUV No-Action Alternative are projected to emit 2.92 Gt carbon (10.7 Gt CO_2) from 2022 to 2100, or 1 percent of the remaining global carbon budget. Under Alternative HDPUV10, this projection decreases to 2.89 Gt carbon (10.6 Gt CO_2) or 1 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 and HDPUV 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 LD vehicle and HDPUV fleet to the same degree that emissions reductions would 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.

5.4.1.2 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 this section under *Atmospheric Carbon Dioxide Concentrations*, *Climate Change Attributes*, and *Climate Sensitivity Variations*, which 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 SSP3-7.0 scenario. This difference 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.

MAGICC7 is a reduced-complexity climate model well calibrated to the mean of the multimodel ensemble results for five of the most commonly used SSP scenarios—SSP1-1.9 [very low], SSP1-2.6 [low], SSP2-4.5 [intermediate], SSP3-7.0 [high], and SSP5-8.5 [very high]—as shown in Table 5.4.1-5.[22] As the table shows, the results of the model runs developed for this analysis agree relatively well with IPCC estimates for both CO_2 concentrations and surface temperature. Table 5.4.1-5 compares the SSP scenario model results with estimates from AR6.

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

Table 5.4.1-5. Comparison of MAGICC Modeling Results and Reported IPCC WGI AR6 Results [a]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
	IPCC (2100)	MAGICC (2100)	IPCC (2081–2100)	MAGICC (2100)
SSP1-1.9	337	337	1.4	1.3
SSP1-2.6	446	446	1.8	1.6
SSP2-4.5	603	603	2.7	2.7
SSP3-7.0	867	867	3.6	4.0
SSP5-8.5	1,135	1,135	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 2021b
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 SSP3-7.0 emissions scenario to represent the relevant No-Action Alternative in the MAGICC modeling runs. The CO_2 concentrations under the SSP3-7.0 emissions scenario for the CAFE No-Action Alternative are 838.31 ppm and range from 838.29 ppm under Alternative PC1LT3 to 837.48 ppm under Alternative PC6LT8 in 2100 (Table 5.4.1-6). Similarly, under the same emissions scenario and the HDPUV No-Action Alternative, CO_2 concentrations from HDPUV FE standards range from 838.31 ppm under Alternative HDPUV4 to 838.27 ppm under Alternative HDPUV14 in 2100 (Table 5.4.1-7). For 2040 and 2060, the corresponding range of ppm differences across alternatives is even smaller. Because CO_2 concentrations are the key determinant of other climate effects (which in turn drive the resource impacts discussed in Section 5.4.2.1, *Greenhouse Gas Emissions*), this leads to very small differences in these effects.

Table 5.4.1-6. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH by CAFE Standards 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												
No-Action	490.19	587.76	838.31	2.008	2.788	4.340	20.10	36.39	83.24	8.4013	8.3328	8.1933
PC1LT3	490.18	587.74	838.29	2.008	2.788	4.339	20.10	36.38	83.24	8.4014	8.3328	8.1933
PC2LT4	490.17	587.71	838.21	2.008	2.788	4.339	20.10	36.38	83.23	8.4014	8.3329	8.1933
PC3LT5	490.15	587.64	838.04	2.008	2.788	4.338	20.10	36.38	83.22	8.4014	8.3329	8.1934
PC6LT8	490.10	587.42	837.48	2.007	2.786	4.336	20.09	36.37	83.16	8.4014	8.3330	8.1937
Reductions Under CAFE Standard Action Alternatives												
PC1LT3	0.01	0.02	0.03	0.000	0.000	0.000	0.00	0.00	0.00	0.0000	0.0000	0.0000
PC2LT4	0.02	0.05	0.10	0.000	0.000	0.000	0.00	0.00	0.01	0.0000	0.0000	0.0000
PC3LT5	0.04	0.11	0.27	0.000	0.001	0.001	0.00	0.01	0.03	0.0000	-0.0001	-0.0001
PC6LT8	0.09	0.34	0.83	0.001	0.002	0.004	0.00	0.02	0.08	-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

Table 5.4.1-7. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH by HDPUV FE Standards 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												
No-Action	490.19	587.76	838.31	2.008	2.788	4.340	20.10	36.39	83.24	8.4013	8.3328	8.1933
HDPUV4	490.19	587.76	838.31	2.008	2.788	4.340	20.10	36.39	83.24	8.4013	8.3328	8.1933
HDPUV10	490.19	587.75	838.30	2.008	2.788	4.339	20.10	36.39	83.24	8.4013	8.3328	8.1933
HDPUV14	490.19	587.74	838.27	2.008	2.788	4.339	20.10	36.39	83.24	8.4013	8.3328	8.1933
Reductions Under HDPUV FE Standard Action Alternatives												
HDPUV4	0.00	0.00	0.00	0.000	0.000	0.000	0.00	0.00	0.00	0.0000	0.0000	0.0000
HDPUV10	0.00	0.00	0.01	0.000	0.000	0.000	0.00	0.00	0.00	0.0000	0.0000	0.0000
HDPUV14	0.00	0.02	0.04	0.000	0.000	0.000	0.00	0.00	0.00	0.0000	0.0000	0.0000

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

Atmospheric Carbon Dioxide Concentrations

As Figure 5.4.1-7 and Figure 5.4.1-8 show, the reduction in projected CO_2 concentrations under the Proposed Action and alternatives compared to the No-Action Alternative for the CAFE standards and HDPUV FE standards amount to a very small fraction of the projected total increases in CO_2 concentrations. The relative impact of the Proposed Action and alternatives is demonstrated by the reduction in the rise of CO_2 concentrations under the range of action alternatives for both sets of standards. As shown in Figure 5.4.1-7, the reduction in CO_2 concentrations by 2100 under CAFE Alternative PC6LT8 compared to the CAFE No-Action Alternative is substantially larger than that of Alternative PC1LT3. As shown in Figure 5.4.1-8, the reduction in CO_2 concentrations by 2100 under the HDPUV FE standards shows a similar trend.

Figure 5.4.1-7. CAFE Standards Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No-Action Alternative

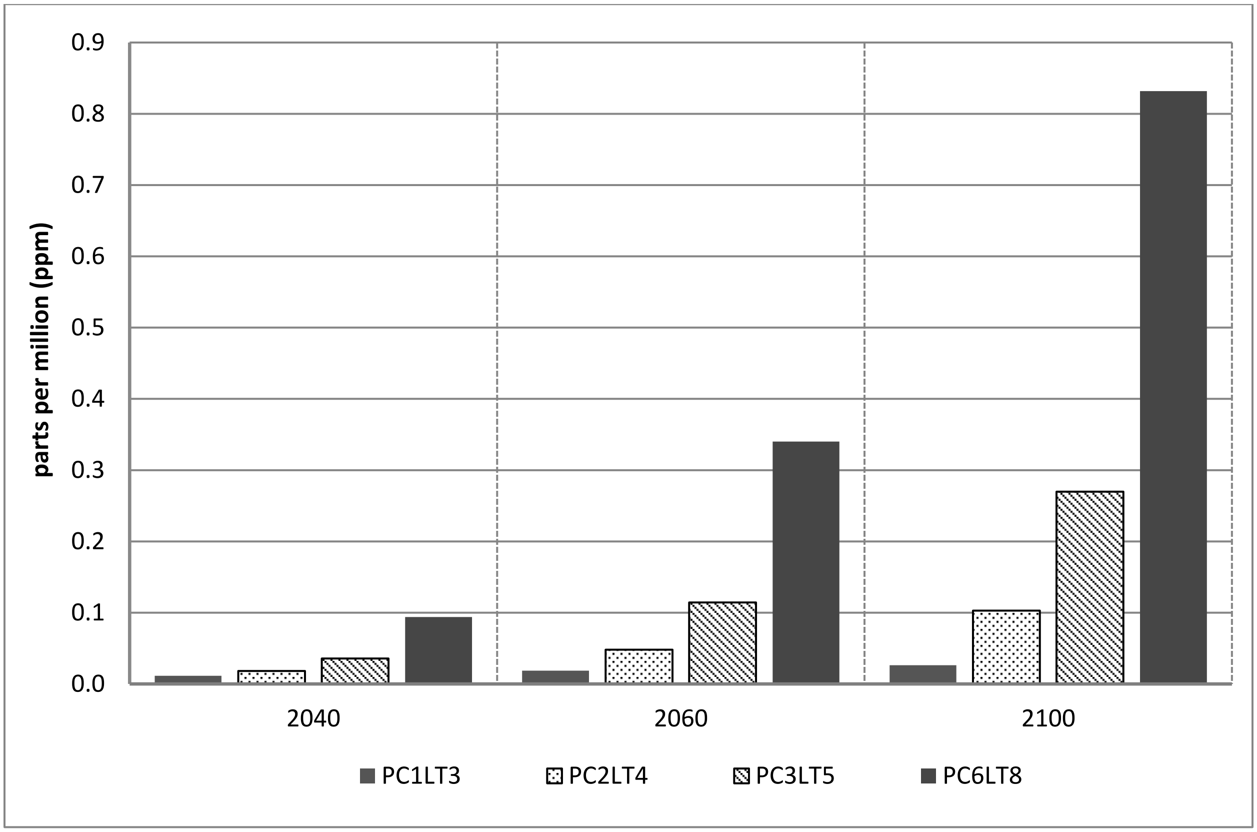
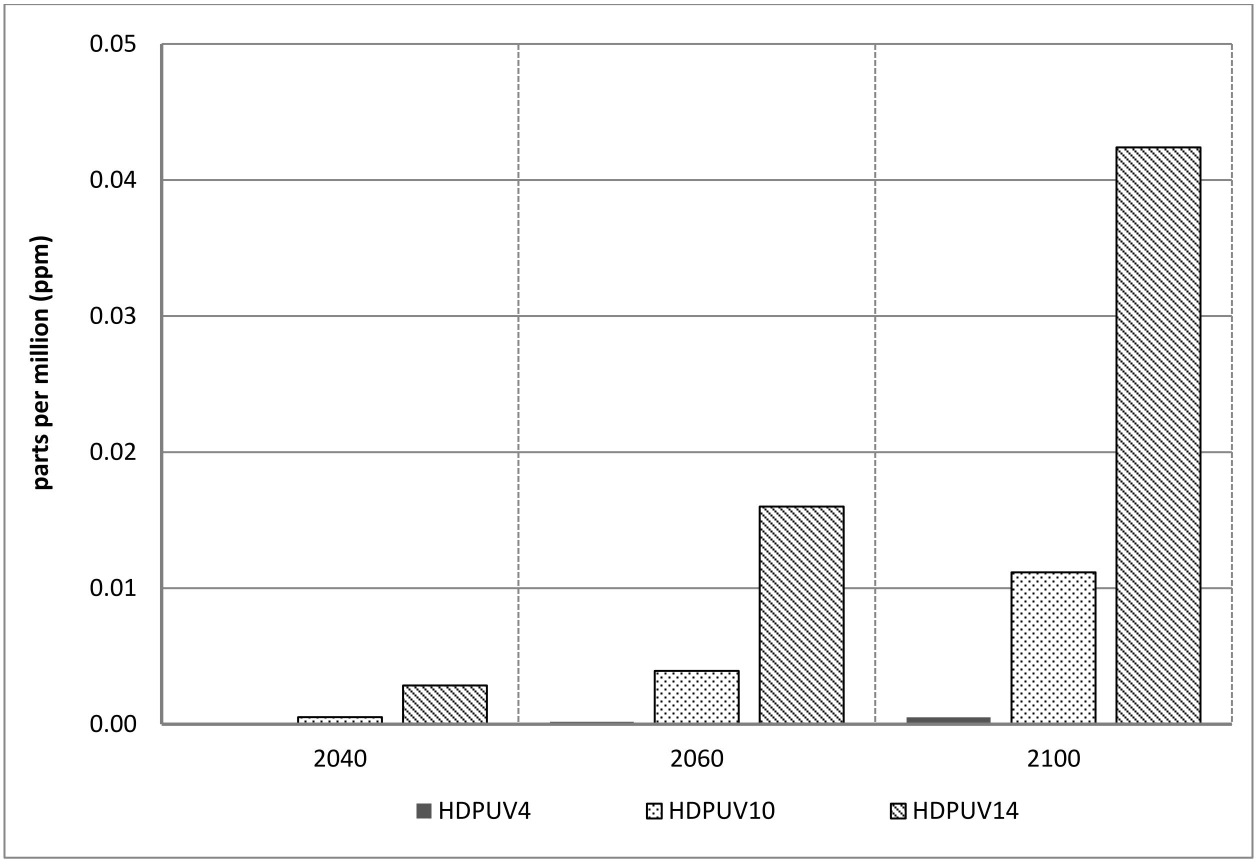


Figure 5.4.1-8. HDPUV FE Standards Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No-Action Alternative



Climate Change Attributes

This section presents an overview of the impacts on climate change attributes of temperature, sea-level rise, precipitation, and ocean pH, which provide evidence of rapid climate change. For more information, see Appendix E, Section E.3.1, *Climate Change Attributes*.

Temperature

Table 5.4.1-6 and Table 5.4.1-7 list MAGICC simulations of mean global surface air temperature increases for the SSP3-7.0 emissions scenario for the CAFE and HDPUV FE standards.[23] Under the No-Action Alternatives,[24] global surface air temperature is projected to increase from 1850 to 1900 average levels by 2.01°C (3.61°F) by 2040, 2.79°C (5.02°F) by 2060, and 4.34°C (7.81°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

[23] Because the actual increase in global mean surface temperature lags behind 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 behind the commitment due primarily to the time required to heat the ocean to the level committed by the concentrations of the GHGs.

[24] No-Action Alternatives (plural) refers to the CAFE No-Action Alternative and the HDPUV No-Action Alternative combined into a single dataset.

5.4.1-9 and Figure 5.4.1-10. For example, the CAFE standards temperature reductions compared to the No-Action Alternative are less than 0.001°C (0.002°F) under Alternative PC1LT3 to 0.004°C (0.007°F) under Alternative PC6LT8. For HDPUV FE standards, reductions compared to the No-Action Alternative are less than 0.001°C under all alternatives.

Figure 5.4.1-9 and Figure 5.4.1-10 also illustrate that reduction in the growth of projected global mean surface temperature for both sets of standards under the Proposed Action and alternatives, compared to the relevant 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 PC1LT3 and PC6LT8 for the CAFE standards and Alternatives HDPUV4 and HDPUV14 for the HDPUV FE standards. The reductions in the projected growth in global temperature under Alternatives PC6LT8 and HDPUV14 are substantially more than under Alternatives PC1LT3 and HDPUV4 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.

According to IPCC AR6 (IPCC 2021b), there is *high confidence* that regions in Asia, Africa, Europe, North America, Central and South America, Australia and New Zealand, Antarctic and the Arctic will experience an increase in mean annual temperature by 2100 and that regions in Asia, North America, Central and South America, and Australia and New Zealand will also see an increase in extreme heat. Regions in Africa are also *very likely* to experience a warming larger than 3°C (under SSP5-8.5). In Africa there is *high confidence* that cold spells and low target temperatures will decrease in the future. Regions in Europe and the Mediterranean will *very likely* experience a decrease in cold spells and frost days, along with more frequent heat waves. An increase in hot days and warm nights and a decrease in cool days and cold nights is projected for Asia *(high confidence)* and regions in Australia and New Zealand *(very likely)*. For Northern and Southwestern regions in North America, there is *high confidence* in projected decreases in cold spells, with the largest decreases most common in the winter season. Similarly, regions in Central and South America are also projected to experience a decrease in cold spells (*high confidence)*.

Figure 5.4.1-9. Reductions in Global Mean Surface Temperature Compared to the CAFE No-Action Alternative

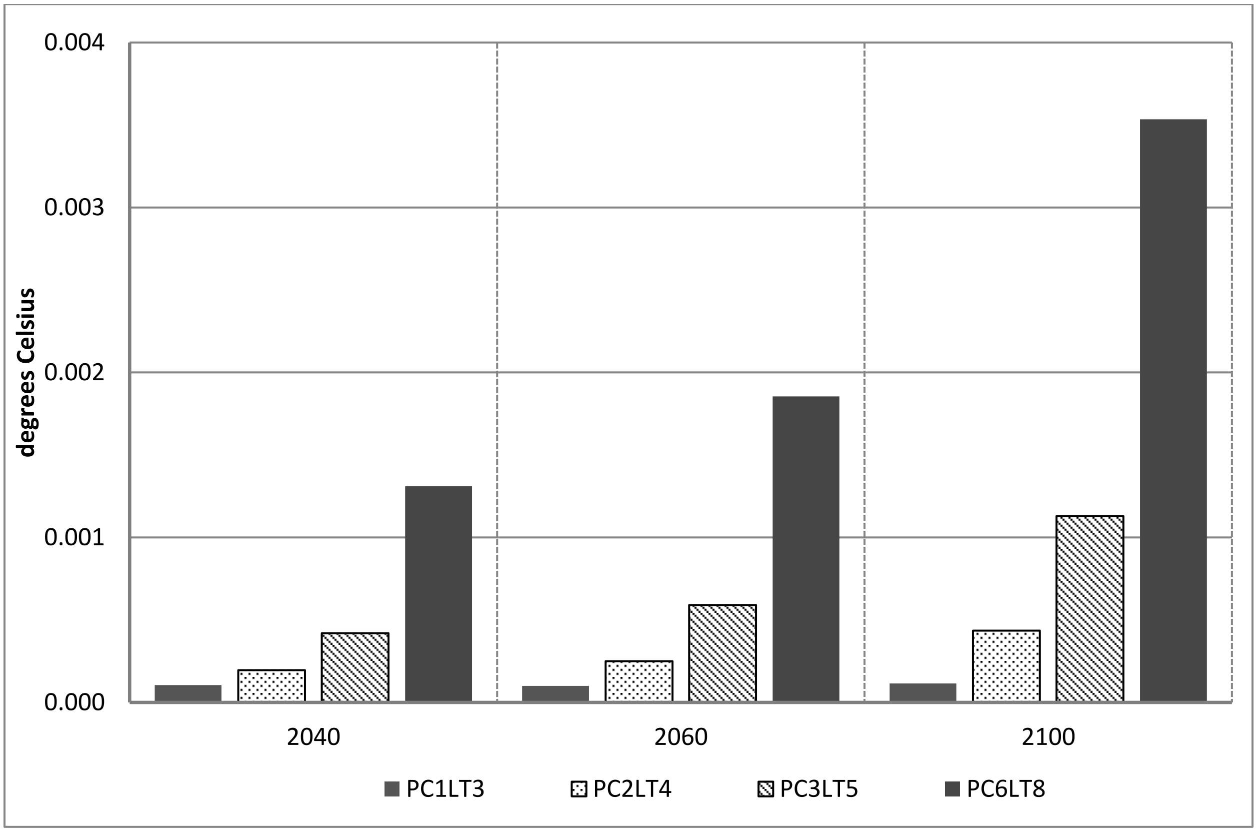
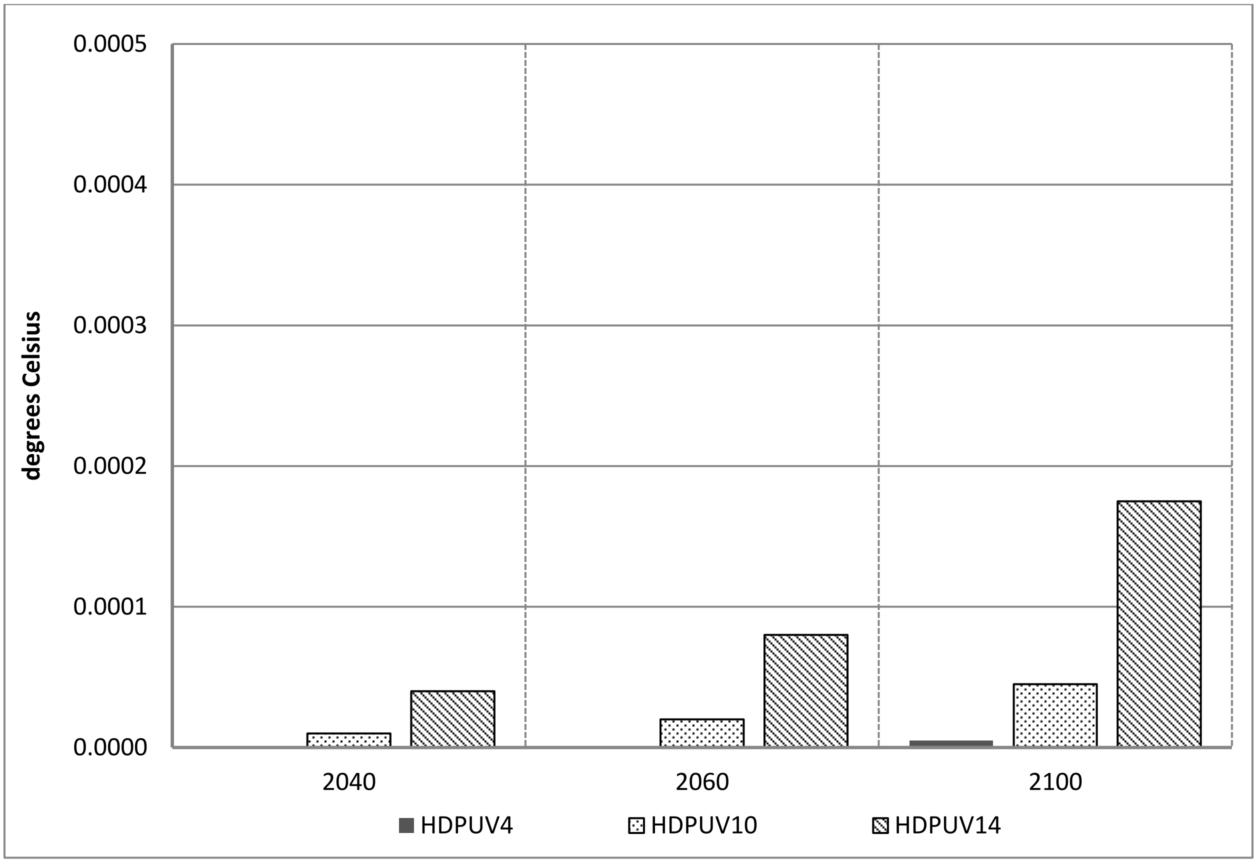


Figure 5.4.1-10. HDPUV FE Standards Reductions in Global Mean Surface Temperature Compared to the HDPUV No-Action Alternative



Sea-Level Rise

Global sea-level rise is the result of changes in both thermal expansion due to warming and ice loss on land from changes in the cryosphere (e.g., melting of glaciers and the Antarctic and Greenland ice sheets) and land-water storage (e.g., surface water, soil moisture and groundwater storage) (IPCC 2021b). Ocean circulation, changes in atmospheric pressure, and geological processes can also influence sea-level rise at a regional scale (EPA 2009). The WGI contribution to the IPCC AR6 (IPCC 2021b) projects the mean sea-level rise for each of the SSP scenarios. As noted in Section 5.3.3, *Methods for Estimating Climate Effects,* NHTSA has used the relationship between the sea-level rise and temperature increases for each of the scenarios from IPCC AR6 to project sea-level rise in this EIS.

IPCC AR6 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.

Table 5.4.1-6 and Table 5.4.1-7 list the impacts of the Proposed Action and alternatives on sea-level rise under the SSP3-7.0 scenario. The CAFE standards analysis shows sea-level rise in 2100 ranging from 83.24 centimeters (32.77 inches) under the No-Action Alternative to 83.24 centimeters (32.77 inches) under Alternative PC1LT3 and 83.16 centimeters (32.74 inches) under Alternative PC6LT8. This represents a maximum reduction of 0.08 centimeters (0.03 inch) by 2100 under Alternative PC6LT8 compared to the No-Action Alternative.

The HDPUV FE standards analysis shows sea-level rise in 2100 ranging from 83.24 centimeters (32.77 inches) under the No-Action Alternative to 83.24 centimeters (32.77 inches) under Alternative HDPUV4 and 83.24 centimeters (32.77 inches) under Alternative HDPUV14. This represents a maximum reduction of less than 0.01 centimeters (0.01 inch)[25] by 2100 under Alternative HDPUV14 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 IPCC (2021b), 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 atmospheric-ocean general circulation model (AOGCM). However, the IPCC (2021b) 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 SSP emissions scenarios (IPCC 2021b) is given as the scaled change in precipitation (expressed as a percentage change 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 5.4.1-8. IPCC provides average scaling factors in the year range of 2006 to 2100. In the analysis of SSP emissions scenarios, NHTSA used the scaling factor for the SSP3-7.0 scenario because it also yields an ERF of approximately 7.0 W/m^2 in the year 2100. Table 5.4.1-8 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).

[25] The HDPUV FE standards analysis only shows the difference between sea-level rise in 2100 at the fourth level decimal place.

Table 5.4.1-8. 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 1995–2014 for 2081–2100 from Table 4.3 in IPCC 2021b.

[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 1995-2014 by subtracting 0.85°C (IPCC 2021b).

°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 for both sets of standards are projected to decrease temperature rise and predicted increases in precipitation slightly compared to the relevant No-Action Alternative, as shown in Table 5.4.1-9 and Table 5.4.1-10 (SSP3-7.0 scenario), based on the scaling factor from the SSP3-7.0 scenario.

Table 5.4.1-9. Global Mean Precipitation (Percent Increase) Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by CAFE Standards 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			
No-Action	2.008	2.788	4.340
PC1LT3	2.008	2.788	4.339
PC2LT4	2.008	2.788	4.339
PC3LT5	2.008	2.788	4.338
PC6LT8	2.007	2.786	4.336
Reductions in Global Temperature (°C) by Alternative (Compared to the No-Action Alternative) [b]			
PC1LT3	0.000	0.000	0.000
PC2LT4	0.000	0.000	0.000
PC3LT5	0.000	0.001	0.001
PC6LT8	0.001	0.002	0.004
Global Mean Precipitation Increase by Alternative (%)			
No-Action	3.43%	4.77%	7.42%
PC1LT3	3.43%	4.77%	7.42%
PC2LT4	3.43%	4.77%	7.42%
PC3LT5	3.43%	4.77%	7.42%
PC6LT8	3.43%	4.76%	7.41%

Scenario	2040	2060	2100
Reductions in Global Mean Precipitation Increase by Alternative (% Compared to the No-Action Alternative) [c]			
PC1LT3	0.00%	0.00%	0.00%
PC2LT4	0.00%	0.00%	0.00%
PC3LT5	0.00%	0.00%	0.00%
PC6LT8	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] Increases in precipitation that are less than 0.005% are rounded to 0.00%.
SSP = Shared Socioeconomic Pathway; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; °C = degrees Celsius

Table 5.4.1-10. Global Mean Precipitation (Percent Increase) Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by HDPUV FE Standards 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			
No-Action	2.008	2.788	4.340
HDPUV4	2.008	2.788	4.340
HDPUV10	2.008	2.788	4.339
HDPUV14	2.008	2.788	4.339
Reductions in Global Temperature (°C) by Alternative (Compared to the No-Action Alternative) [b]			
HDPUV4	0.000	0.000	0.000
HDPUV10	0.000	0.000	0.000
HDPUV14	0.000	0.000	0.000
Global Mean Precipitation Increase by Alternative (%)			
No-Action	3.43%	4.77%	7.42%
HDPUV4	3.43%	4.77%	7.42%
HDPUV10	3.43%	4.77%	7.42%
HDPUV14	3.43%	4.77%	7.42%
Reductions in Global Mean Precipitation Increase by Alternative (% Compared to the No-Action Alternative) [c]			
HDPUV4	0.00%	0.00%	0.00%
HDPUV10	0.00%	0.00%	0.00%
HDPUV14	0.00%	0.00%	0.00%

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the increases might not reflect the exact difference of the values in all cases.
[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.
[c] Increases in precipitation that are less than 0.005% are 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.[26] Regional variations and changes in the intensity of precipitation cannot be further quantified, primarily due to the lack of available AOGCMs required to estimate these changes. These models typically are used to provide results among scenarios with very large changes in emissions, such as the selection of the 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. According to IPCC (IPCC 2021b), there is considerable regional variation in projected precipitation, with some land areas experiencing a likely increase in annual and seasonal precipitation and others a likely decline. Annual precipitation in most regions of Central and South America (except Southeastern South America), Australia and New Zealand, Southern Europe and the Mediterranean, and the Caribbean are projected to decrease by 2100. A decrease in mean annual precipitation is also projected for many subregions of Africa, including Northern Sahara, Western Africa, Southern Africa, and some parts of Eastern Africa. On the other hand, there is *high confidence* that most parts of Asia, North America, Northern Europe, and Eastern Africa will experience an increase in annual precipitation by end of century. There are also varying degrees of *confidence* (*medium to high*) that many regions of the world, such as Central and Western Africa, and Northern and Central Europe, will likely see an increase in extreme precipitation events. Decrease in snow and/or snow season length is also projected (with *high to medium confidence)* for most world regions, including the Polar regions, Asia, Mediterranean and Europe, North America, and Australia. In the Arctic, the Antarctic, and regions of North America, snow may increase in some high elevations and during the cold seasons but decrease at lower elevations and in other seasons.

Ocean pH

Table 5.4.1-6 and Table 5.4.1-7 show the projected increase of ocean pH under each action alternative compared to the relevant No-Action Alternative under the SSP3-7.0 scenario for the CAFE standards and HDPUV FE standards. For CAFE standards, ocean pH under the alternatives ranges from 8.1933 under the No-Action Alternative to 8.1937 under Alternative PC6LT8, for a maximum increase in pH of 0.0004 by 2100. For the HDPUV FE standards, ocean pH under the alternatives varies less than 0.0001 from the No-Action Alternative value of 8.1933 by 2100.

Climate Sensitivity Variations

Using the methods described in Appendix E, Section E.4.3.6, *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 relevant No-Action Alternative using the SSP3-7.0 scenario.

[26] As described in Meehl et al. 2007, the "intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but periods between rainfall events would be longer. The mid-continental areas tend to dry during summer, indicating a greater risk of droughts in those regions. Precipitation extremes increase more than the mean in most tropical and mid- and high-latitude areas."

Table 5.4.1-11 and Table 5.4.1-12 list the results from the sensitivity analysis under the SSP3-7.0 scenario for CAFE standards and HDPUV FE standards, which includes climate sensitivities of 2.4°C, 3.0°C, and 3.9°C (4.3°F, 5.4°F, and 7.0°F) for a doubling of CO_2 compared to preindustrial atmospheric concentrations (278 ppm CO_2) (Appendix E, Section E.4.3.6, *Sensitivity Analysis*).

Table 5.4.1-11. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for Selected CAFE Standards Alternatives [a]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [b, c]			Sea Level Rise (cm) [d]	Ocean pH [e]
		2040	2060	2100	2040	2060	2100	2100	2100
No-Action	2.4	484.64	572.03	791.90	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.76	838.31	2.008	2.788	4.340	83.24	8.1933
	3.9	496.65	604.77	886.21	2.308	3.292	5.202	106.54	8.1707
PC1LT3	2.4	484.63	572.01	791.87	1.736	2.390	3.610	65.72	8.2162
	3.0	490.18	587.74	838.29	2.008	2.788	4.339	83.24	8.1933
	3.9	496.64	604.75	886.18	2.308	3.292	5.202	106.54	8.1707
PC2LT4	2.4	484.62	571.98	791.80	1.736	2.389	3.610	65.72	8.2162
	3.0	490.17	587.71	838.21	2.008	2.788	4.339	83.23	8.1933
	3.9	496.63	604.72	886.10	2.308	3.292	5.202	106.53	8.1707
PC6LT8	2.4	484.55	571.69	791.13	1.735	2.388	3.608	65.67	8.2166
	3.0	490.10	587.42	837.48	2.007	2.786	4.336	83.16	8.1937
	3.9	496.55	604.41	885.30	2.307	3.290	5.198	106.43	8.1711
Reductions Under Alternative PC1LT3 Compared to the No-Action Alternative									
PC1LT3	2.4	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.0	0.01	0.02	0.03	0.000	0.000	0.000	0.00	0.0000
	3.9	0.01	0.02	0.03	0.000	0.000	0.000	0.01	0.0000
Reductions Under Alternative PC2LT4 Compared to the No-Action Alternative									
PC2LT4	2.4	0.02	0.05	0.09	0.000	0.000	0.000	0.01	0.0000
	3.0	0.02	0.05	0.10	0.000	0.000	0.000	0.01	0.0000
	3.9	0.02	0.05	0.12	0.000	0.000	0.000	0.01	-0.0001
Reductions Under Alternative PC6LT8 Compared to the No-Action Alternative									
PC6LT8	2.4	0.09	0.34	0.76	0.001	0.002	0.003	0.06	-0.0004
	3.0	0.09	0.34	0.83	0.001	0.002	0.004	0.08	-0.0004
	3.9	0.10	0.36	0.91	0.001	0.002	0.004	0.11	-0.0004

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.

[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.

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

Table 5.4.1-12. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for the HDPUV FE Standards Alternatives [a]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [b, c]			Sea Level Rise (cm) [d]	Ocean pH [e]
		2040	2060	2100	2040	2060	2100	2100	2100
No-Action	2.4	484.64	572.03	791.90	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.76	838.31	2.008	2.788	4.340	83.24	8.1933
	3.9	496.65	604.77	886.21	2.308	3.292	5.202	106.54	8.1707
HDPUV4	2.4	484.64	572.03	791.90	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.76	838.31	2.008	2.788	4.340	83.24	8.1933
	3.9	496.65	604.77	886.20	2.308	3.292	5.202	106.54	8.1707
HDPUV10	2.4	484.64	572.02	791.89	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.75	838.30	2.008	2.788	4.339	83.24	8.1933
	3.9	496.65	604.76	886.18	2.308	3.292	5.202	106.54	8.1707
HDPUV14	2.4	484.64	572.01	791.86	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.74	838.27	2.008	2.788	4.339	83.24	8.1933
	3.9	496.65	604.75	886.17	2.308	3.292	5.202	106.54	8.1707
Reductions Under Alternative HDPUV4 Compared to the No-Action Alternative									
HDPUV4	2.4	0.00	0.00	0.00	0.000	0.000	0.000	0.00	0.0000
	3.0	0.00	0.00	0.00	0.000	0.000	0.000	0.00	0.0000
	3.9	0.00	0.00	0.01	0.000	0.000	0.000	0.00	0.0000
Reductions Under Alternative HDPUV10 Compared to the No-Action Alternative									
HDPUV10	2.4	0.00	0.00	0.01	0.000	0.000	0.000	0.00	0.0000
	3.0	0.00	0.00	0.01	0.000	0.000	0.000	0.00	0.0000
	3.9	0.00	0.00	0.03	0.000	0.000	0.000	0.00	0.0000
Reductions Under Alternative HDPUV14 Compared to the No-Action Alternative									
HDPUV14	2.4	0.00	0.02	0.04	0.000	0.000	0.000	0.00	0.0000
	3.0	0.00	0.02	0.04	0.000	0.000	0.000	0.00	0.0000
	3.9	0.00	0.02	0.05	0.000	0.000	0.000	0.01	0.0000

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.
[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.
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 5.4.1-11 and Table 5.4.1-12 show, projected future atmospheric CO_2 concentrations differ with varying climate sensitivities even under the same alternatives for the CAFE and HDPUV FE standards, 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 SSP3-7.0 scenario to variation in the climate sensitivity parameter similarly varies among the years 2040, 2060, and 2100, as shown in Table 5.4.1-11 and Table 5.4.1-12. For the CAFE standards, the increase in 2100 global mean surface temperature from the No-Action Alternative to Alternative PC6LT8 ranges from 0.003°C (0.005°F) for the 1.5°C (2.7°F) climate sensitivity to 0.004°C (0.007°F) for the 6.0°C (10.8°F) climate sensitivity. For the HDPUV FE standards, the increase in 2100 global mean surface temperature from the No-Action Alternative to Alternative HDPUV14 ranges from 0.0001°C (0.0002°F) for the 1.5°C (2.7°F) climate sensitivity to 0.0002°C (0.0004°F) for the 6.0°C (10.8°F) climate sensitivity.

The sensitivity of the simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.1-11 and Table 5.4.1-12. 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 relevant 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 relevant No-Action Alternative. For CAFE standards, the range in reductions of sea-level rise under Alternative PC6LT8 compared to the No-Action Alternative ranges from 0.06 to 0.11 centimeter (0.023 to 0.042 inch), depending on the assumed climate sensitivity. For HDPUV FE standards, the range in reductions of sea-level rise under Alternative HDPUV14 compared to the No-Action Alternative ranges from less than 0.01 to 0.01 centimeter (0.001 to 0.002 inch), depending on the assumed climate sensitivity.

5.4.2 Cumulative Impacts on Greenhouse Gas Emissions and Climate Change

5.4.2.1 Greenhouse Gas Emissions

Using the methods described in Section 5.3, *Analysis Methods*, NHTSA estimated projected emissions reductions under the combined impacts from 2027 to 2100. These emissions reductions represent the differences in total annual emissions in future years of U.S. LD vehicles and HDPUVs in use under the No-Action Alternatives and the combined action alternatives, determined by the projected change in fuel production and use under each alternative. As discussed in Section 5.4.1, *Direct and Indirect Impacts on Greenhouse Gas Emissions and Climate Change*, NHTSA's consideration of GHG impacts focuses primarily on reductions in CO_2 emissions expected under the combined alternatives, but also incorporates reductions in all GHGs in assessing the direct and indirect impacts and cumulative impacts on climate change indicators.

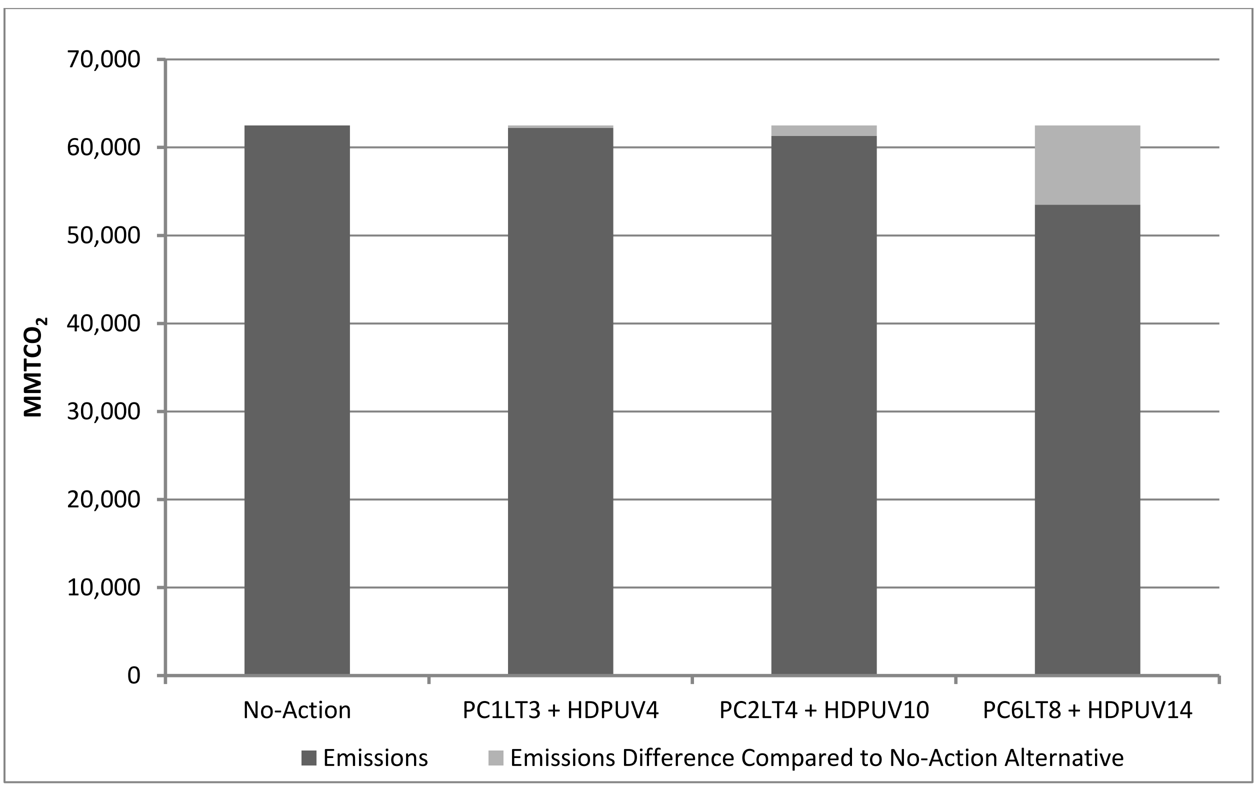
Table 5.4.2-1 shows total U.S. LD vehicle and HDPUV CO_2 emissions under the No-Action Alternatives and emissions reductions that would result from the combined alternatives from 2027 to 2100. All combined alternatives would result in lower CO_2 emissions than the No-Action Alternatives because all combined alternatives involve more stringent CAFE standards and HDPUV FE standards than the No-Action Alternatives. All U.S. LD vehicle and HDPUV emissions from 2027 to 2100 would range from a low of 53,500 $MMTCO_2$ under Alternatives PC6LT8 and HDPUV14 to a high of 62,500 $MMTCO_2$ under the No-Action Alternatives. Compared to the No-Action Alternatives, projected emissions reductions from 2027 to 2100 under the action alternatives would range from 300 to 9,000 $MMTCO_2$. Emissions reductions compared to the No-Action alternative are shown in Figure 5.4.2-1. Compared to the SSP2-4.5 total global emissions projection of 2,484,191 $MMTCO_2$ over this period, reductions from the combined alternatives would range from approximately 0.01 to 0.36 percent from projected levels. Figure 5.4.2-2 shows the projected annual emissions from LD vehicles and HDPUVs under the alternatives.

Table 5.4.2-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All LD Vehicles and HDPUVs, 2027 to 2100, by Alternative [a]

Combined Impacts	Total Emissions	Emissions Reductions Compared to No-Action	Percent (%) Emissions Reductions Compared to No-Action Alternative Emissions
No-Action	62,500	--	--
PC1LT3 + HDPUV4	62,200	300	0.5%
PC2LT4 + HDPUV10	61,300	1,200	1.9%
PC6LT8 + HDPUV14	53,500	9,000	14.4%

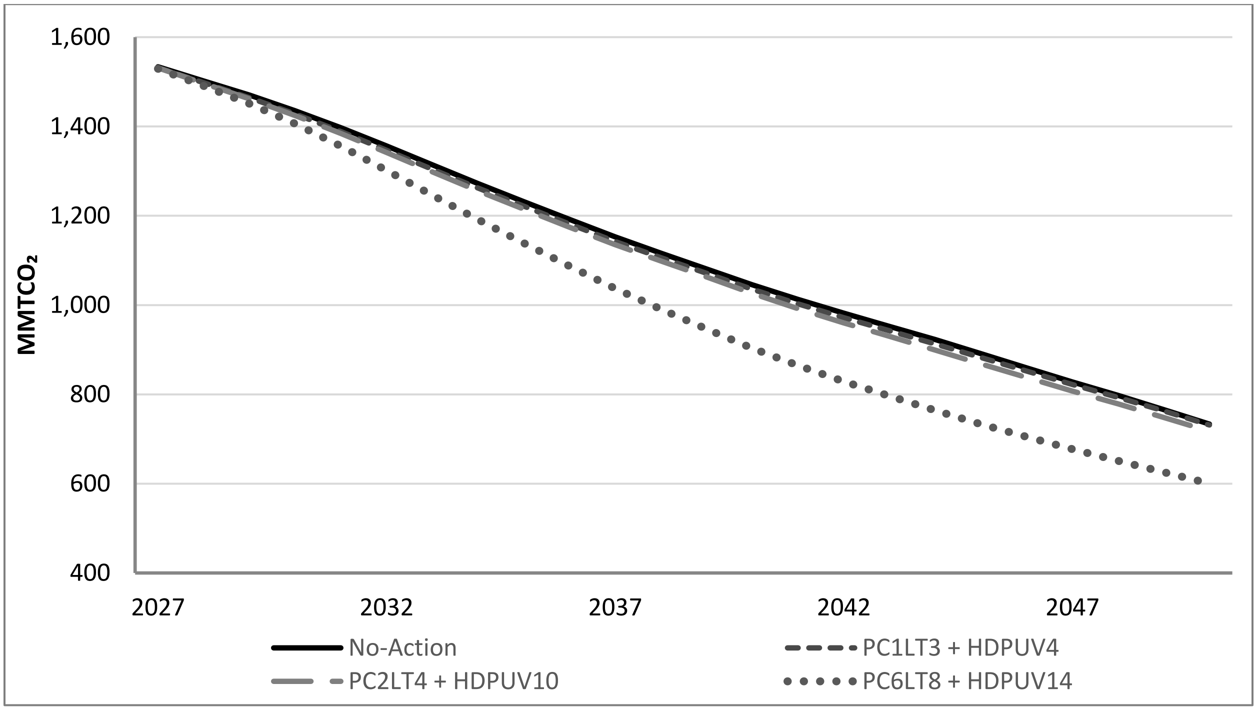
Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.
$MMTCO_2$ = million metric tons of carbon dioxide

Figure 5.4.2-1. Carbon Dioxide Emissions and Emissions Reductions ($MMTCO_2$) from All LD Vehicles and HDPUVs, 2027 to 2100, by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Figure 5.4.2-2. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All LD Vehicles and HDPUVs by Alternative



MMTCO2 = million metric tons of carbon dioxide

Table 5.4.2-2 shows that the combined alternatives would reduce emissions of CO_2, CH_4, and N_2O from their projected levels under the No-Action Alternatives. The CH_4 and N_2O reductions are presented in CO_2 equivalents ($MMTCO_2e$) in the table below. Similar to the trends indicated in Section 5.4.1, *Direct and Indirect Impacts on Greenhouse Gas Emissions and Climate Change,* all combined alternatives would result in emissions reductions compared to the No-Action Alternatives. Of all the combined alternatives, Alternatives PC6LT8 and HDPUV14 would result in the greatest emissions reductions.

Table 5.4.2-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All LD Vehicles and HDPUVs by Alternative [a]

GHG and Year	No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Carbon dioxide (CO_2)				
2020	1,721	1,721	1,721	1,721
2040	1,045	1,035	1,026	903
2060	730	728	714	597
2080	724	722	709	593
2100	674	672	659	552
Methane (CH_4)				
2020	58	58	58	58
2040	39	39	38	35
2060	30	30	30	26
2080	30	30	29	26
2100	28	28	27	24
Nitrous oxide (N_2O)				
2020	21	21	21	21
2040	11	11	11	9
2060	7	7	7	6
2080	7	7	7	5
2100	7	7	6	5
Total (all GHGs)				
2020	1,800	1,800	1,800	1,800
2040	1,095	1,085	1,075	947
2060	767	765	750	629
2080	761	759	745	625
2100	708	706	693	581

Notes:
[a] Emissions from 2051 to 2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the SSP3-7.0 scenario. These assumptions project a slight decline over this period.
$MMTCO_2e$ = million metric tons of carbon dioxide equivalent

5.4.2.2 Cumulative Impacts on Climate Change Indicators

Using the methods described in Section 5.3, *Analysis Methods*, this section describes the cumulative impacts of the combined 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 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 SSP2-4.5 scenario was used to represent the No-Action Alternatives for the cumulative impacts analysis. Table 5.4.2-3 and Figures 5.4.2-3 and 5.4.2-4 show the results for all combined alternatives. As Figure 5.4.2-3 and Figure 5.4.2-4 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. The values range from 587.78 ppm under the No-Action Alternatives to 587.00 ppm under Alternatives PC6LT8 and HDPUV14. The values for Alternatives PC1LT3 and HDPUV4 and Alternatives PC2LT4 and HDPUV10 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. Global CO_2 emissions from all sources between 2027 to 2100 are projected to be 2,484,191 $MMTCO_2$ under this scenario, which projects emissions to begin to decline around mid-century. The incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.01 (Alternatives PC1LT3 and HDPUV4) and 0.36 (Alternatives PC6LT8 and HDPUV14) percent by 2100. The values for Alternatives PC2LT4 and HDPUV10 fall within this range.

Table 5.4.2-3. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH for Combined Impacts [a]

Combined Impacts	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
No-Action	472.65	532.40	587.78	1.852	2.370	2.826	19.17	33.85	67.12	8.4149	8.3704	8.3328
PC1LT3 + HDPUV4	472.64	532.39	587.76	1.852	2.370	2.826	19.17	33.85	67.11	8.4149	8.3704	8.3328
PC2LT4 + HDPUV10	472.63	532.35	587.68	1.852	2.370	2.826	19.17	33.85	67.11	8.4149	8.3704	8.3329
PC6LT8 + HDPUV14	472.56	532.05	587.00	1.851	2.368	2.822	19.17	33.83	67.03	8.4150	8.3706	8.3333
Reductions Under Alternatives												
PC1LT3 + HDPUV4	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.00	0.00	0.0000	0.0000	0.0000
PC2LT4 + HDPUV10	0.02	0.05	0.10	0.000	0.000	0.001	0.00	0.00	0.01	0.0000	0.0000	-0.0001
PC6LT8 + HDPUV14	0.09	0.35	0.78	0.001	0.002	0.004	0.00	0.02	0.08	-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.

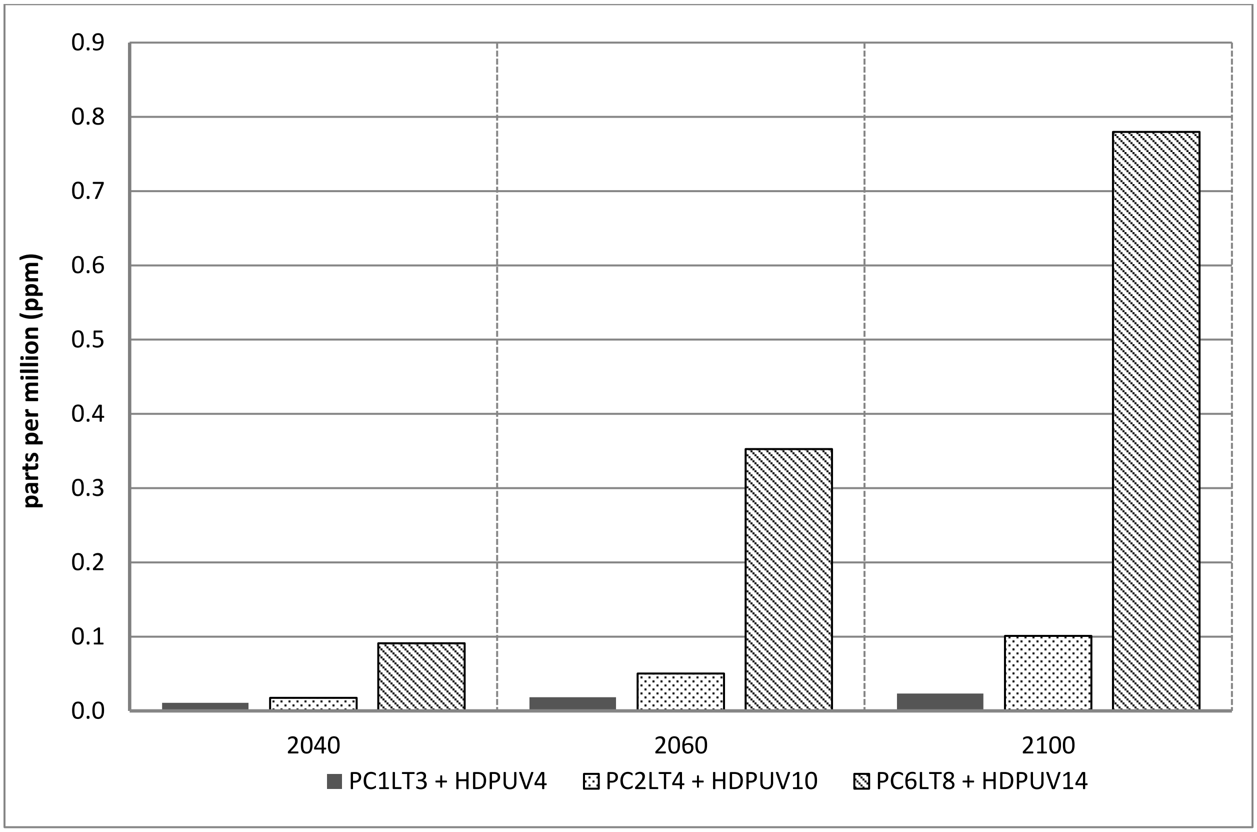
[c] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.

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

Atmospheric Carbon Dioxide Concentrations

As Figure 5.4.2-3 shows, the reductions in projected CO_2 concentrations under the Proposed Action and alternatives compared to the No-Action Alternatives for cumulative impacts 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 Alternatives. As shown in Table 5.4.2-3, the reduction in CO_2 concentrations by 2100 under Alternatives PC6LT8 and HDPUV14 compared to the No-Action Alternative is significantly larger than that of Alternatives PC1LT3 and HDPUV4 compared to the No-Action Alternative. Reductions from Alternatives PC2LT4 and HDPUV10 fall within this range.

Figure 5.4.2-3. Combined Impact Reductions in Atmospheric Carbon Dioxide Concentrations Compared to the No-Action Alternatives



Climate Change Attributes

This section presents an overview of the impacts on climate change attributes of temperature, sea-level rise, precipitation, and ocean pH, which provide evidence of rapid climate change. For more information, see Appendix E, Section E.3.1, *Climate Change Attributes*.

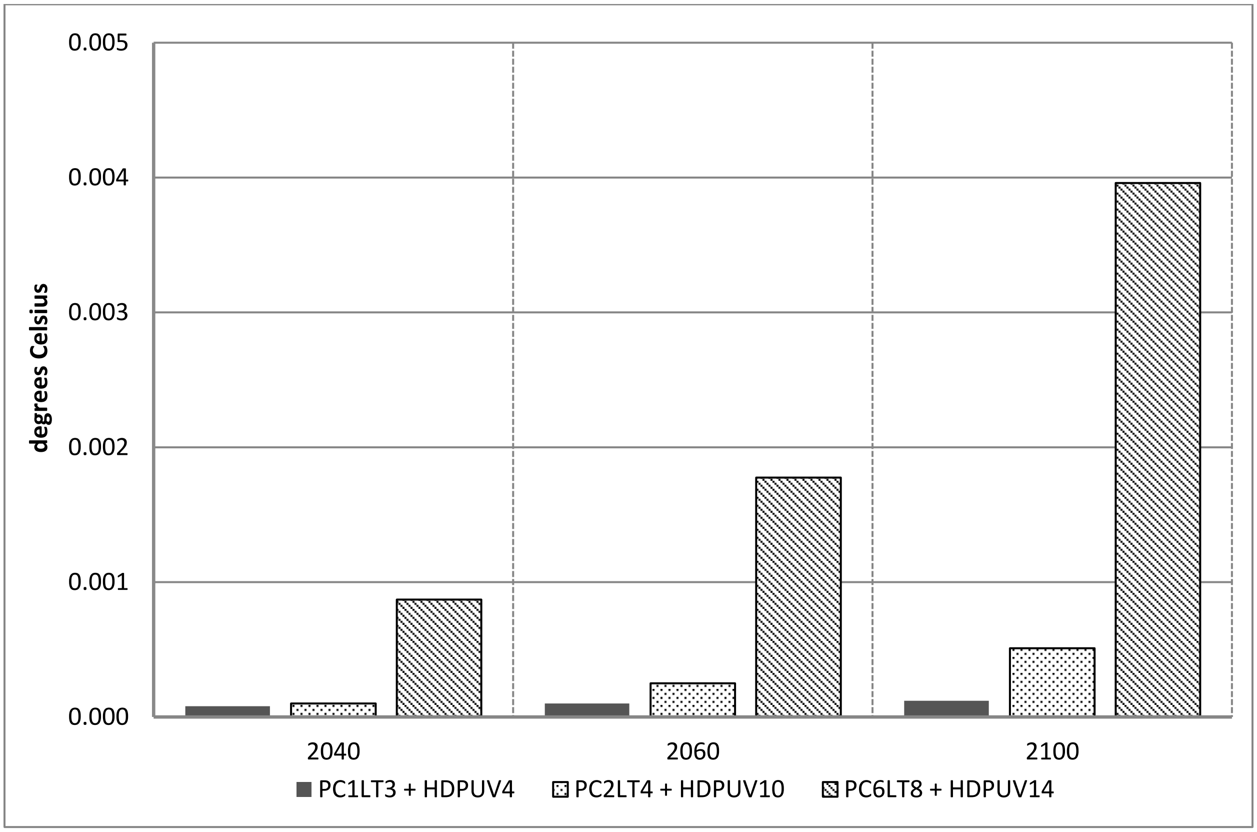
Temperature

MAGICC simulations of mean global surface air temperature increases are shown in Figure 5.4.2-4. The cumulative global mean surface temperature is projected to increase by 1.852°C (3.333°F) by 2040, 2.370°C (4.266°F) by 2060, and 2.826°C (5.088°F) by 2100.[27] The differences among alternatives are small (Figure 5.4.2-4). For example, in 2100, the decrease in temperature under the action alternatives would range from less than 0.001°C (0.002°F) under Alternatives PC1LT3 and HDPUV4 to 0.004°C

[27] Because the actual increase in global mean surface temperature lags behind 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 behind the commitment due primarily to the time required to heat the oceans.

(0.007°F) under Alternatives PC6LT8 and HDPUV14. Reductions under Alternatives PC2LT4 and HDPUV10 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. Additional information on regional impacts is summarized in Section 5.4.3.3, *Regional Impacts of Climate Change*.

Figure 5.4.2-4. Combined Impacts Reductions in Global Mean Surface Temperature Compared to the No-Action Alternatives



Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.4.1.2, *Direct and Indirect Impacts on Climate Change Indicators*, under *Sea-Level Rise*. Table 5.4.2-3 presents the cumulative impact on sea-level rise from each action alternative under the SSP2-4.5 scenario and shows sea-level rise in 2100 ranging from 67.12 centimeters (26.42 inches) under the No-Action Alternatives to 67.03 centimeters (26.39 inches) under Alternatives PC6LT8 and HDPUV14, for a maximum decrease of 0.08 centimeter (0.03 inch) by 2100. The values for Alternatives PC2LT4 and HDPUV10 fall within these ranges.

Precipitation

The effects of higher temperatures on the amount of precipitation and the intensity of precipitation events, as well as the IPCC scaling factors to estimate global mean precipitation change, are discussed in Section 5.4.1.2, *Direct and Indirect Impacts on Climate Change Indicators*, under *Precipitation*. Applying these scaling factors to the increase in global mean surface warming provides estimates of changes in global mean precipitation. Given that the combined impacts would reduce temperatures slightly compared to the No-Action Alternatives, they also would reduce predicted increases in precipitation slightly; however, as shown in Table 5.4.2-4, the reduction would be less than 0.01 percent in all instances.

Regional variations and changes in the intensity of precipitation events cannot be quantified further. This inability is due primarily to the lack of availability of AOGCMs required to estimate these changes. AOGCMs are typically used to provide results among scenarios with very large changes in emissions, such as the SSP1-1.9 (low), SSP1-2.6 (medium-low), SSP2-4.5 (medium), SSP3-7.0 (medium-high) and SSP5-8.5 (high) scenarios; very small changes in emissions profiles produce results that would be difficult to resolve. Also, the various AOGCMs produce results that are regionally consistent in some cases but inconsistent in others.

Table 5.4.2-4. Global Mean Precipitation (Percent Increase) Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Combined Impacts [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			
No-Action	1.852	2.370	2.826
PC1LT3 + HDPUV4	1.852	2.370	2.826
PC2LT4 + HDPUV10	1.852	2.370	2.826
PC6LT8 + HDPUV14	1.851	2.368	2.822
Reductions in Global Temperature (°C) Compared to the No-Action Alternative [b]			
PC1LT3 + HDPUV4	0.000	0.000	0.000
PC2LT4 + HDPUV10	0.000	0.000	0.001
PC6LT8 + HDPUV14	0.001	0.002	0.004
Global Mean Precipitation Increase (%)			
No-Action	4.00%	5.12%	6.11%
PC1LT3 + HDPUV4	4.00%	5.12%	6.10%
PC2LT4 + HDPUV10	4.00%	5.12%	6.10%
PC6LT8 + HDPUV14	4.00%	5.12%	6.10%
Reductions in Global Mean Precipitation Increase Compared to the No-Action Alternative [c]			
PC1LT3 + HDPUV4	0.00%	0.00%	0.00%
PC2LT4 + HDPUV10	0.00%	0.00%	0.00%
PC6LT8 + HDPUV14	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 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

Ocean pH

Table 5.4.2-3 shows the projected increase of ocean pH under each action alternative compared to the No-Action Alternatives under the SSP2-4.5 scenario. Ocean pH values range from 8.3328 (No-Action Alternatives) to 8.3333 (Alternatives PC6LT8 and HDPUV14), for a maximum increase in pH of 0.005 by 2100. The values for Alternatives PC2LT4 and HDPUV10 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, Alternatives PC1LT3 and HDPUV4, and Alternatives PC6LT8 and HDPUV14. 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 Alternatives PC2LT4 and HDPUV10 would fall within the ranges presented below. Table 5.4.2-5 through Table 5.4.2-7 present the results of the sensitivity analyses for cumulative impacts.

Table 5.4.2-5. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, [a] and Ocean pH for SSP1-2.6 for Selected Combined Impacts [b]

Combined Impacts	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [c, d]			Sea-Level Rise (cm) [c, e]	Ocean pH [f]
		2040	2060	2100	2040	2060	2100	2100	2100
No-Action	2.4	450.29	458.64	422.33	1.473	1.551	1.348	38.80	8.4563
	3.0	455.64	469.40	433.77	1.719	1.873	1.685	52.21	8.4465
	3.9	461.60	481.57	454.48	1.994	2.242	2.121	69.94	8.4294
PC1LT3 + HDPUV4	2.4	450.28	458.63	422.32	1.473	1.550	1.348	38.79	8.4563
	3.0	455.63	469.38	433.75	1.719	1.873	1.684	52.21	8.4465
	3.9	461.59	481.55	454.46	1.994	2.241	2.121	69.94	8.4294
PC2LT4 + HDPUV10	2.4	450.27	458.60	422.26	1.473	1.550	1.348	38.79	8.4563
	3.0	455.62	469.35	433.68	1.719	1.873	1.684	52.20	8.4466
	3.9	461.59	481.52	454.39	1.994	2.241	2.121	69.92	8.4294
PC6LT8 + HDPUV14	2.4	450.20	458.32	421.74	1.472	1.549	1.345	38.73	8.4568
	3.0	455.55	469.05	433.09	1.718	1.871	1.680	52.11	8.4471
	3.9	461.52	481.23	453.77	1.993	2.239	2.116	69.80	8.4300
Reductions Under Low CAFE + Low HDPUV Compared to the No-Action Alternative									
PC1LT3 + HDPUV4	2.4	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.0	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.9	0.01	0.02	0.02	0.000	0.000	0.000	0.01	0.0000
Reductions Under Preferred CAFE + Preferred HDPUV Compared to the No-Action Alternative									
PC2LT4 + HDPUV10	2.4	0.02	0.05	0.08	0.000	0.000	0.000	0.01	-0.0001
	3.0	0.02	0.05	0.09	0.000	0.000	0.001	0.01	-0.0001
	3.9	0.02	0.05	0.09	0.000	0.000	0.001	0.02	-0.0001

Combined Impacts	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [c, d]			Sea-Level Rise (cm) [c, e]	Ocean pH [f]
		2040	2060	2100	2040	2060	2100	2100	2100
Reductions Under High CAFE + High HDPUV Compared to the No-Action Alternative									
PC6LT8 + HDPUV14	2.4	0.09	0.32	0.60	0.001	0.002	0.003	0.07	-0.0005
	3.0	0.09	0.35	0.68	0.001	0.002	0.005	0.10	-0.0006
	3.9	0.09	0.34	0.72	0.001	0.002	0.005	0.15	-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.
[d] Temperature changes reported as 0.000 are more than zero but less than 0.001.
[e] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.
[f] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.
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, soils) by a greater extent. As a result, emissions reductions under higher emissions scenarios avoid more of the anthropogenic emissions that are otherwise expected to stay in the atmosphere (i.e., 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 5.4.2-6 and Table 5.4.2-7, 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 Alternatives PC6LT8 and HDPUV14 and Alternatives PC1LT3 and HDPUV4) 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 (SSP3-7.0 scenario), and the least impact in the scenarios with the lowest CO_2 emissions (SSP1-2.6). The total range of the impact of Alternatives PC6LT8 and HDPUV14 on CO_2 concentrations in 2100 is roughly 0.60 to 0.94 ppm across all six global emissions scenarios. Alternatives PC6LT8 and HDPUV14, using the SSP2-4.5 scenario and a 3.0°C (5.4°F) climate sensitivity, would have a 0.78 ppm decrease compared to Alternatives PC1LT3 and HDPUV4, which would have a 0.02 ppm decrease in 2100. The values for Alternatives PC2LT4 and HDPUV10 fall within the aforementioned ranges.

Table 5.4.2-6. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, [a] and Ocean pH for SSP2-4.5 for Selected Combined Impacts [b]

Combined Impacts	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c, d]			Sea-Level Rise (cm) [c, e]	Ocean pH [f]
		2040	2060	2100	2040	2060	2100	2100	2100
No-Action	2.4	467.16	518.61	558.07	1.597	2.015	2.298	51.76	8.3526
	3.0	472.65	532.40	587.78	1.852	2.370	2.826	67.12	8.3328
	3.9	478.62	546.17	617.33	2.132	2.807	3.427	86.81	8.3140
PC1LT3 + HDPUV4	2.4	467.15	518.59	558.05	1.597	2.014	2.297	51.76	8.3526
	3.0	472.64	532.39	587.76	1.852	2.370	2.826	67.11	8.3328
	3.9	478.61	546.15	617.30	2.132	2.807	3.427	86.80	8.3140
PC2LT4 + HDPUV10	2.4	467.14	518.56	557.98	1.597	2.014	2.297	51.75	8.3526
	3.0	472.63	532.35	587.68	1.852	2.370	2.826	67.11	8.3329
	3.9	478.61	546.12	617.22	2.132	2.807	3.426	86.79	8.3140
PC6LT8 + HDPUV14	2.4	467.07	518.28	557.38	1.596	2.013	2.294	51.70	8.3530
	3.0	472.56	532.05	587.00	1.851	2.368	2.822	67.03	8.3333
	3.9	478.53	545.81	616.52	2.131	2.805	3.422	86.69	8.3145
Reductions Under Low CAFE + Low HDPUV Compared to the No-Action Alternative									
PC1LT3 + HDPUV4	2.4	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.0	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.9	0.01	0.02	0.02	0.000	0.000	0.000	0.01	0.0000
Reductions Under Preferred CAFE + Preferred HDPUV Compared to the No-Action Alternative									
PC2LT4 + HDPUV10	2.4	0.02	0.05	0.09	0.000	0.000	0.000	0.01	-0.0001
	3.0	0.02	0.05	0.10	0.000	0.000	0.001	0.01	-0.0001
	3.9	0.02	0.05	0.10	0.000	0.000	0.001	0.02	-0.0001
Reductions Under High CAFE + High HDPUV Compared to the No-Action Alternative									
PC6LT8 + HDPUV14	2.4	0.09	0.33	0.69	0.001	0.002	0.003	0.06	-0.0005
	3.0	0.09	0.35	0.78	0.001	0.002	0.004	0.08	-0.0005
	3.9	0.09	0.36	0.81	0.001	0.002	0.005	0.12	-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.
[d] Temperature changes reported as 0.000 are more than zero but less than 0.001.
[e] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.
[f] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.
ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters; SSP = Shared Socioeconomic Pathway

Table 5.4.2-7. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, [a] and Ocean pH for SSP3-7.0 for Selected Combined Impacts [b]

Combined Impacts	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C) [c, d]			Sea-Level Rise (cm) [c, e]	Ocean pH [f]
		2040	2060	2100	2040	2060	2100	2100	2100
No-Action	2.4	484.64	572.03	791.90	1.737	2.390	3.610	65.72	8.2162
	3.0	490.19	587.76	838.31	2.008	2.788	4.340	83.24	8.1933
	3.9	496.65	604.77	886.21	2.308	3.292	5.202	106.54	8.1707
PC1LT3 + HDPUV4	2.4	484.63	572.01	791.87	1.736	2.390	3.610	65.72	8.2162
	3.0	490.18	587.74	838.29	2.008	2.788	4.339	83.24	8.1933
	3.9	496.64	604.75	886.17	2.308	3.292	5.202	106.54	8.1707
PC2LT4 + HDPUV10	2.4	484.62	571.98	791.79	1.736	2.389	3.610	65.72	8.2162
	3.0	490.17	587.70	838.20	2.008	2.788	4.339	83.23	8.1933
	3.9	496.63	604.71	886.09	2.308	3.292	5.202	106.53	8.1708
PC6LT8 + HDPUV14	2.4	484.54	571.68	791.10	1.735	2.388	3.607	65.67	8.2166
	3.0	490.09	587.40	837.44	2.007	2.786	4.336	83.17	8.1937
	3.9	496.55	604.40	885.27	2.307	3.290	5.198	106.44	8.1711
Reductions Under Low CAFE + Low HDPUV Compared to the No-Action Alternative									
PC1LT3 + HDPUV4	2.4	0.01	0.02	0.02	0.000	0.000	0.000	0.00	0.0000
	3.0	0.01	0.02	0.03	0.000	0.000	0.000	0.00	0.0000
	3.9	0.01	0.02	0.04	0.000	0.000	0.000	0.01	0.0000
Reductions Under Preferred CAFE + Preferred HDPUV Compared to the No-Action Alternative									
PC2LT4 + HDPUV10	2.4	0.02	0.05	0.10	0.000	0.000	0.000	0.01	-0.0001
	3.0	0.02	0.05	0.11	0.000	0.000	0.000	0.01	-0.0001
	3.9	0.02	0.05	0.13	0.000	0.000	0.001	0.02	-0.0001
Reductions Under High CAFE + High HDPUV Compared to the No-Action Alternative									
PC6LT8 + HDPUV14	2.4	0.09	0.35	0.80	0.001	0.002	0.003	0.06	-0.0004
	3.0	0.10	0.35	0.87	0.001	0.002	0.004	0.08	-0.0004
	3.9	0.10	0.37	0.94	0.001	0.002	0.004	0.10	-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*.
[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.
[d] Temperature changes reported as 0.000 are more than zero but less than 0.001.
[e] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.
[f] Ocean pH changes reported as 0.0000 are less than zero but more than -0.0001.
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 5.4.2-5 through Table 5.4.2-7. 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 SSP3-7.0 scenario (the reference scenario for the analysis of direct and indirect impacts, representing a high scenario of global GHG emissions), the action alternatives result in a greater reduction in global mean surface temperature than when modeled under SSP1-2.6 (representing a low scenario of global GHG emissions). This difference 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 5.4.2-5 through Table 5.4.2-7. 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.

5.4.3 Health, Societal, and Environmental Impacts of Climate Change

5.4.3.1 Introduction

As described in Section 5.4, *Environmental Consequences*, 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, *Environmental Consequences*, 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 relevant 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 differences between the climate change impacts of the Proposed Action and alternatives are far too small to address quantitatively in terms of impacts on the specific resources.[28] Consequently, the discussion of resource impacts in this section does not distinguish between the alternatives; rather,

[28] 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.

it provides a qualitative review of projected impacts (where the potential benefits of reducing GHG emissions would result in reducing in these impacts).

The health, societal, and environmental impacts are discussed in two parts: Section 5.4.3.2, *Sectoral Impacts of Climate Change*, discusses the sector-specific impacts of climate change, while Section 5.4.3.3, *Regional Impacts of Climate Change*, discusses the region-specific impacts of climate change.

5.4.3.2 Sectoral Impacts of Climate Change

This section briefly discusses how climate change resulting from global GHG emissions (including the U.S. LD transportation sector and HDPUVs under the Proposed Action and alternatives) could affect certain key natural and human resources. In addition, this section also highlights the significance of compound events, tipping points, and abrupt climate change.

NHTSA's analysis draws largely from recent studies and reports, including the IPCC AR6 (IPCC 2021a, 2021b, 2022a), the *IPCC Special Report on Global Warming of 1.5 °C* (IPCC 2018), the IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC 2019a), the IPCC *Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (IPCC 2019b), and the GCRP NCA4 (GCRP 2017, 2018a). 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 and have been well vetted, both by the climate change research community and by the U.S. government. For a detailed discussion of climate change impacts on key sectors, see Appendix E, Section E.5.2, *Sectoral Impacts of Climate Change.*

Freshwater Resources: Projected risks to freshwater resources are expected to increase due to changing temperature and precipitation patterns as well as the intensification of extreme events like floods and droughts, affecting water security in many regions of the world and exacerbating existing water-related vulnerabilities. For a detailed discussion of climate change impacts on freshwater resources and potential adaptation measures, see Appendix E, Section E.5.2.1, *Freshwater Resources.*

Terrestrial and Freshwater Ecosystems: Climate change is affecting terrestrial and freshwater ecosystems, including their component species and the services they provide. This impact can range in scale (from individual to population to species) and can affect all aspects of an organism's life, including its range, phenology, physiology, and morphology. For a detailed discussion of climate change impacts on terrestrial and freshwater ecosystems and potential adaptation measures, see Appendix E, Section E.5.2.2, *Terrestrial* and *Freshwater Ecosystems.*

Ocean Systems, Coasts, and Low-Lying Areas: Climate change-induced impacts on the physical and chemical characteristics of oceans (primarily through ocean warming and acidification) are exposing marine ecosystems to unprecedented conditions and adversely affecting life in the ocean and along its coasts. Anthropogenic climate change is also worsening the impacts on non-climatic stressors, such as habitat degradation, marine pollution, and overfishing. For a detailed discussion of climate change impacts on ocean and coastal systems and potential adaptation measures, see Appendix E, Section E.5.2.3, *Ocean Systems, Coasts, and Low-Lying Areas.*

Food, Fiber, and Forest Products: Through its impacts on agriculture, forestry and fisheries, climate change adversely affects food availability, access, and quality, and increases the number of people at risk of hunger, malnutrition, and food insecurity. For a detailed discussion of climate change impacts on food systems and potential adaptation measures, see Appendix E, Section E.5.2.4, *Food, Fiber, and Forest Products.*

Urban Areas: Extreme temperatures, extreme precipitation events, and rising sea levels are increasing risks to urban communities, their health, wellbeing, and livelihood, with the economically and socially marginalized being most vulnerable to these impacts. For a detailed discussion of climate change impacts on urban areas and potential adaptation measures, see Appendix E, Section E.5.2.5, *Urban Areas.*

Rural Areas: A high dependence on natural resources, weather-dependent livelihood activities, lower opportunities for economic diversity, and limited infrastructural resources subject rural communities to unique vulnerabilities to climate change impacts. For a detailed discussion of climate change impacts on rural areas and potential adaptation measures, see Appendix E, Section E.5.2.6*, Rural Areas.*

Human Health: Climate change can affect human health, directly through mortality and morbidity caused by heatwaves, floods and other extreme weather events, changes in vector-borne diseases, changes in water and food-borne diseases, and impacts on air quality as well as through indirect pathways such as increased malnutrition and mental health impacts on communities facing climate-induced migration and displacement. For a detailed discussion of climate change impacts on human health and potential adaptation measures, see Appendix E, Section E.5.2.7, *Human Health.*

Human Security: Climate change threatens various dimensions of human security, including livelihoods security, food security, water security, cultural identity, and physical safety from conflict, displacement and violence. These impacts are interconnected and unevenly distributed across regions and within societies based on differential exposure and vulnerability. For a detailed discussion of climate change impacts on human security and potential adaptation measures, see Appendix E, Section E.5.2.8, *Human Security.*

Stratospheric Ozone: There is strong evidence that anthropogenic influences, particularly the addition of GHGs and ozone-depleting substances to the atmosphere, have led to detectable reduction in stratospheric ozone concentrations and contributed to tropospheric warming and related cooling in the lower stratosphere. These changes in stratospheric ozone have further influenced the climate by affecting the atmosphere's temperature structure and circulation patterns. For a detailed discussion of how climate change may affect stratospheric ozone concentrations and associated feedbacks on climate, see Appendix E, Section E.5.2.9, *Stratospheric Ozone.*

Compound events: Compound events consist of combinations of multiple hazards that contribute to amplified societal and environmental impacts. Observations and projections show that climate change may increase the underlying probability of compound events occurring. To the extent the Proposed Action and alternatives would decrease the rate of CO_2 emissions relative to the relevant No-Action Alternative, they would contribute to the general decreased risk of extreme compound events. While this rulemaking alone would not necessarily decrease compound event frequency and severity from climate change, it would be one of many global actions that, together, could reduce these effects. For a detailed discussion of compound events and their impacts, see Appendix E, Section E.5.2.10, *Compound Events.*

Tipping Points and Abrupt Climate Change: Tipping points represent 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. For example, the melting of the Greenland ice sheet, Arctic sea-ice loss, destabilization of the West Antarctic ice sheet, and deforestation in the Amazon and dieback of boreal forests are seen as potential tipping points that can cause large-scale, abrupt changes in the climate system and lead to significant impacts on human and natural systems. For a detailed discussion of compound events and their impacts, see Appendix E, Section E.5.2.11, *Tipping Points and Abrupt Climate Change.*

5.4.3.3 Regional Impacts of Climate Change

In response to the MY 2017–2025 CAFE Standards Draft EIS, NHTSA received a public comment that is reproduced and responded to in Final EIS Chapter 9, Section 9.3.2.1, *Methodology*. The comment notes 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 2016b), 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, which 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). 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 2016b), and the GCRP NCA4 (GCRP 2017, 2018a). The NCA4 provides regional scale observations and projections for climatic factors (GCRP 2017), and sectoral impacts of climate change for each region of the United States (GCRP 2018a). The regions addressed 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, some 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 relevant 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.

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 detail in Appendix E, Section E.5.2, *Sectoral Impacts of Climate Change*.

CHAPTER 6 LIFE-CYCLE ASSESSMENT IMPLICATIONS OF VEHICLE MATERIALS

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 or electricity for vehicle use and sourcing of material inputs, contributes to greenhouse gas (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 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 saves 93 percent of the energy required to produce aluminum from bauxite ore and reduces the carbon footprint by 94 percent (Wang 2022).[1]

In this EIS, NHTSA uses the following terms:

- *Fuel cycle* refers to raw material extraction for fuels, fuel transportation, fuel refining, and fuel delivery (discussed in Chapter 3, *Energy*).
- *Vehicle operation* refers to the vehicle use phase.
- *Vehicle cycle* refers to raw material extraction for materials used for vehicle manufacture, material processing for materials used for vehicle manufacture, component manufacture and vehicle assembly, and vehicle end of life (i.e., disposal and recycling).

The vehicle life cycle includes three main phases: **(1) the vehicle production phase** including production of fuel or electricity for vehicle use, raw material extraction and production of vehicle inputs, and the vehicle manufacture; **(2) the use/operation phase** of vehicle operation, including fuel combustion and/or electricity use and vehicle maintenance; and **(3) the vehicle end-of-life phase** of recycling or disposal of the vehicle and vehicle parts. In addition, transportation of fuel and materials occurs between each of these phases.

A vehicle LCA study can identify major sources of environmental impacts throughout a vehicle's life cycle, and it can identify opportunities for impact mitigation. 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 can decrease potential emissions during vehicle use but increase them during raw material extraction and manufacturing (with some exceptions such as high-strength steel) (e.g., Kim and Wallington 2013; Dai et al. 2016, 2017a; Wolfram et al. 2021). Because a high proportion of total

[1] This is based on aluminum produced for the North American market and recycled in North America. This recent study found that increasing the aluminum recycling rate by just 1 percent can lower the overall carbon footprint by 80 kilograms (kg) carbon dioxide equivalent per 1,000 kg of aluminum products (Wang 2022).

emissions occur during the vehicle's use for internal combustion engine (ICE) vehicles and hybrid electric vehicles (HEVs), the fuel-saving benefits from improved fuel economy often outweigh the additional energy investment associated with material changes (Cheah et al. 2009; Dai et al. 2017a; Milovanoff et al. 2019, Wolfram et al. 2021). However, some studies have found that the emissions occurring during manufacturing of more advanced materials can exceed those occurring during ICE vehicle use (e.g., Kim and Wallington 2013; Kelly et al. 2015; Wu et al. 2019). For battery electric vehicles (BEVs), while the battery increases vehicle weight, the use of low-carbon electricity for charging during the vehicle operation phase brings down the life-cycle GHG emissions below those of ICE vehicles (Pathak et al. 2022, Kelly et al. 2022). The reliance of lithium-ion batteries on critical mineral supplies and steep rise in demand for EVs has presented other environmental concerns, such as those related to resource availability and mining, and increased the importance placed on recycling (Pathak et al. 2022). To meet the growing demand, the U.S. government and industry are prioritizing investment in domestic lithium production projects and battery recycling (DOE 2023d).

In prior CAFE EISs, NHTSA qualified that a complete LCA of the impacts of a CAFE rulemaking, which is beyond the scope of an EIS, would require extensive data collection on many variables that are highly uncertain. These variables included:

- The future design and technology response of passenger car and light truck manufacturers to a given set of fuel economy standards.
- An applied technology's manufacturing processes, material choice, application to vehicles, and disposal after use.
- Interactions between applications of multiple fuel savings technologies.
- Regional fuel sourcing projections and electric grid compositions.
- 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.

In this rulemaking action to set CAFE and heavy-duty pickup truck and van (HDPUV) fuel efficiency (FE) standards, different regulatory alternatives (both for CAFE and HDPUV FE standards) are based on performance and the alternative standards do not mandate the adoption of specific technologies. As a result, NHTSA cannot know precisely how manufacturers will choose from a suite of available technologies to meet a particular regulatory alternative. Because the information necessary to quantitatively differentiate between the alternatives in a light-duty (LD) vehicle or HDPUV LCA is too extensive and unknowable, the intent of the LCA discussion in prior CAFE EISs was to understand the life-cycle implications of energy production, material substitution, and FE technologies for passenger cars and light trucks.

To provide this understanding to the decision-makers and the public, and in light of the uncertainties outlined above, NHTSA identified LCA studies across a range of sources, including academic journals and publications of industry associations and nongovernmental organizations, and provided a qualitative summary of those studies. Prior CAFE EIS LCA discussions focused on existing credible scientific information to evaluate the most significant environmental impacts from some of the fuels, materials, and technologies that could be used to comply with different levels of standards. The previous LCA EIS chapters also discussed the extent to which different levels of standards 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. NHTSA incorporates by reference the qualitative discussion of vehicle LCAs presented in previous CAFE EISs.[2]

For this EIS, analysis of the environmental impacts of a vehicle's life cycle are discussed throughout several chapters and consider passenger cars, light trucks, and HDPUVs. Physical fuel life-cycle impacts (e.g., gallons of fuel used, water and land use impacts from feedstock extraction) are discussed in Chapter 3, *Energy*. Air quality and climate impacts reported in Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, include upstream emissions from several stages of the fuel life cycle.[3] Upstream emissions from the fuel cycle phase account for around 20 percent of total GHG emissions from 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 vehicle manufacturing materials or technologies that might be applied to improve fuel efficiency, including emissions related to vehicle manufacturing.

This chapter synthesizes literature related to the vehicle cycle phase; that is, the impacts related to raw material extraction for materials used for vehicle manufacture, material processing for materials used for vehicle manufacture, component manufacture and vehicle assembly, and vehicle end of life (i.e., disposal and recycling). The purpose of this chapter is to provide an understanding of the life-cycle implications of vehicle cycle phase for LD vehicles and HDPUVs. As discussed above, there are many uncertain factors in manufacturer acceptance and future action. A quantitative analysis is not included with this EIS, but a qualitative discussion is included to inform the decision-maker about the vehicle cycle phases and impacts of commonly used vehicle materials that could be used as manufacturers respond to the standards. Section 6.2, *Raw Material Extraction through Vehicle Assembly*, discusses raw material extraction, processing, and component manufacture for the most common non-battery components, and separately for batteries, and discusses vehicle assembly impacts. Section 6.3, *Vehicle Disposal and Recycling*, synthesizes literature related to the impacts from non-battery powertrain vehicle disposal and recycling, and battery disposal and recycling. Section 6.4, *Conclusions*, provides a summary of the findings alongside the CAFE Model's projections of vehicle technology penetration for the CAFE and HDPUV FE alternatives considered.

6.2 Raw Material Extraction through Vehicle Assembly

This section discusses environmental impacts occurring during raw material extraction, material processing, and manufacture of vehicle components, as well as vehicle assembly. Section 6.2.1, *Non-Battery Components*, presents findings related to non-battery component materials, focusing on those that comprise the greatest share of vehicle content. Section 6.2.2, *Battery Components*, presents findings related to EV batteries, focusing on lithium-ion batteries. Section 6.2.3, *Vehicle Assembly*,

[2] Chapter 6 of the *Final Environmental Impact Statement for Corporate Average Fuel Economy Standards, Model Years 2017–2025* (NHTSA 2012); Chapter 6 of the *Final Environmental Impact Statement for Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles* (NHTSA 2016a); Chapter 6 of the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule MY 2021–2026 EIS (NHTSA 2020); and Chapter 6 of the *Supplemental Environmental Impact Statement for Corporate Average Fuel Economy Standards, Model Years 2024–2026* (NHTSA 2022).

[3] Specifically, 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); and electricity generation.

presents findings related to the manufacture and assembly of the remainder of the vehicle beyond vehicle batteries.

Steel comprises the vast majority of U.S. vehicle components, followed by plastics and aluminum (Kelly et al. 2022; American Chemistry Council [ACC] 2020). Table 6.2-1 and Table 6.2-2 show the material composition by component for midsize sedans and small sport utility vehicles (SUVs), respectively (Kelly et al. 2022), and Table 6.2-3 shows the material composition for LD vehicles in pounds and percentage between 2009 and 2019 in the North American market (ACC 2020). Although LD vehicle weight has been gradually increasing over time with the popularity of larger passenger vehicles (i.e., crossovers, SUVs, and light trucks), that growth has been tempered by the replacement of heavier materials used in those vehicles (particularly steel) with lighter materials (including aluminum, carbon fiber, and plastic). The Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model analysis (Kelly et al. 2022) shows that plastics comprise a larger share of material composition than aluminum, while the ACC analysis (ACC 2020) shows the reverse; this could partly be explained by geographical coverage of the studies with the GREET analysis' focus on U.S. vehicles and the ACC analysis' focus on vehicles within the North American market. According to the latter report, the overall share of conventional steel used in vehicles decreased by 19 percent between 2009 and 2019, while the share of high- and medium-strength steel and aluminum increased by 55 percent and 34 percent, respectively (ACC 2020). Steel use dominates vehicle content regardless of vehicle technology type—from gasoline ICE vehicles to all types of BEVs—as shown in Table 6.2-4 and Table 6.2-5 (Kelly et al. 2022).

In this chapter, data on energy use, water use, and emissions, where available for vehicle components and processes from the GREET2 Vehicle-Cycle Model,[4] a public-domain model developed by Argonne National Laboratory (ANL) as part of its GREET Model Series, are presented in respective sections.

Table 6.2-1. Material Composition of Components for Midsize Sedans, Excluding Batteries (%)

Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	Magnesium	GFRP	Glass	Average Plastic	Rubber	Stainless Steel	CFRP	Cast Iron	Others
Glider (chassis, body, etc.)													
Body	79	3	–	–	–	–	6	10	1	–	–	–	–
Exterior	29	2	–	8	–	7	8	43	2	–	–	–	–
Interior	33	3	1	4	–	1	–	46	5	–	–	–	–
Chassis	81	2	3	2	–	–	–	3	8	–	–	–	–
Powertrain													
Engine	44	5	39	2	–	3	–	5	2	–	–	–	–
Engine fuel storage system	30	–	–	3	–	–	–	63	3	–	–	–	–
Exhaust	92	2	4	–	–	–	–	–	1	–	–	–	–
Powertrain electrical	17	2	3	28	–	–	–	50	1	–	–	–	–
Powertrain thermal	17	21	7	5	–	9	–	33	9	–	–	–	–

[4] https://greet.es.anl.gov/index.php?content=download2x

Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	Magnesium	GFRP	Glass	Average Plastic	Rubber	Stainless Steel	CFRP	Cast Iron	Others
Fuel cell stack & BOP	19	17	–	2	–	3	–	17	6	31	–	–	6
H_2 storage and BOP	9	–	–	–	–	4	–	8	–	8	66	–	4
Transmission													
ICE vehicle	66	5	23	2	–	1	–	3	–	–	–	–	–
HEV, FCEV, and PHEV	61	20	–	19	–	–	–	–	–	–	–	–	–
Traction motor	36	–	36	28	–	–	–	–	–	–	–	–	–
Wheels component (50% wheels and 50% tires by mass)													
Wheels	–	–	–	100	–	–	–	–	–	–	–	–	–
Tires	33	–	–	–	–	–	–	67	–	–	–	–	–

Notes:
Source: Kelly et al. 2022:Table 31
BOP = Balance of Plant; CFRP = carbon fiber reinforced plastic; FCEV = fuel cell electric vehicle; GFRP = glass fiber reinforced plastic; HEV = hybrid electric vehicle; ICE = internal combustion engine; PHEV = plug-in hybrid electric vehicle

Table 6.2-2. Material Composition of Components for Small SUVs, Excluding Batteries (%)

Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	Magnesium	GFRP	Glass	Average Plastic	Rubber	Stainless Steel	CFRP	Cast Iron	Others
Glider (chassis, body, etc.)													
Body	78	3	–	1	–	–	6	12	1	–	–	–	–
Exterior	21	9	1	12	–	4	9	42	2	–	–	–	–
Interior	40	2	1	4	–	1	1	45	4	–	–	–	2
Chassis	78	2	5	2	–	1	–	4	8	–	–	–	–
Powertrain													
Engine	38	4	40	3	–	3	–	8	2	–	–	1	–
Engine fuel storage system	20	3	–	3	–	1	–	70	2	–	–	–	–
Exhaust	77	2	19	–	–	–	–	1	1	–	–	–	–
Powertrain electrical	10	1	2	31	–	2	–	53	1	–	–	–	–
Powertrain thermal	16	21	4	4	–	6	–	38	11	–	–	–	–
Fuel cell stack & BOP	19	17	–	2	–	3	–	17	6	31	–	–	6
H_2 storage and BOP	9	–	–	–	–	4	–	8	–	8	66	–	4

Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	Magnesium	GFRP	Glass	Average Plastic	Rubber	Stainless Steel	CFRP	Cast Iron	Others
Transmission													
ICE vehicle	67	4	21	3	–	1	–	5	–	–	–	–	–
HEV, FCEV, and PHEV	61	20	–	19	–	–	–	–	–	–	–	–	–
Traction motor	36	–	36	28	–	–	–	–	–	–	–	–	–
Wheels component (50% wheels and 50% tires by mass)													
Wheels	–	–	–	100	–	–	–	–	–	–	–	–	–
Tires	33	–	–	–	–	–	–	67	–	–	–	–	–

Notes:
Source: Kelly et al. 2022:Table 32
BOP = Balance of Plant; CFRP = carbon fiber reinforced plastic; FCEV = fuel cell electric vehicle; GFRP = glass fiber reinforced plastic; HEV = hybrid electric vehicle; ICE = internal combustion engine; PHEV = plug-in hybrid electric vehicle

Table 6.2-3. Average Materials Content of U.S./Canada Light Vehicles (lbs/vehicle and % of total weight)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Average Weight	**3,854**	**3,867**	**3,920**	**3,816**	**3,822**	**3,845**	**3,895**	**3,935**	**3,950**	**3,976**	**3,977**
Regular Steel	1,462	1,421	1,405	1,334	1,321	1,307	1,290	1,293	1,217	1,210	1,190
High- & Medium-Strength Steel	510	541	594	604	612	632	680	719	761	769	793
Stainless Steel	67	70	71	66	72	71	73	72	71	71	71
Other Steels	30	31	31	29	31	31	31	31	31	30	29
Iron Castings	201	236	255	263	264	271	260	241	241	248	238
Aluminum	319	332	337	342	348	361	387	404	414	426	427
Magnesium	11	11	11	10	10	9	9	10	10	9	11
Copper and Brass	69	73	72	71	70	67	66	68	70	69	68
Lead	41	40	39	35	35	35	35	35	38	37	38
Zinc Castings	9	9	9	8	8	8	8	8	9	9	10
Powder Metal	40	40	41	43	44	45	44	43	44	43	42
Other Metals	5	5	5	5	5	4	5	5	5	5	5
Plastics/Polymer Composites	365	344	340	325	323	323	328	329	345	350	355
Rubber	245	228	224	207	199	198	199	199	208	211	217
Coatings	35	35	32	28	28	28	28	29	30	29	29
Textiles	56	54	49	49	50	49	45	45	47	47	47
Fluids and Lubricants	214	215	217	215	218	220	220	222	222	222	220
Glass	87	90	96	93	94	94	93	92	95	97	94
Other	88	90	91	89	90	91	93	91	92	95	94

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
As a Percent of Total Weight	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Regular Steel	37.9%	36.8%	35.8%	35.0%	34.6%	34.0%	33.1%	32.9%	30.8%	30.4%	29.9%
High- & Medium-Strength Steel	13.2%	14.0%	15.1%	15.8%	16.0%	16.4%	17.5%	18.3%	19.3%	19.3%	19.9%
Stainless Steel	1.7%	1.8%	1.8%	1.7%	1.9%	1.8%	1.9%	1.8%	1.8%	1.8%	1.8%
Other Steels	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.7%
Iron Castings	5.2%	6.1%	6.5%	6.9%	6.9%	7.0%	6.7%	6.1%	6.1%	6.2%	6.0%
Aluminum	8.3%	8.6%	8.6%	9.0%	9.1%	9.4%	9.9%	10.3%	10.5%	10.7%	10.7%
Magnesium	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.3%	0.2%	0.3%
Copper and Brass	1.8%	1.9%	1.8%	1.9%	1.8%	1.8%	1.7%	1.7%	1.8%	1.7%	1.7%
Lead	1.1%	1.0%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%	1.0%	0.9%	1.0%
Zinc Castings	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Powder Metal	1.0%	1.0%	1.0%	1.1%	1.2%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%
Other Metals	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Plastics/Polymer Composites	9.5%	8.9%	8.7%	8.5%	8.4%	8.4%	8.4%	8.4%	8.7%	8.8%	8.9%
Rubber	6.4%	5.9%	5.7%	5.4%	5.2%	5.1%	5.1%	5.1%	5.3%	5.3%	5.5%
Coatings	0.9%	0.9%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.8%	0.7%	0.7%
Textiles	1.5%	1.4%	1.3%	1.3%	1.3%	1.3%	1.2%	1.1%	1.2%	1.2%	1.2%
Fluids and Lubricants	5.6%	5.6%	5.5%	5.6%	5.7%	5.7%	5.7%	5.6%	5.6%	5.6%	5.5%
Glass	2.2%	2.3%	2.4%	2.4%	2.5%	2.4%	2.4%	2.3%	2.4%	2.4%	2.4%
Other	2.3%	2.3%	2.3%	2.3%	2.4%	2.4%	2.4%	2.3%	2.3%	2.4%	2.4%

Source: ACC 2020:Table 2

Table 6.2-4. Material Composition for Midsize Sedans by Vehicle Type, Excluding Batteries (%)

Current Technology	Gasoline ICEV	E85 ICEV	Diesel ICEV	CNG	HEV	FCEV 300	FCEV 400	PHEV50	BEV200	BEV300	BEV400
Steel	60	60	59	59	60	54	53	61	63	63	63
Cast iron	2	2	2	2	3	-	-	2	-	-	-
Wrought aluminum	5	5	5	5	3	4	4	3	2	2	2
Cast aluminum	8	8	9	9	10	7	7	10	8	8	8
Copper	2	2	3	3	4	3	3	5	4	4	4
Glass	2	2	2	2	2	2	2	2	3	3	3
Average plastic	15	15	15	15	13	14	14	13	15	15	15
Rubber	4	4	4	4	3	4	4	3	4	4	4
Stainless steel	-	-	-	-	-	4	4	-	-	-	-
CFRP	-	-	-	-	-	4	6	-	-	-	-
Others	1	1	1	1	1	3	3	1	1	1	1
Future Technology	**Gasoline ICEV**	**E85 ICEV**	**Diesel ICEV**	**CNG**	**HEV**	**FCEV 300**	**FCEV 400**	**PHEV50**	**BEV200**	**BEV300**	**BEV400**
Steel	59	59	58	58	60	55	54	60	62	62	62
Cast iron	3	3	3	3	3	-	-	3	-	-	-
Wrought aluminum	5	5	5	5	3	4	4	3	2	2	2
Cast aluminum	8	8	9	9	10	7	7	10	8	9	9
Copper	2	2	3	2	5	3	3	5	4	4	4
Glass	2	2	2	2	2	2	2	2	3	3	3
Average plastic	15	15	15	15	13	14	14	13	15	15	15
Rubber	4	4	4	4	3	4	4	3	4	4	4
Stainless steel	-	-	-	-	-	3	4	-	-	-	-
CFRP	-	-	-	-	-	4	5	-	-	-	-
Others	1	1	1	1	1	3	3	1	1	1	1

Notes:
Source: Kelly et al. 2022:Table 33
BEV = battery electric vehicle; CNG = compressed natural gas; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; ICEV = internal combustion engine vehicle

Table 6.2-5. Material Composition for Small SUVs by Vehicle Type, Excluding Batteries (%)

Current Technology	Gasoline ICEV	E85 ICEV	Diesel ICEV	CNG	HEV	FCEV 300	FCEV 400	PHEV50	BEV200	BEV300	BEV400
Steel	59	59	58	57	60	53	52	61	62	62	62
Cast iron	2	2	2	2	2	-	-	2	-	-	-
Wrought aluminum	5	5	5	5	3	4	4	3	3	3	3
Cast aluminum	6	6	7	7	8	5	5	8	6	6	6
Copper	3	3	3	3	5	3	3	5	4	4	4
Glass	2	2	2	2	2	2	2	2	3	3	3
Average plastic	16	16	16	16	13	15	14	13	15	15	15
Rubber	6	6	6	6	5	6	6	5	6	6	6
Stainless steel	-	-	-	-	-	4	5	-	-	-	-
CFRP	-	-	-	-	-	5	6	-	-	-	-
Others	1	1	1	1	1	3	3	1	1	1	1
Future Technology	**Gasoline ICEV**	**E85 ICEV**	**Diesel ICEV**	**CNG**	**HEV**	**FCEV 300**	**FCEV 400**	**PHEV50**	**BEV200**	**BEV300**	**BEV400**
Steel	58	58	57	57	60	55	54	60	62	62	62
Cast iron	3	3	3	3	3	-	-	2	-	-	-
Wrought aluminum	5	5	5	5	3	4	4	3	3	3	3
Cast aluminum	6	6	7	7	8	5	5	8	6	6	6
Copper	3	3	3	3	5	3	3	5	4	4	4
Glass	2	2	2	2	2	2	2	2	3	3	3
Average plastic	16	16	16	16	13	15	14	13	15	15	15
Rubber	6	6	6	6	5	6	6	5	6	6	6
Stainless steel	-	-	-	-	-	4	4	-	-	-	-
CFRP	-	-	-	-	-	4	6	-	-	-	-
Others	1	1	1	1	1	3	3	1	1	1	1

Notes:
Source: Kelly et al. 2022:Table 34
BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; ICEV = internal combustion engine vehicle

Table 6.2-6 presents the material composition of lead-acid and lithium-ion vehicle batteries (Kelly et al. 2022). While lead-acid batteries have historically been the preferred choice for ICE vehicles, lithium-ion batteries are the favored option for electric vehicles (EVs) and plug-in hybrid EVs (PHEVs). For more information on this transition and various chemistry makeups of lithium-ion batteries, please refer to Section 6.3.2.2, *Lithium-Ion Batteries*.

Table 6.2-6. Material Composition of Vehicle Batteries (%)[5]

Material	Lead-Acid Battery	Li-ion Battery			
		Gasoline HEVs, H_2 FCEVs (NMC111)	PHEV50 (NMC111)	EVs (NMC111)	EVs (NMC811)
Lead	69	–	–	–	–
Active material	–	19	31	38	32
Wrought aluminum	–	18	16	17	18
Copper	–	18	12	7	7
Graphite/carbon	–	10	16	20	24
Electronic parts	–	15	5	2	2
Plastic: polypropylene	6	2	1	1	1
Plastic: polyethylene	–	0	0	0	0
Plastic: polyethylene terephthalate	–	0	0	0	0
Electrolyte: ethylene carbonate	–	4	5	4	4
Electrolyte: dimethyl carbonate	–	4	5	4	4
Electrolyte: $LiPF_6$	–	1	2	1	1
Steel	–	2	1	1	1
Coolant: glycol	–	4	4	3	3
Binder	–	1	1	2	2
Water	14	–	–	–	–
Sulfuric acid	8	–	–	–	–
Fiberglass	2	–	–	–	–
Others	1	–	–	–	–

Source: Kelly et al. 2022:Table 35
Note: There are several cathode chemistries in use either in HEVs or BEVs. This table provides an example of material composition for NMC111 and NMC811 as modeled in GREET.

[5] The *active material* listing in Table 6.2-6 includes cathode chemistries such as nickel, cobalt, aluminum, manganese, silicon, and others and constitutes the highest material composition percentage of lithium-ion vehicle batteries.

6.2.1 Non-Battery Components

This section discusses the life-cycle GHG, energy, and other environmental impacts for non-battery vehicle components focusing on materials that account for the largest shares of vehicle weight and/or with production activities with more notable adverse impacts on the environment. In this section, the environmental impacts of different materials are assessed through the extraction, processing, and manufacturing phases, with some discussion on the vehicle use phase with these materials. Analysis of the environmental impacts of vehicle materials during the end-of-life phase are detailed in Section 6.3, *Vehicle Disposal and Recycling*. The materials addressed include those that comprise the vehicle glider and powertrain, such as steel, aluminum, plastics/polymer composite; fluids and lubricants; iron castings; and additional metals used in the vehicle powertrain. The mining and processing of metals that are used in the vehicle glider and powertrain are generally the most GHG-intensive parts of the vehicle life cycle for those metals; additional emissions result when the components are recycled.

6.2.1.1 Steel

Currently, steel comprises the greatest share of a vehicle's weight. Excluding batteries, Kelly et al. (2022) report that steel currently accounts for about 60 percent of the material composition of gasoline ICE vehicles and around 63 percent of BEVs in the United States. ACC 2020 reports that steel accounted for about 50 percent of LD vehicle weight in 2019 in North America, comprised of about 30 percent conventional or mild steel (a lower-carbon steel) and 20 percent high- and medium-strength steel (higher-carbon steels). Conventional or mild steel is the most common form of steel. While it is weaker than other steel alternatives, it is less expensive to produce. Medium- and high-strength steel materials are stronger alternatives and, as a result, less material is needed to fulfill the same function as conventional steel (Ilic et al. 2012).

Iron and steel production and metallurgical coke production rank as the fourth largest source of carbon dioxide (CO_2) emissions in the United States (EPA 2023a). In 2020, steel production resulted in 2.6 billion metric tons of direct CO_2 emissions, approximately 7 to 9 percent of global emissions (World Steel Association 2021). In 2021, an average of 1.4 metric tons of direct CO_2 emissions were emitted for every 1 metric ton of steel produced (International Energy Agency [IEA] 2022b). This is about 13 percent of the emissions intensity of mining and producing aluminum (IEA 2022c). Virgin steel manufacture involves iron ore extraction and processing, coke production, sintering, and production using a blast furnace and basic oxygen furnace (BOF), among other steps. The blast furnace and BOFs typically use coke as an input. Recycled steel production involves use of an electric arc furnace (EAF), which relies on electricity to melt steel scrap. Compared to BOFs, EAFs use electricity rather than coal for fuel and instead primarily use recycled scrap steel and direct reduced iron as inputs. As of 2021, approximately 72 percent of global steel was produced using BOFs and 28 percent was produced using EAFs (IEA 2022b). In general, secondary steel production made using EAFs is estimated to emit just 35 percent of the emissions level of primary steel production using BOFs (Di Schino 2019). Table 6.2.1-1 presents the steel production inputs, energy use, and emissions for different processes for virgin and recycled steel production, as used in the GREET2 vehicle life-cycle model (Kelly et al. 2022). While EAFs require more input fuels (mostly electricity), they require a small amount of intermediate fuel compared to blast furnaces and BOFs (0.17 million British thermal units [MMBtu] compared to 11 MMBtu).

Table 6.2.1-1. Steel Production Inputs, Energy Use, and Emissions (per short ton of steel)

Input/Emission and Unit		Virgin Steel										Recycled/Stainless Steel		
			Steel Production											
		Iron Ore Extraction and Processing[a]	Coke Production[a]	Sintering[a]	Blast Furnace[a]	Basic Oxygen Furnace[a]	Hot rolling[a]	Skin Mill[a]	Cold Rolling[a]	Galvanizing[a]	Stamping[b]	Electric Arc Furnace[a]	Rod and Bar Mill[a]	Machining[c]
Input fuel														
Residual oil	MMBtu	0.18	–	–	1.13	–	–	–	–	–	–	–	–	–
Gasoline	MMBtu	–	–	–	–	–	–	–	–	–	–	–	–	–
Diesel	MMBtu	0.03	–	–	–	–	–	–	–	–	–	–	–	–
NG	MMBtu	0.19	–	–	0.30	0.04	0.63	–	–	–	–	1.19	2.16	–
Coal	MMBtu	–	15.41	–	–	–	–	–	–	–	–	–	–	–
Electricity	MMBtu	1.39	0.17	0.06	0.35	0.65	0.70	0.04	1.40	0.70	0.86	4.99	1.08	0.54
Intermediate fuel														
Coke	MMBtu	–	–	0.15	10.07	–	–	–	–	–	–	0.17	–	–
Blast furnace gas	MMBtu	–	0.36	–	–	0.33	0.03	0.03	0.25	0.18	–	–	–	–
Coke oven gas	MMBtu	–	–	0.02	0.55	0.06	1.29	–	0.34	1.12	–	–	–	–
Material														
Limestone	ton	–	–	0.009	0.043	–	–	–	–	–	–	–	–	–
Lime	ton	–	–	–	–	0.063	–	–	–	–	–	–	–	–
Iron ore	ton	–	–	0.002	1.144	–	–	–	–	–	–	–	–	–
Intermediate steel product	ton	–	–	–	–	–	1.03	1.02	1.05	1.00	1.00	–	1.04/1.61 [d]	1.00
Non-combustion emissions														
Volatile organic compound	ton	–	0.002	–	0.001	–	–	–	–	–	–	–	–	–
CO	ton	–	–	0.003	0.016	0.002	–	–	–	–	–	0.003	–	–
CO_2	ton	–	–	0.032	0.026	–	–	–	–	–	–	0.026	–	–

Notes:
[a] Source: Markus Engineering Services (2002)
[b] Source: Dai et al. (2017a)
[c] Source: Sullivan et al. (2010)
[d] 1.04 and 1.61 short tons of intermediate steel from electric arc furnace are needed per short ton of recycled and stainless-steel products, respectively.
Source: Kelly et al. 2022:Table 36

Pressure to meet Paris Agreement climate commitments, automobile manufacturers' efforts to reduce their carbon footprint, and consumer demand for lower-carbon steel have pushed the steel industry to produce less carbon-intensive products (Hoffmann et al. 2020). One method of lowering steel's carbon intensity is transitioning from production of steel using the primary steelmaking process with BOFs to production of secondary steel with EAFs. Steel manufacturers are also making efforts to improve the efficiency of BOFs. The degree to which EAFs are an effective alternative for achieving decarbonization is partially dependent on the share of renewable energy sources powering the grid. Currently, the share of regional electricity grids made up by renewable energy varies depending on the fuel sources used to generate electricity in each region, as discussed in Chapter 3, Section 3.2.2.2, *Region-Specific Electricity Grid Impacts*. Regions with a fuel mix primarily composed of carbon-intensive fuels such as coal will not receive as much of a carbon-intensity reduction in steel production using EAFs. High-quality scrap steel is also important in this process. Because of these factors, the optimal decarbonization strategy for steel manufacturing can differ from one location to another (Hoffmann et al. 2020).

The life-cycle impacts of vehicles that use steel can also be improved by substituting conventional steel with other alternatives. Lighter-weight materials offer a way to decrease vehicle use phase emissions by improving vehicle fuel efficiency. Several studies have examined the life-cycle impacts of substituting conventional steel components in vehicles with lighter-weight materials like high-strength steel, aluminum, and plastics (Mayyas et al. 2012; Shinde et al. 2016; Kelly et al. 2015; Modaresi et al. 2014; Hardwick and Outteridge 2015; Sebastian and Thimons 2017; Milovanoff et al. 2019). High-strength steel provides the greatest weight-reduction benefits in structural or load-bearing applications, where strength is a key factor in material selection (compared to aluminum and other potential substitutes, which are lighter but less strong) (Cheah and Heywood 2011; Kim et al. 2010a; Koffler and Provo 2012; Mohapatra and Das 2014). In general, the reduced energy use and GHG emissions during the vehicle use phase due to high-strength steel material substitution is greater than the increased energy use (and associated GHG emissions) needed to manufacture these lightweight materials (Modaresi et al. 2014; Sebastian and Thimons 2017). Lightweight materials can also be especially helpful for improving the efficiency and driving range of EVs (U.S. Department of Energy [DOE] no date [b]). The total life-cycle impact of using high-strength steel as a substitute for conventional steel is also dependent on how much recycled steel is used in production of the vehicle and the end-of-life treatment of the steel (Sebastian and Thimons 2017). The more recycled steel used in production and the higher the end-of-life recycling rate, the greater the emissions reduction potential of substituting high-strength steel for conventional steel.

Steel production can have other adverse environmental impacts. The mining process can degrade land, contaminate nearby soil, and pollute water sources. Toxic chemicals from mine waste can enter nearby streams, lakes, and other groundwater sources either through accidental spills or the discharge of contaminated wastewater from the mines. This pollution can have negative impacts on the surrounding ecosystem, such as habitat degradation, surface water and groundwater contamination, and health risks for both wildlife and nearby residential communities (Jhariya et al. 2016).

Despite the high risk of manufacturing activities generally on nearby environments, current research into the environmental impact of steel production is lagging. Recent studies of small samples of steel processing plants have found specific environmental impacts. One study of a plant in Canada found that, in addition to CO_2 and other GHGs, the steel plant emits sulfur dioxide (SO_2), nitrogen dioxide, and carbon monoxide (CO), and that concentrations of these emissions were 50 to 100 percent higher in areas immediately surrounding the steel plant (compared to 5 kilometers away) (Liu et al. 2014). Another study in Australia found that soil near two iron and steelmaking facilities had a larger concentration of toxic metals such as manganese, titanium, zinc, chromium, and lead. This was especially true near the facility using BOFs for steel production (Strezov and Chaudhary 2017). Studies show that increased exposure to these chemicals and metals can have adverse impacts on human health and the environment. SO_2, nitrogen oxides (NO_X), and CO are all included in the EPA's criteria pollutants list because of the risk they pose to human respiratory and cardiovascular health in high concentrations. SO_2 and NO_X can also contribute to acid rain, which harms nearby ecosystems (EPA 2022j). Deposits of chromium, zinc, lead, and other heavy metals in soil can be absorbed by plants or end up in drinking water. Exposure to these heavy metals through food or drinking water can harm cardiovascular health, cause nerve damage, and increase the risk of cancer and diabetes (Rehman et al. 2018).

In summary:

- Steel comprises the greatest share of a vehicle's weight.
- Steel manufacture is an energy- and GHG-intensive process, but less so than virgin aluminum production.
- Production with EAFs is less energy intensive and results in lower GHG emissions than production using blast furnaces and BOFs; however, the extent to which they lower emissions is dependent on the grid mix powering the EAFs.
- Increasing secondary steel production with EAFs can help to lower the emissions of the steel industry but will also require improvements in steel recycling processes and continued expansion of renewable energy utilization across energy grids.
- Substitution of conventional steel with high-strength steel offers net energy and GHG reduction benefits across the vehicle life cycle—the reduced energy use and GHG emissions during the vehicle use phase outweighs the increased energy use (and associated GHG emissions) during the vehicle production phase.
- Other environmental impacts from raw material extraction for steel production include degradation of land, contamination of nearby soil, and pollution of water. Steel production also emits criteria air pollutants and can lead to soil contamination.

6.2.1.2 Plastics/Polymer Composites

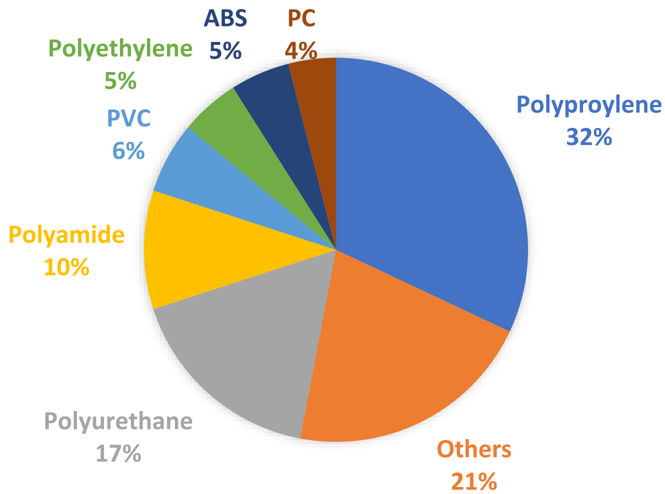
Plastics comprise the second largest share of a vehicle's weight, representing about 13 to 16 percent of the material composition of vehicles across different technologies in the U.S. market (Kelly et al. 2022).[6] Plastics tend to be lightweight, resistant to corrosion and electricity, have a low thermal conductivity, and be formable. They are typically cheaper than aluminum and high-strength steel and lighter than conventional steel (Munjurulimana et al. 2016 citing McKinsey 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). However, polymer composites such as nanocomposites can offer strength that is comparable to conventional steel and thus can be used for body panels. A NHTSA study on weight reduction strategies proposes several instances in which advanced plastic and composites could be substituted for steel

[6] The ACC study found that plastics accounted for the third largest share of vehicle weight at 8.9 percent of North American LD vehicle weight in 2019 (ACC 2020).

parts. Substitution of plastic for steel in parts such as the oil pan, water pump, and other components can reduce the weight of these individual components by 5 to 6 percent (Singh et al. 2018).

Approximately 65 percent of the plastics used in a vehicle comes from four polymers: polypropylene, polyurethane, polyamide, and polyvinyl chloride, as shown in Figure 6.2.1-1 (Nexant 2019). 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).

Figure 6.2.1-1. North America Plastics Consumption in the Automotive Sector in 2017[7]



Source: Nexant 2019

Several studies show that the 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 steel, but typically less than those for aluminum (Cheah 2010; Tempelman 2011; Khanna and Bakshi 2009; Raugei et al. 2015; Koffler and Provo 2012). Table 6.2.1-2 shows the plastic resin production energy use and the shares of each plastic type in a vehicle (Kelly et al. 2022). 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).

Table 6.2.1-2. Plastic Resin Energy Use and Shares in a Vehicle

Plastic Type	Resin Production Energy (MMBtu/ton)	Shares of Individual Plastic in a Vehicle (%)	
		Average Plastic	CFRP
ABS[a]	23.9	8	–
EPDM[a]	7.4	7	–
Liquid epoxy[a]	58.7	11	30
GPPS[a]	22.7	1	–
HIPS[a]	22.4	1	–
HDPE[a]	11.2	1	–

[7] PC = polycarbonate; PVC = polyvinyl chloride; ABS = acrylonitrile butadiene styrene. Polypropylene (32 percent), polyurethane (17 percent), polyamide (10 percent), and polyvinyl chloride (6 percent) together account for 65 percent of plastic consumption in the automotive sector.

Plastic Type	Resin Production Energy (MMBtu/ton)	Shares of Individual Plastic in a Vehicle (%)	
		Average Plastic	CFRP
LDPE[a]	14.6	1	–
LLDPE[a]	10.8	1	–
Nylon 6[a]	52.2	1	–
Nylon 66[a]	51.2	7	–
PC[a]	42.6	4	–
PET[a]	18.2	2	–
PP[a]	9.3	18	–
PUR flexible foam[a]	27.2	12	–
PUR rigid foam[a]	24.4	12	–
PVC[a]	18.3	14	–
Carbon fiber[b]	278.8	–	70

Notes:
[a] Source: Keoleian et al. 2012
[b] Source: Iyer and Kelly 2021
Source: Kelly et al. 2022:Table 39
CFRP = carbon-fiber-reinforced plastic

While polymer composites used in vehicle body panels are more energy and GHG intensive to produce compared to conventional steel and, in some cases, aluminum, when assessed from cradle to grave, using polymer composites in vehicle body panels results in overall energy savings and reduced GHG emissions. This is due to the energy and GHG emissions reduction during the vehicle use phase, which offsets increased energy use and GHG emissions during the production phase (Delogu et al. 2016). One study notes that a 66-percent reduction in the weight of vehicle parts by switching from steel to glass-reinforced plastic results in a decrease in use-phase emissions (74 kilograms [kg] [163.2 pounds] carbon dioxide equivalent [CO_2e]/part) (Koffler and Provo 2012). 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.

In general, studies that examine multiple environmental impact categories conclude that these lightweight composite materials offer overall environmental benefits compared to conventional steel—and, in most cases, compared to aluminum—across the vehicle life cycle. The studies that examine the life cycle of these components draw the boundaries of the analysis such that they only include entry into the landfills, including measurable landfill considerations (e.g., space, leaching, pollution). Plastics and composites take thousands of years to break down within a landfill, or can break down into microplastics that can be carried out to surface water by runoff. These impacts are serious, but due to the long time scale and high uncertainty are not usually included in LCAs. Carbon-fiber-reinforced polymer composite used in vehicle closure panels[8] shows 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 steel parts, glass-fiber-reinforced polypropylene has a lower breakeven

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

distance[9] than magnesium, carbon-fiber-reinforced polypropylene, and welded aluminum.[10] When analyzing fiber-reinforced polypropylene and polyamide, one study found that a majority of the eutrophication and acidification potential occurs during the raw material extraction and processing phase of a vehicle's life cycle (Delogu et al. 2016). Glass-reinforced polymer composite manufacturing can have greater soil and water acidification than steel manufacturing (Koffler and Provo 2012).

Studies acknowledge that large uncertainties underlie the results and that certain assumptions have a significant influence on the outcome. For example, consideration of fleet effects, such as 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). 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 compared to conventional and proposed lightweight materials (e.g., steel, aluminum, virgin carbon fiber) (Meng et al. 2017).

While the increased use of plastics and composites in vehicles can help improve fuel efficiency and reduce use-phase GHG emissions, there are also additional environmental impacts caused by using more plastics. Creating these plastics requires the additional extraction and refining of petroleum. The environmental impacts from petroleum extraction, transportation, and refining are elaborated on in Chapter 3, *Energy*, in Sections 3.2.1.1, *Petroleum Extraction*, through 3.2.1.3, *Petroleum Refining*. These impacts include soil and water contamination, risk of oil spills, land use change (e.g., deforestation), and more. Furthermore, decomposition of these plastics results in microplastics that can have adverse impacts on surrounding ecosystems and human health if they are ingested through food or water. There is still uncertainty and a growing field of research on the exact health impacts of microplastics (Lim 2021).

In summary:

- Plastics account for the second largest share of vehicle weight in the U.S. market, and are increasingly used as substitutes for heavier materials, such as steel and aluminum.
- The raw material extraction, including oil extraction and refining, and manufacturing phases for polymer composites are more energy and GHG intensive than those for conventional steel, but typically less than those for aluminum; however, over the life cycle, these impacts are lower for these lighter composites due to the fuel use reductions during the vehicle use phase.
- The environmental impacts across a range of impact categories, including energy use, GHG emissions, acidification potential, and more, are lower for polymer composites than those for steel and aluminum across the vehicle life cycle.

6.2.1.3 Aluminum

After steel and plastics, cast aluminum makes up the third largest share of a vehicle's weight and represents about 5 to 10 percent of the material composition of vehicles with different technologies (Kelly et al. 2022). Wrought aluminum accounted for 1 to 6 percent of vehicle weight (Kelly et al.

[9] The *breakeven distance* is the distance a vehicle must travel to offset emissions from production of the material. At the breakeven distance, the reduction in use phase emissions from using a lighter-weight material offsets the additional emissions during the production phase for the material.

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

2022).[11] Virgin production of both cast and wrought aluminum begins with mining of bauxite ore followed by a series of processing steps. Similar to high-strength steel, aluminum can reduce vehicle weight while still providing strength and rigidity similar to and sometimes greater than conventional steel. Automotive-grade aluminum, which is used extensively in the transportation sector, has a high strength-to-weight ratio, corrosion resistance, and processability (Cheah et al. 2009). Aluminum is a suitable substitute for cast-iron components, molded steel parts such as wheels, and stamped-steel body panels.

Global aluminum production for all uses was responsible for approximately 275 million metric tons of direct CO_2 emissions in 2021, accounting for just less than 1 percent of the 36.3 billion tons of global CO_2 emissions in 2021 (IEA 2022c). For comparison, steel production emissions accounted for 2.6 billion metric tons of global CO_2 in 2020, which accounts for 7 to 9 percent of global emissions (World Steel Association 2021). However, the mining and processing emissions intensity was much higher for aluminum—11.6 metric tons CO_2e per metric ton of aluminum versus 1.6 metric tons CO_2e per metric ton of iron and steel in 2022 (IEA 2022d). Ninety percent of aluminum production emissions occur during aluminum refining and smelting. Carbon anodes used during the smelting process release carbon emissions during electrolysis. To date, improvements to the emissions intensity of aluminum production have been small, with the emissions intensity falling 1.6 percent over 3 years from 2018 to 2021 (IEA 2022c). However, production with recycled inputs can considerably lower the energy intensity of aluminum production. In North America, producing 1,000 kg of primary aluminum ingot requires approximately 135 gigajoules (GJ) of primary energy demand. Producing 1,000 kg of recycled aluminum ingot requires far less, at approximately 9 GJ of primary energy demand (Wang 2022). Table 6.2.1-3 presents the aluminum production inputs, energy use, and emissions for different processes (Kelly et al. 2022).

[11] The ACC study found aluminum (wrought aluminum and cast aluminum) accounted for the second largest share of vehicle weight at 10.7 percent of LD vehicle weight in the North American market in 2019 (ACC 2020).

Table 6.2.1-3. Aluminum Production Inputs, Energy Use, and Emissions (per short ton of aluminum)

		Virgin Aluminum					Recycled Aluminum		Wrought Aluminum Production					Cast Aluminum Production	
Input	**Unit**	**Bauxite Mining[a]**	**Alumina Production[a]**	**Anode Production[a]**	**Hall-Héroult Process[a]**	**Primary Ingot Casting[a]**	**Wrought Al Scrap Preparation[a]**	**Cast Al Scrap Preparation[a]**	**Secondary Ingot Casting[a]**	**Hot Rolling[a]**	**Cold Rolling[a]**	**Stamping[a]**	**Extrusion[a]**	**Shape Casting[b]**	**Machining[b]**
Fuel															
Residual oil	MMBtu	0.21	2.94	0.52	-	0.11	-	-	-	-	-	-	-	-	-
Diesel	MMBtu	0.35	-	0.10	-	0.03	-	-	-	-	-	-	-	-	-
Gasoline	MMBtu	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NG	MMBtu	-	12.91	0.71	-	0.66	0.75	0.75	4.12	3.28	1.89	-	5.29	-	-
Coal	MMBtu	-	1.34	-	-	-	-	-	-	-	-	-	-	-	-
LPG	MMBtu	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity	MMBtu	0.02	0.64	0.16	46.78	0.21	0.35	0.35	0.34	0.35	1.13	0.86	0.61	0.86	0.54
Material															
NaOH (50%)	ton	-	0.306	-	-	-	-	-	0.0004	0.00002	0.0001	-	0.008	-	-
Lime	ton	-	0.078	-	-	-	0.001	0.001	0.004	0.0002	0.0003	-	-	-	-
Pet coke input	ton	-	-	0.286	-	-	-	-	-	-	-	-	-	-	-
Coke input	ton	-	-	0.063	0.006	-	-	-	-	-	-	-	-	-	-
Steel Sheet Part	ton	-	-	0.003	0.004	-	-	-	0.0001	0.00001	0.0002	-	0.001	-	-
Primary Al ingot	ton	-	-	-	-	-	-	-	0.080	-	-	-	-	-	-
Non-combustion emissions															
CF_4	g	-	-	-	69.764	-	-	-	-	-	-	-	-	-	-
C_2F_6	g	-	-	-	9.616	-	-	-	-	-	-	-	-	-	-
CO_2	ton	-	-	0.042	1.392	-	-	-	0.00001	-	-	-	-	-	-

Notes:
[a] Source: Dai et al. 2015
[b] Source: Sullivan et al. 2010
Source: Kelly et al. 2022:Table 38

Several studies have examined the life-cycle impacts of substituting aluminum for conventional steel components in vehicles (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; Sebastian and Thimons 2017; Milovanoff et al. 2019; Palazzo and Geyer 2019).[12] In general, studies show a net energy and GHG reduction over the vehicle life cycle; energy use and GHG emissions reductions during the use phase of aluminum material substitution are greater than the energy use and GHG emissions increases needed to manufacture these lightweight materials at the vehicle production phase. 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). The impacts of a future fleet with a more aluminum-intensive design than currently implemented could result in global savings as high as 2.9 gigaton CO_2e by 2050 (Milovanoff et al. 2019).[13] The magnitude of life-cycle GHG emissions reductions and energy-use savings are influenced by the location of aluminum production, the amount of recycled material used in vehicle components, end-of-life recycling rate, and lifetime of vehicles in use.[14]

Aluminum production can have other adverse environmental impacts, including acidification of nearby water sources and soils, eutrophication, and smog formation. Aluminum production emits NO_X, SO_2, and ammonia, which cause acidification of the surrounding environment. The production of 1 metric ton of primary aluminum ingot in North America emits approximately 37 kg of sulfur dioxide equivalent (SO_2e). In terms of eutrophication potential, producing 1 metric ton of primary aluminum ingot emits approximately 0.82 kg of nitrogen equivalent. The production of 1 metric ton of primary aluminum contributes approximately 274 kg ozone equivalent (O_3e), the main measure of smog formation potential. Most of the emissions that contribute to acidification, eutrophication, and smog formation come from the refining and electrolysis processes of aluminum production (Wang 2022). These impacts are much lower for recycled aluminum. Producing 1 metric ton of recycled aluminum emits 0.87 kg SO_2e, 0.04 kg nitrogen equivalent, and 15.64 kg O_3e (Wang 2022).

In summary:

- Cast aluminum comprises the third largest share of a vehicle's weight (Kelly et al. 2022).

[12] 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).

[13] Another study used a fleet-based life-cycle model to estimate the GHG emissions savings from lightweighting the U.S. LD 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).

[14] 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., kg 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 affect results, which is why many vehicle LCAs express results per kilometer or mile as a functional unit.

- Virgin aluminum production is far more energy and GHG intensive than recycled aluminum production and contributes to higher levels of other environmental impacts, such as acidification, eutrophication, and smog.
- Substituting lighter-weight aluminum for conventional steel results in lower energy use and GHG emissions over the vehicle life cycle due to the fuel use reductions during the vehicle use phase.

6.2.1.4 Fluids and Lubricants

Fluids and lubricants accounted for 5.5 percent of vehicle weight in 2019 (ACC 2020). Vehicle fluids and lubricants include adhesives, transmission fluid, powertrain coolant (50 percent ethylene glycol and 50 percent water), engine oil, windshield fluid (50 percent methanol and 50 percent water), and brake fluid (ANL 2022). The GREET2 Vehicle-Cycle Model provides a breakdown of the weight of various vehicle fluids across different vehicle types. GREET2 does not break down the per vehicle fluid weight by vehicle size. These data are shown in Table 6.2.1-4. The same quantities of adhesives, windshield fluid, and brake fluid are used across the vehicle types, while PHEVs and EVs use about 6 percent as much transmission fluid as ICE vehicles; and EVs use about 69 percent as much powertrain coolant as ICE vehicles and PHEVs. EVs also do not require engine oil.

Table 6.2.1-4. Per Vehicle Fluid Weight (lbs.) by Vehicle Type

Vehicle Type	Adhesives	Transmission fluid	Powertrain coolant	Engine oil	Windshield fluid	Brake fluid
ICE vehicle	30.0	24.0	23.0	8.5	6.0	2.0
PHEV	30.0	1.8	23.0	8.5	6.0	2.0
EV	30.0	1.8	15.8	0.0	6.0	2.0

Source: ANL 2022

The GREET2 model also provides data on the per vehicle lifetime energy consumption and GHG emissions associated with all fluids included in Table 6.2.1-4 for different vehicle types. The per vehicle lifetime energy consumption and GHG emissions from vehicle fluids are significantly lower for EVs than for ICE vehicles, as shown in Table 6.2.1-5.

Table 6.2.1-5. Per Vehicle Lifetime Energy Use and GHG Emissions from Fluids by Vehicle Type

Vehicle Type	Energy Use (MMBtu)	GHG Emissions (kg)
ICE vehicle	11.96	765
PHEV	10.94	699
EV	2.82	183

Source: ANL 2022
Note: Data from the GREET2 model analyze the following fluids: adhesives, transmission fluids, powertrain coolant, engine oil, windshield fluid, ad brake fluid.

The GREET2 model also provides a breakdown of the energy required to produce certain vehicle fluids and fluid components. These data are shown in Table 6.2.1-6.

Table 6.2.1-6. Energy Consumption from the Production of Certain Vehicle Fluids or Fluid Components

Vehicle Fluids & Fluid Components	Energy Use (MMBtu/ton of fluid)
Adhesives	75.2
Transmission fluid	46.1
Engine oil	46.1
Brake fluid	46.1
Ethylene Glycol (Powertrain coolant component)[a]	39.9
Methanol (Windshield fluid component)[b]	26.6

Notes:
[a] Powertrain coolant is composed of 50% ethylene glycol and 50% water.
[b] Windshield fluid is composed of 50% methanol and 50% water.
Source: ANL 2022

In addition to the energy use and GHG emissions from vehicle fluids and lubricants, these substances can have additional adverse impacts on the environment. One study that focuses on petroleum-based lubricants such as engine oil found that approximately 50 percent of lubricants end up in the environment "via total loss applications, volatility, spills or accidents" (Madanhire and Mbohwa 2016). When these substances enter the environment, they can have adverse impacts on the ecosystem and human health. Additives in vehicle lubricants can contaminate water sources, degrade soil, and have carcinogenic risk potential for human health (Madanhire and Mbohwa 2016).

As the share of EVs in vehicle fleets grows over the coming years, the market for vehicle fluids is expected to decline because EVs use fewer fluids than ICE vehicles. EVs do not require engine oil and require less transmission fluid and powertrain coolant than ICE vehicles. A 2021 report from McKinsey estimates that BEVs use between two and three times fewer fluids over their lifetime than ICE vehicles. The report estimates that while both ICE vehicles and BEVs use between 4 and 12 liters of driveline fluids[15] over their lifetime, BEVs only use 10 to 20 liters of coolant over their lifetime (compared to 20 to 80 liters for ICE vehicles) and no engine oil (compared to 50 to 90 liters for ICE vehicles) (Herrmann et al. 2021).

In summary:

- Various fluids and lubricants are used in vehicles and account for about 6 percent of vehicle weight.
- EVs use far less transmission fluid and less powertrain coolant than ICE vehicles and no engine oil, contributing to lower fluid-related energy use and GHG emissions for EVs.

6.2.1.5 Iron Castings

Iron castings accounted for about 6 percent of a vehicle's weight in the North American market in 2019, according to the ACC (ACC 2020) or about 2 percent of vehicle weight in the U.S. market according to the ANL analysis (Kelly et al. 2022). Cast-iron parts are made using scrap iron and steel and are used to make vehicle parts like engine blocks (Kelly et al. 2022). In order to make cast-iron parts, different processes including "shredding, shearing, cutting, or crushing" reduce the size of the scrap iron. It is

[15] Driveline fluid functions to optimize and protect a vehicle's power transmission.

then melted in a furnace using an energy-intensive foundry coke heat supply, and the melted metal is then molded into auto parts (Kelly et al. 2022).

Iron casting is a highly energy- and emissions-intensive process. A large share of the emissions come from energy consumption during the production process, particularly the melting process, which is typically responsible for over 50 percent of the carbon footprint to produce a cast-iron alloy material (Abdelshafy et al. 2022). As a result, increasing the share of steel scrap in cast iron is one method of reducing carbon intensity because steel scrap is less energy intensive. However, steel scrap requires additives like ferrosilicon and carburizing[16] agents to maintain the same alloy composition. These additives can be expensive and emissions intensive, offsetting the benefits of using steel scrap. A recent study concluded that a 25 to 40 percent weight composition of steel scrap is the optimal range for cast-iron alloys to balance environmental benefits, economic considerations, and material performance. The study also found that alloys containing 25 percent or more of steel scrap have a carbon footprint of at least 650 kg CO_2e/ton. The more steel scrap included in the alloy beyond 25 percent, the higher the carbon footprint due to the additives that must also be included (Abdelshafy et al. 2022). Therefore, even when steel scrap is included to reduce the emissions intensity of cast iron, the material is still carbon intensive. A breakdown of the energy consumed during cast-iron production is shown in Table 6.2.1-7.

Table 6.2.1-7. Energy Consumption from Cast Iron Production

Fuel	Unit	Iron Recycling[a]	Iron Casting[a]	Iron Forging[b]	Machining[b]
Diesel	MMBtu/ton	1.25	-	-	-
NG	MMBtu/ton	-	-	32.6	-
Electricity	MMBtu/ton	0.09	-	1.18	0.54
Coke	ton/ton	-	0.84	-	-

Notes:
[a] Source: Burnham et al. 2006
[b] Source: Sullivan et al. 2010
Source: Kelly et al. 2022:Table 37

Cast iron also has other non-energy environmental impacts. One study that focuses on grey cast iron—the most common form of cast iron with a graphitic microstructure—found that cast-iron production can harm the surrounding ecosystem and can have negative impacts on human health, including ozone depletion, soil acidification, and eutrophication of nearby water sources. The majority of these impacts (approximately 74 percent) result from the smelting stage of cast-iron production (Mitterpach et al. 2017).

In summary:

- Iron castings comprise about 2 to 6 percent of vehicle weight, varying by study.
- Iron casting is a highly energy- and emissions-intensive process; increasing the recycled content of steel scrap requires additives in the production process, which can increase the carbon footprint of the cast iron when the steel scrap content of the alloy exceeds 25 percent.

[16] *Carburization* is the process in which carbon is added to a metal while it is being heated to harden the metal.

6.2.1.6 Other Powertrain Metals (Copper, Cobalt, Nickel)

The powertrain of ICE vehicles takes energy from the engine and delivers it as power to the vehicle wheels. Some of the materials that compose the powertrain, including copper and ferromagnetic materials such as cobalt and nickel, have a significant impact on the environment. Powertrain components such as the gearbox and heat exchanger use copper, the braking system uses copper-nickel brake lines, and magnets used in motors and drivers are often composed of ferromagnetic materials such as cobalt and nickel. Copper can account for over 1 percent of the overall vehicle weight (IEA 2022e; Aniziol 2020). The quantities of ferromagnetic metals such as cobalt and nickel used in vehicles are relatively low; however, their mining, production, and recycling activities can result in high GHG emissions and geological impacts (Sullivan et al. 2018; Organisation for Economic Cooperation and Development [OECD] 2019). Several of the major environmental impacts for all of these metals occur during the extraction and production phases (OECD 2019; Nickel Institute 2023).

GHG emissions from copper production are, at an average, 2.6 kg CO_2e/1 kg copper metal. This is an average emissions intensity from several copper-producing mines across the globe. GHG emissions from production of copper are typically associated with the consumption of fuel in the mining and materials transport process, and indirect emissions from electrical energy use in extractive and beneficiation processes (International Copper Association Australia 2020). GHG emissions from cobalt production are 28.6 kg CO_2e/1 kg cobalt metal. This value reflects a cradle-to-gate emissions intensity for refined cobalt metal. Cradle-to-gate represents the entire life cycle of a product or process, from the extraction of raw materials (cradle) to the point of manufacture or production (gate). In the context of emissions intensity for refined cobalt metal, cradle-to-gate refers to the total GHG emissions associated with the production of refined cobalt to the point of leaving the factory gate or facility. The scope of the emissions intensity for cobalt production includes mining, beneficiation and ore preparation, tailings, primary extraction, refining, water and wastewater treatment, and transportation activities (Cobalt Institute 2019). The emissions intensity represents a global average for the cobalt industry. GHG emissions from Class I nickel production are 7.64 kg CO_2e/1 kg Class I nickel. The scope of the emissions intensity includes mining, beneficiation, ore preparation, primary extraction, and refining (Mistry et al. 2016).

Mining and extraction of metals such as copper, cobalt, and nickel can have significant geological impacts, negatively affecting land and water resources. Copper mining, for example, can destroy nearby natural habitats and displace local communities. In addition, the large quantity of water used in the mining process can lead to water scarcity and pollution. The mining of cobalt and nickel has similar impacts on land and water resources. These materials are mostly mined in developing countries, raising ethical concerns regarding labor practices and safety measures (OECD 2019; Mudd 2010).

Current global production of copper is around 19 million metric tons annually, with the largest share (27 percent) coming from Chile (OECD 2019). The most common approach for copper production is the pyrometallurgical route used for sulfide ores (Calvo et al. 2016). Environmental impacts from copper mining and concentration can largely depend on enforcement of environmental regulations. In a well-regulated environment, geological impacts should be relatively low. However, in environments where regulation is lacking or not adequately enforced, substantial contamination of land and water resources can occur. Geological impacts can include, but are not limited to, release of toxic and hazardous waste into local water systems, contamination of drinking water, and destruction of agricultural land. These potential impacts can be prevented or successfully mitigated against, in most cases, with a sound environmental management plan (OECD 2019).

GHG emissions associated with extracting and producing copper can vary greatly depending on the type of electricity used by mining and production facilities (OECD 2019). According to data from Grimes et al. (2008), the carbon footprint of producing copper cathode from primary and secondary sources varies substantially among major global producers. This variation is largely due to differences in energy sources; for example, Kazakhstan has a high emissions rate due to heavy reliance on fossil fuels, while Zambia has a low emissions rate because the majority of its electricity is generated from hydropower, and the U.S. emissions rate is between the two (Grimes et al. 2008).

The high-intensity energy and GHG emissions related to copper mining and processing and cobalt mining and processing are summarized in Table 6.2.1-8 and Table 6.2.1-9, respectively (ANL 2022).

Table 6.2.1-8. Final Copper Product Energy Consumption and GHG Emissions

Process	Energy Use (MMBtu/ton)	GHG Emissions (g CO_2e/ton)
Final Copper (Sulfide Ore) from U.S. Consumption Mix	65.03	4,815,250
Final Copper (Laterite Ore) from U.S. Consumption Mix	28.04	1,899,498
Final Copper Product (U.S. Consumption Mix, assuming Laterite + Sulfide)	56.06	4,073,352

Notes:
Source: ANL 2022
CO_2e = carbon dioxide equivalent; g = gram; MMBtu = million British thermal units

Table 6.2.1-9. Final Cobalt Product Energy Consumption and GHG Emissions

Process	Energy Use (MMBtu/ton)	GHG Emissions (g CO_2e/ton)
Cobalt Ore Mining	25.84	2,078,958
Cobalt Ore Processing	24.66	1,406,241
Final Virgin Co Metal Product	262.35	18,655,545

Notes:
Source: ANL 2022
CO_2e = carbon dioxide equivalent; g = gram; MMBtu = million British thermal units

Demand for cobalt is growing globally, particularly as a result of its use in lithium-ion batteries, including those for EVs. According to Transport & Environment (2017), citing Bloomberg, the demand for cobalt used in lithium-ion batteries is expected to rise dramatically, from under 5,000 metric tons in 2016 to around 90,000 metric tons in 2030. As of 2019, production of cobalt metal was 110,000 metric tons annually, with more than half mined in Democratic Republic of the Congo, much of which is then refined in China (OECD 2019). The majority of cobalt is found in copper and nickel deposits, so production of cobalt is closely tied to demand for these metals. The Joint Research Centre (JRC) states that 43 percent of cobalt is obtained through nickel extraction, 32 percent through copper extraction, and 25 percent through primary cobalt operations (Cusano et al. 2017).

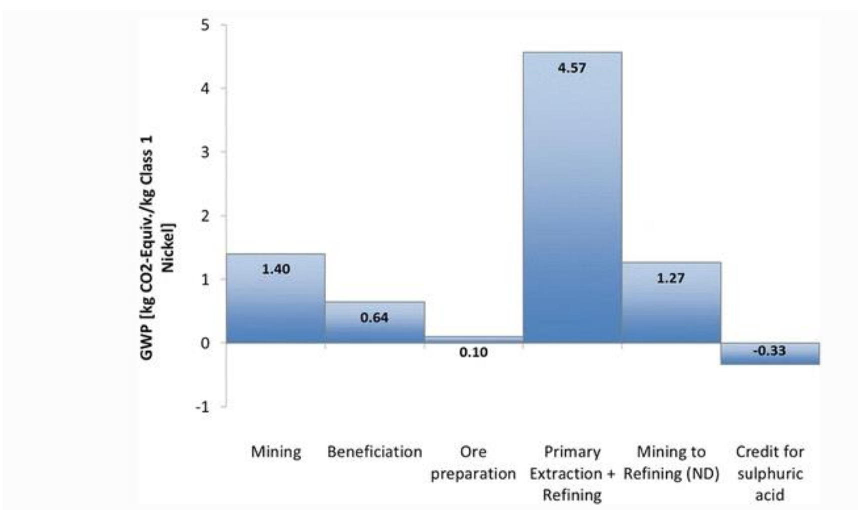
Cobalt processing is carried out using different methods for different types of ore, depending on their composition and physical and chemical characteristics (JRC 2017; Farjana et al. 2019). Some of the methods include hydrometallurgy, electrowinning, vapometallurgy, and pyrometallurgy (OECD 2019). An LCA found that the cumulative energy demand of the lithium-ion battery pack is dominated by the "embodied" energy in the input materials for the cathode, including cobalt (Raugei and Winfield 2019).

Another LCA of the cobalt extraction process shows that fossil fuel consumption has the greatest environmental impact, but also notes significant impacts from blasting and the composition of the cobalt ores (Farjana et al. 2019). These ores are associated with toxic metals such as arsenic, cadmium, manganese, and cobalt itself, which can lead to exposure to dusts containing these substances. Cobalt mining production also contributes to global GHG emissions (Farjana et al. 2019). The life-cycle inventory of cobalt mining shows that most GHGs from cobalt mining come from CO_2 emissions as a result of medium-voltage electricity generated from fossil fuels, accounting for 9.5 kg CO_2e out of 10.8 kg CO_2e (Farjana et al. 2019).

Powertrains and other vehicle parts that contain nickel have the potential to improve energy efficiency, increase the lifespan of a product, or reduce maintenance needs due to the unique physical and chemical properties of nickel. Nickel-containing materials offer enhanced corrosion resistance and reliable and efficient electrical and spark systems (Nickel Institute 2023). The way in which nickel is mined, ore grade, and mineralogy of the mined nickel can affect energy consumption during the mining and processing stages. Extracting nickel from oxidic (laterite) ore deposits generally requires less energy, but subsequent processing of these ores consumes more energy. The location, depth, and shape of the ore deposit can also have a significant impact on energy demand (Mistry et al. 2016).

According to Mistry et al. (2016), the energy demand for producing 1 kg of Class I nickel from cradle to gate is 147 megajoule (MJ). The majority of this demand comes from energy consumption for fuels and electricity during the primary extraction and refining stages, which make up 60 percent of the total energy demand, as displayed in Figure 6.2.1-2. The GHG emissions for 1 kg of Class I nickel is 7.64 kg CO_2e. These emissions are closely related to fossil fuel consumption, so the emissions results show the same trend as the energy demand. Emissions from on-site activities are the main contributor to the GHG emissions due to fuel combustion.

Figure 6.2.1-2. Global Warming Potential of 1 Kilogram Class I Nickel



Notes:
Source: Mistry et al. 2016
GWP = global warming potential

Table 6.2.1-10 summarizes the average energy consumption and related GHG emissions for the processes needed to produce a Class I nickel ore, and final refined nickel from virgin and recycled (Class I) nickel.

Table 6.2.1-10. Nickel Products (Virgin vs Recycled) Energy Consumption and GHG Emissions

Process	Energy Use (MMBtu/ton)	GHG Emissions (g CO_2e/ton)
Class I Nickel Production (Sulfidic Ore)	158.83	8,104,438
Final Class I Nickel	415.18	19,336,884
Final Recycled Nickel	19.37	1,381,100

Notes:
Source: ANL 2022
CO_2e = carbon dioxide equivalent; g = gram; MMBtu = million British thermal units

Cobalt and nickel mining can have a range of geological impacts on the environment including, but not limited to, deforestation, loss of biodiversity, and destruction of natural habitats. These impacts are caused by surface mining and the collapse of underground structures, which leads to subsidence and land instability, as well as underground mining and disruption of the hydrological balance of the area due to excavation of ore, which leads to changes in water flow and quality, acid mine drainage, and heavy metal contamination of soil and water. The mining process can generate large quantities of waste rock and tailings, which can have negative impacts on air and water quality if not properly managed. The mining process can also cause soil erosion, landslides, and sedimentation of streams and rivers. The use of chemicals and explosives can also have negative impacts on the surrounding environment, including contamination of water resources and negative impacts on local wildlife (Slack et al. 2017; Nickel Institute 2023; Mudd 2010; Savinova et al. 2023). Open pit mining, a common method for extracting nickel, can have a significant impact on the landscape, altering the topography and destroying the local ecosystem (Mudd 2010).

There are several steps metal suppliers globally are taking to minimize their impact on the environment and local communities. For example, a global supplier of cobalt and nickel has taken steps to protect the environment; preserve biodiversity; safely manage wastewater, tailings, and other waste; minimize impacts on land, air, water, and human beings; and restore ecosystems (Jervois Global 2022).

In summary:

- Powertrain components such as copper and ferromagnetic materials such as cobalt and nickel play a vital role in the functioning of vehicles, but their extraction and production can have significant environmental impacts.
- These impacts include GHG emissions, geological impacts on land and water resources, and hazardous health impacts on communities.

6.2.2 Battery Components

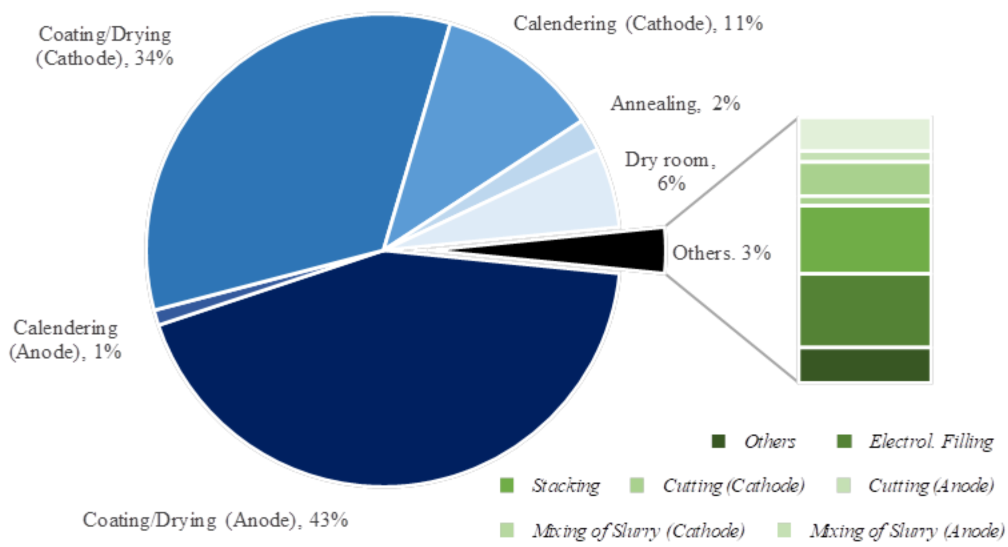
Historically, battery manufacturers for passenger cars and light trucks have used lead-acid chemistries for ICE vehicles. EV, PHEV, and HEV manufacturers have begun using new battery chemistries based on the results of research to increase energy storage capacity. The lithium-ion battery is the preferred battery technology for EVs and PHEVs because of its electrochemical potential, lightweight properties, high-temperature performance, 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 (DOE 2023e). HDPUVs, which adopted electrification efforts more recently than passenger cars and light trucks, similarly use lithium-ion batteries as their main technology based on a survey of available EVs in the market (Birky et al. 2017). Lithium-ion batteries are an evolving technology. Researchers and manufacturers are continually developing new battery chemistries to increase energy density while reducing costs. Nickel-metal hydride (Ni-MH) batteries are an alternative to lithium-ion batteries. They have a longer life and safer characteristics (lower flammability) compared to lithium-ion batteries, but they have a relatively high cost, self-discharge, and generate heat at high temperatures. Hydrogen gas that forms from overcharging Ni-MH batteries needs to be monitored and controlled (DOE 2023e). Ni-MH batteries have been used most notably in the Toyota hybrid family of cars because of their minimal maintenance requirements and ability to be recycled effectively (Toyota 2022); however, lithium-ion batteries are increasingly being used in their place in newer generation HEVs (Gaines 2022).

Lithium-ion batteries primarily consist of stacked battery cells. Cells represent the bulk of material weight; the stacked battery cells consist of 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 2013c).

LCA literature has focused on three cathode types: lithium manganese oxide (LMO), lithium iron phosphate (LFP), and lithium nickel manganese cobalt oxide (NMC) (Nealer and Hendrickson 2015), with NMC becoming the most popular choice among EVs in recent years (ANL 2019). The manufacturing of lithium-ion batteries is an energy-intensive process, particularly with the coating and drying phases[17], as can be seen in Figure 6.2.2-1 for a battery cell lot. A study by Wessel et al. (2021) found that over 78 percent of overall energy use in the manufacturing stage was spent on coating and drying of the anode and cathode, or over 19 kilowatt-hours (kWh) per battery cell. A review of other studies by the same source found coating and drying to similarly be the most energy-intensive production process, albeit a much smaller share on average of 33 percent of total energy use during battery production (followed closely by maintenance of the dry room at 32 percent on average). 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). Additionally, the use of N-Methyl-2-Pyrrolidone (NMP) to prepare the cathode during the dry room phase is extremely energy intensive because the levels of NMP vapor in the air need to be controlled closely due to flammability. Advancements using water-based solvents for this slurry preparation phase for the cathode would significantly reduce energy needs during this phase (Dai et al. 2017b).

[17] 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.

Figure 6.2.2-1. Proportional Energy Consumption per Lithium-Ion Battery Process Step



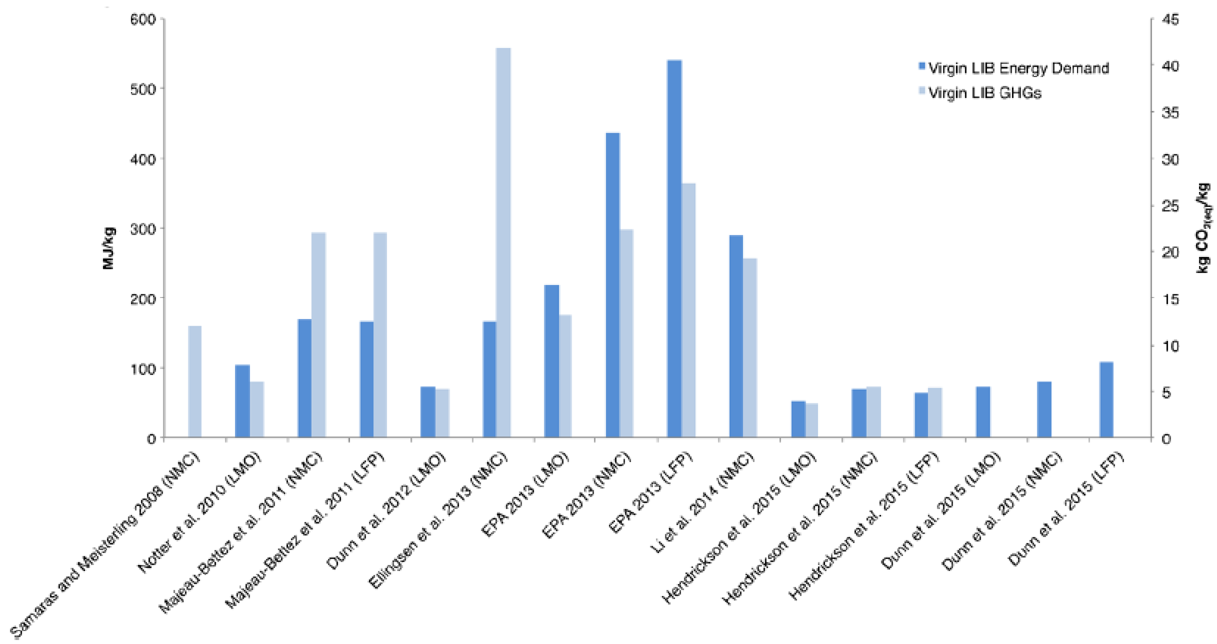
Source: Wessel et al. 2021:Figure 3B

Life-cycle studies show 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 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 because 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; studies have shown batteries can contribute 10 percent or less (Notter et al. 2010; EPA 2013c) to almost 25 percent of total GHG emissions (Dunn et al. 2014; EPA 2013c; Hawkins et al. 2013). LCAs and LCA reviews have highlighted this but focus on different drivers of results. Some studies 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 2013c; 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). A study focused on the implications of upscaled production of batteries used Ellingsen et al. (2014) as a model and applied updated production methods to account for expanded operations (Chordia et al. 2021). It found that energy demands per output in the upscaled factory were 58 percent lower than that used in Ellingsen et al. and that GHG emissions dropped from 188 kg CO_2e per kWh to 109 kg CO_2e per kWh (Chordia et al. 2021).

Figure 6.2.2-2 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). Bouter and Guichet (2022) conducted a review of 32 studies from 2010 to 2020 with 377 unique observations and found little variation in the median emissions total based on cathode chemistry: 72.5 kg CO_2e per kWh for NMC, 73.5 kg CO_2e per kWh for LFP, and 74.1 kg CO_2e per kWh for LMO. 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 kg (154.3–385.8 pounds) CO_2e per kWh with a median of 120 kg (264.6 pounds) 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 decreased substantially in 2 years—from 150 to 200 kg (330.7–440.9 pounds) CO_2e per kWh battery capacity in 2017 to 61 to 106 kg (134.5–233.7 pounds) 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 emissions reduction potential.

Figure 6.2.2-2. GHG Emissions and Energy Consumption of Electric Vehicle Lithium-Ion Battery Production (per kilogram of battery)



Notes:
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-based 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 NMC-dominated battery scenario,[18] 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, and for nickel by 28 to 31 times (Xu et al. 2020). Meeting the

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

rising demand for these raw materials will require increased mining activities in relatively dry areas globally (Sakunai et al. 2021).

Beyond GHG emissions and energy consumption, the production of lithium-ion batteries from virgin materials can have local adverse environmental impacts.[19] 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). Water is also consumed in the anode production and coating process, with one study estimating 8.6 gallons per kWh battery (Dai et al. 2017b).

The reliance of lithium-ion batteries on critical mineral supplies presents other environmental concerns, such as those related to resource availability and mining, and increases the importance placed on recycling[20] (Pathak et al. 2022). Lithium extraction can cause local environmental degradation including affecting water availability, contaminating soil and air, and harming nearby ecosystems (Liu et al. 2019). Lithium mining can have severe associated environmental impacts depending on the method of extraction. Lithium extracted from liquid natural brine can cause up to 95 percent of extracted brine water to be lost to evaporation, depleting nearby aquifers, and increased risk of unintended leaks and spills of processing fluids that could increase the environmental toxicity of local flora and fauna (Kaunda 2020). Lithium ore mined from solid pegmatite requires ecosystem disturbances standard to large-scale mineral mining operations, but also includes the risk of toxic chemical leaks, and further risks to soils, surface water, and human health from the toxic fine particulate matter byproducts of ore and mineral concentrate (Kaunda 2020).

In spite of these impacts, the overall impact of lithium extraction as part of the BEV life cycle was found to account for less than 2.3 percent of overall environmental impact from BEV production, operation, and disposal (based on one report using the Eco-indicator 99 methodology[21] [Notter et al. 2010]), because other metals such as copper and aluminum require significantly more energy to extract. Copper, in particular, has a large impact on human health and ecosystem quality compared to the other processes in battery production (Notter et al. 2010). Section 6.2.1.6, *Other Powertrain Metals (Copper, Cobalt, Nickel)*, provides further discussion of copper- and cobalt-related extraction impacts. While the extraction of materials affects human health about the same as processing and manufacturing of the battery for an EV (8.2 percent versus 8.1 percent of overall EV impact, respectively), these early life-cycle stages are dwarfed by the impacts occurring during the product use stage of the EV (83.7 percent of overall impact on human health). However, the opposite holds true for ecological toxicity impacts, with material extraction accounting for more than 94 percent of overall impacts on freshwater habitats. The extraction of aluminum needed in the cathode and steel required for the battery pack housing specifically are key drivers of impacts on ecosystem health and human health impacts regarding carcinogenic and non-carcinogenic chemical hazards to workers at mining locations (EPA 2013c).

[19] See Chapter 7, *Environmental Justice*, for NHTSA's analysis of potential localized impacts from mining that may affect environmental justice populations.

[20] For more information on lithium recycling and battery reuse, please see Section 6.3.2, *Battery Disposal and Recycling*.

[21] This includes an evaluation of damage to resources, ecosystems, and human health (Ministry of Housing, Spatial Planning and the Environment 2000).

Concerns and questions on resource availability are also well documented, given the sharp increase in BEV manufacturing and the need for minerals like lithium, cobalt, copper, nickel, and phosphorous that are essential for battery manufacturing (Intergovernmental Panel on Climate Change 2022a). More than 84 percent of current lithium reserves are in Chile (45 percent), Australia (28 percent), and Argentina (11 percent) (British Petroleum [BP] 2022). Demand for lithium slightly surpassed supply in 2022, driven in large part by a 70 percent increase in demand for batteries in China and 80 percent increase in the United States. Global demand for lithium in EV batteries increased 51 percent from 2021 to 2022 and 208 percent from 2020 to 2022 (IEA 2023), and demand for lithium-ion batteries is expected to increase by 25 percent annually to 2030. However, additional countries are announcing projects to enter the field of lithium mining using budding technology and techniques, and supply is expected to keep pace with growing demand (Azevedo et al. 2022). Based on the IEA's Stated Policies Scenario, which reflects current and planned global policies and planned operations, lithium carbonate equivalent production is expected to meet demand until 2028 (IEA 2022f). In part due to provisions in the Inflation Reduction Act of 2022 to incentivize critical mineral projects, the United States has 24 domestic projects confirmed to increase lithium production, ranging from early-stage exploratory projects to plants already producing lithium (DOE 2023d). The Inflation Reduction Act also authorized Domestic Manufacturing Conversion Grants to help fund the conversion of current manufacturing capabilities to help support production of EVs (DOE 2023f). The Bipartisan Infrastructure Law, passed in 2021, allotted $2.8 billion to support domestic lithium processing, along with other critical materials needed for batteries (DOE 2022e). Further research has also been conducted to study how lithium recovery may be a co-benefit of geothermal facilities in California, capable of producing up to 600 kilotons of lithium per year (Blue Ribbon Commission 2022).

International policy advancements to support the battery supply chain include the European Union's 2023 Green Deal Industry Plan, which includes provisions to allow faster permitting for battery production facilities and the creation of the Critical Raw Materials Act, which will highlight environmental standards around material extraction as well as supply security. Similarly, India is hoping to boost domestic battery production by allocating $2.2 billion in incentives with the goal of reaching 50 gigawatt-hours in domestic manufacturing capacity (IEA 2023). The confirmed supply of other necessary minerals is expected to last close to 600 years based on current levels of demand as well, although that number could drop as the market changes (BP 2022). This is supported by an LCA report's findings on the abiotic resource depletion potential indicator of BEVs, which measures the potential for resource depletion of nonrenewable materials and found that the extraction of materials for the battery accounted for less than 10 percent of the BEV's total impacts (EPA 2013c).

Research into alternatives to lithium also has been conducted to verify the viability of potential substitutes. Alternatives include sodium-ion batteries, which are more suitable to stationary energy shortage or smaller vehicles because they do not offer as high level of performance as lithium-ion batteries (BNEF 2023). The DOE's Pacific Northwest National Laboratory has also found success in building a low-cost battery using abundant materials like sodium and aluminum for use in storage systems, which could help alleviate lithium demand (Hede 2023). Finally, because lithium-ion batteries are not suitable for aircraft due to the liquid in their design, the National Aeronautics and Space Administration (NASA) has committed research into solid-state batteries. While the main drawback of solid-state batteries is their poor discharge rate (i.e., the amount of energy that can flow out at once), NASA has achieved double the normal discharge rate of solid-state batteries. Further improvements in design and scalability could provide another alternative to lithium-ion batteries and reduce overall demand in the future (Gould 2021).

In summary:

- The lithium-ion battery, and specifically the NMC cathode type, is the preferred battery technology for EVs and PHEVs due to its high electrochemical potential and high-temperature performance.
- The mining of materials for lithium-ion batteries most negatively affects freshwater ecosystems, soil, air, and the health of those working at the mining locations; however, the impacts from the extraction of lithium are relatively low compared to the extraction of the other materials (e.g., copper, aluminum) needed in the battery and the use phase.
- The manufacturing of lithium-ion batteries is an energy-intensive process, particularly during the coating and drying phases.
- Battery life-cycle GHG emissions levels can vary widely largely due to variation in the electricity grid mix where vehicles are charged. Estimates for the relative contribution of lithium-ion batteries on the vehicle life-cycle GHG impact also varies significantly both between and within LCAs; however, studies show substantial emissions reduction potential in battery life-cycle GHG emissions.
- Production of lithium-ion batteries with virgin materials, if unmitigated, may cause local adverse environmental impacts including air, soil, and water pollution during the mining and processing stages, and high levels of water consumption in the production and coating process using conventional technologies.[22]
- Concerns around resource availability of critical mineral supplies for lithium-ion batteries have spurred investments from governments and the private sector to increase extraction and production capabilities in order to meet the growing global demand.

6.2.3 Vehicle Assembly

The vehicle assembly process generally consists of two assembly lines: one for the body and one for the chassis. The body of a vehicle is the outer structure, including the engine cover, roof, trunk cover, and doors. Welding and adhesives are used to construct the body of the car during the assembly process. The chassis is the frame of the vehicle, including the springs, wheels, steering gear, powertrain, brakes, and exhaust. The chassis is the primary load-bearing portion of the vehicle. For EVs, the structure of the chassis can differ from ICE vehicles because the battery weighs significantly more and makes up a key structural component of the chassis while other components such as the exhaust system are excluded (Stanley Engineered Fastenings 2021). The body and chassis are then attached together and other remaining components of the vehicle are added. These components include the windshields, windows, and interior of the car such as the seats, upholstery, electronics, and wiring (Galitsky and Worrell 2008). Some vehicles use an alternative assembly method called unitized construction, in which the body and chassis are assembled simultaneously (Galitsky and Worrell 2008).

The main processes involved in vehicle assembly include “painting; heating, ventilation and air conditioning (HVAC); material handling; welding; and supplying compressed air” (Kelly et al. 2022). Natural gas and electricity are the predominant energy sources used during the vehicle assembly process (Energy Star 2015). According to Energy Star’s 2015 report, *Industrial Insights: Automobile Assembly Plants*, the most energy-intensive aspects of the vehicle assembly process are: paint booths (27–50 percent), HVAC (11–20 percent), lighting (15 percent), compressed air (9–14 percent), welding

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[22] See Chapter 7, *Environmental Justice*, and Chapter 8, *Historic and Cultural Resources*, for NHTSA’s discussions of potential adverse impacts of increased mining of energy-transition resources resulting from NHTSA’s Proposed Action and alternatives.

(9–10 percent), material handling/tools (7–8 percent), and metal forming (2–9 percent) (Energy Star 2015).

In this analysis of vehicle assembly, processes like stamping, machining, and casting are not included. This is consistent with other literature which categorizes those processes as part of the material transformation or parts production phase separate from the vehicle assembly. For example, the data used to create Energy Star's Automobile Assembly Plant Energy Performance Indicator only drew from "assembly plants that contained body welding, assembly, and painting operations, while excluding those facilities that also included activities like stamping, machining, and casting" (Sullivan et al. 2010).

The breakdown in energy use can differ depending on the region and type of vehicle being produced. Fuel consumption tends to range from 60 to 69 percent of total energy use with electricity consumption making up the rest (Energy Star 2015). However, electricity tends to make up the largest share of energy cost in production (Energy Star 2015). Fuels are mainly used for space heating and for controlling the temperature and humidity in the paint booth. Electricity is used throughout assembly facilities for various purposes including HVAC, paint systems, lighting, compressed air, materials handling, metal forming, welding, and more (Galitsky and Worrell 2008; Giampieri et al. 2020). The painting process consumes the majority of electricity, accounting for approximately 89 percent of electricity use in the assembly process (Oumer et al. 2016). Temperature and humidity control requirements in the paint shop are responsible for the high consumption of electricity, natural gas, and chilled water (Giampieri et al. 2020).

One study compiled data from various automobile manufacturers' sustainability reports to compare the per vehicle energy and emissions intensity and water use from their global manufacturing operations in 2012 (data for Toyota is only based on North America manufacturing) (Oh and Hildreth 2014). The findings of this study are shown in Table 6.2.3-1.

Table 6.2.3-1. Energy, Emissions, and Water Usage in Vehicle Manufacturing

Intensity (Use per Vehicle)	General Motors	Volkswagen	Ford	BMW	Toyota (North America)	Equivalence
Energy (Electricity + Fuel) MWh/Vehicle	2.30	2.21	2.45	2.44	2.13	Energy for the production of 4 vehicles equals approximately the average annual electricity consumption for a U.S. residential utility customer
Carbon (Scopes 1 & 2) Ton/Vehicle	0.88	0.89	0.9	0.68	0.78	Carbon emitted from the production of 1 vehicle equals approximately the carbon offset of 80 trees grown for 10 years

Intensity (Use per Vehicle)	General Motors	Volkswagen	Ford	BMW	Toyota (North America)	Equivalence
Water m^3/Vehicle	4.62	4.55	4.3	2.1	3.41	Water for the production of 1 vehicle is similar to that required to fill a small pool
Data source	GM Sustainability Report [3]	Volkswagen Sustainability Report [4]	Ford Sustainability Report [6]	BMW Sustainability Report [6]	Toyota North American Environmental Report [7]	Note: the average annual electricity consumption for a U.S. residential utility customer was 11,280 kWh, an average of 940 kWh per month according to U.S. Energy Information Administration in 2011

Source: Oh and Hildreth 2014

Direct emissions from assembly plants in the United States in 2012 were almost 2 million metric tons CO_2e ($MMTCO_2$e), while indirect emissions from the purchase of electricity totaled approximately 4.4 $MMTCO_2$e. In total, automobile assembly plants were responsible for approximately 6.4 $MMTCO_2$e emissions in 2012 (Energy Star 2015).

Sullivan et al. (2010) estimated the per kg energy consumption and CO_2 emissions of each aspect of the material transformation and vehicle assembly process. The data show the average energy consumption and average CO_2 emissions for various processes and provides a range of data when possible. These values are shown in Table 6.2.3-2. Estimates for the energy consumption and noncombustion emissions occurring during the specific vehicle assembly processes from Kelly et al. (2022) are shown in Table 6.2.3-3. Further detail on the energy and water consumed and the emissions are shown in Table 6.3-2 in Section 6.3, *Vehicle Disposal and Recycling*. Beyond energy use, water use, and GHG emissions, the vehicle manufacturing process also results in other air and soil emissions. These include air emissions of particulate matter, volatile organic compounds, sulfur oxides, NO_X, CO, and emissions to water from paint overspray and to soil from paint sludge (Rivera and Reyes-Carillo 2014). Painting activities are responsible for most of the environmental impacts occurring during vehicle assembly (Rivera and Reyes-Carillo 2014).

Table 6.2.3-2. Material Transformation and Vehicle Assembly Process Data

Process	Avg. Energy Consumption (MJ/kg)	Avg. CO_2 Emissions (kg CO_2/kg material)
Material Transformation Processes		
Shape casting, aluminum	55.3	3.08
Forging	45.1	2.61
Iron	32.0	1.69
Injection mold		
PP	26.4	1.53
PVC	24.3	1.56
Blow mold, HDPE	19.7	1.13
Glass pane forming	16.0	0.93
Moldings		
Rubber	12.9	0.74
Thermosets	4.8	0.27
Secondary lead production	8.5	0.49
Brass from scrap	7.4	0.42
Copper wire production	7.1	0.43
Extrusion, HDPE pipe	7.0	0.42
Calendaring, PVC sheet	6.2	0.36
Stamping	5.1	0.31
Machining	2.0	0.12
Vehicle Assembly Processes		
Painting	4,167	268
HVAC and lighting	3,335	225
Heating	3,110	195
Compressed air	1,380	93
Welding	920	62
Material handling	690	40

Source: Sullivan et al. 2010
Notes: CO_2 = carbon dioxide; HVAC = heating, ventilation, and air conditioning; kg = kilogram; MJ = megajoule; HDPE = high density polyethylene

Table 6.2.3-3. Vehicle Assembly Energy Use and Non-Combustion Emissions

Input or Emission	Unit	Vehicle Assembly						Vehicle Disposal and Recycling
		Painting	HVAC & Lighting	Heating	Material Handling	Welding	Compressed Air	
Fuel								
NG	MMBtu/vehicle	2.30	–	2.98	–	–	–	–
Electricity	MMBtu/vehicle	0.46	0.99	–	0.21	0.27	0.41	1.47
Noncombustion emissions								
Volatile organic compounds	ton/vehicle	0.002	–	–	–	–	–	–

Source: Kelly et al. 2022:Table 43

Previous literature has extensively explored existing strategies to improve the energy efficiency and reduce the emissions intensity of vehicle assembly plants in the United States. In 2021, EPA released an updated version of the Energy Performance Indicator resource. This tool enables vehicle assembly plants to benchmark against other assembly plants in the United States and encourages plants to improve energy efficiency (Energy Star 2021). Specific energy efficiency strategies for various stages of the assembly process include energy-efficient joining technologies, more efficient painting facilities, shorter conveyor systems, less plant square footage, less energy use for transporting materials, and optimized assembly system layout (Oumer et al. 2016). Galitsky and Worrell (2008) provide a highly granular analysis of different energy efficiency measures by utility systems and processes of assembly, as listed in Table 6.2.3-4 and Table 6.2.3-5. Another study highlights the potential for heat recovery from compressed air and chilled water systems during the painting process. The study also notes that the addition of liquid desiccant technology, which absorbs moisture and improves paint quality, could make use of the low-temperature waste heat and offer energy reductions (Giampieri et al. 2020).

Table 6.2.3-4. Vehicle Assembly Plant Energy Efficiency Measures by Utility System

General Utilities	Motors
Energy management systems	Sizing of motors
Combined heat and power (CHP)	High efficiency motors
CHP combined with absorption cooling	Switch reluctance drives
District heating	Adjustable/variable speed drives
Alternative fuels	Variable voltage controls
Compressed Air Systems	**Heat and Steam Distribution - Boilers**
Maintenance	Improve process control
Monitoring	Reduce flue gas
Reduce leaks in pipes and equipment	Reduce excess air
Turn off unnecessary compressed air	Correct sizing in design
Modify system instead of increasing system pressure	Improve insulation
Use sources other than compressed air	Boiler maintenance
Load management	Recover heat from flue gas
Use sources other than compressed air	Boiler maintenance
Load management	Recover heat from flue gas
Use air at lowest possible pressure	Return condensate
Minimize distribution system pressure drop	Recover steam from blowdown
Cold air intake	Replace obsolete burners by new optimized boilers
Controls	**Heat and Steam Distribution – distribution**
Correctly sizing pipe diameter	Improve insulation
Properly size regulators	Maintain insulation
Systems improvements	Improve steam traps
Heat recovery for water preheating	Maintain steam traps
Natural gas engine-driven compressors	Monitor steam traps automatically
Energy efficient chillers	Repair leaks
Compressor motors	Recover flash steam
Adjustable speed drives	**HVAC**
High efficiency motors	Electronic controls
Lighting	Weekend setback temperatures
Controls	Ventilation and cooling system design improvements
Setting lighting standards	Recover cooling water
Daylighting	Solar heating (Solarwall)
Replace incandescent with fluorescents or CFLs	Building shell
Replace mercury with metal halide or high-pressure sodium	Modifying fans
Replace metal halide HID with high-intensity fluorescents	Other measures
Replace magnetic with electronic ballasts	**Materials Handling and Tools**
Reflectors	High efficiency belts
Light emitting diodes (LEDs) or radium strips	**Miscellaneous**
System improvements	Improvements in electrical harmonic filters
	Energy efficient transformers

Source: Galitsky and Worrell 2008

Table 6.2.3-5. Vehicle Assembly Plant Energy Efficiency Measures by Process

Painting Systems	
Maintenance and controls	Wet on wet paint
Minimize stabilization period	New paint—powders
Reduce air flow in paint booths	New paint—powder slurry coats
Insulation	New paint—others
Heat recovery	Ultrafiltration/reverse osmosis for wastewater cleaning
Efficient ventilation system	Carbon filters and other volatile organic compound removers
Oven type	Infrared paint curing
High pressure water jet system	Microwave heating
Body Weld	**Stamping**
Computer controls	Variable voltage controls
High efficiency welding/inverter technology	Air actuators
Multi-welding units	
Frequency modulated DC-welding machine	
Hydroforming	
Electric robots	

Source: Galitsky and Worrell 2008

Compared to other industrial manufacturing processes in the United States, the energy intensity of automobile manufacturing is relatively low when measured as total energy expenditures (e.g., fuel and electricity costs) divided by total operating expenditures (e.g., material costs, labor, capital expenses). Energy expenditures make up 0.4 percent of total operating expenditure for automobile manufacturing compared to 37.2 percent for lime manufacturing and 34.6 percent for industrial gas manufacturing (Oh and Hildreth 2014). Furthermore, automobile manufacturing plants have options to improve efficiency to further reduce the energy and emissions intensity of the automobile manufacturing process (Giampieri et al. 2020). In summary:

- Vehicle assembly includes separate assembly lines for the body and chassis before they are attached together.
- Painting (primarily from controlling the temperature and humidity in the paint booths and maintaining proper ventilation), HVAC, lighting, and supplying of compressed air are the most energy-intensive vehicle assembly processes and those that emit the most GHG emissions.
- Various strategies exist to improve the energy efficiency and reduce the emissions intensity of U.S. vehicle assembly plants.
- The energy intensity of vehicle manufacturing is relatively low in the context of energy expenditures to total operating expenditures.

6.3 Vehicle Disposal and Recycling

End-of-life practices are critical considerations when assessing vehicles and any technology life-cycle impact. The ability to reuse, recycle or re-integrate in the supply chain parts or materials of a vehicle at its end of life can lessen its environmental impact, especially if these solutions are implemented at a large scale. Recovery of scrap from vehicles and other products allows manufacturers to increase their use of recycled material inputs. Table 6.3-1 summarizes the GREET 2022 model's estimates for average virgin and recycled materials (in percentage by weight) for a 2021 MY vehicle.

Table 6.3-1. Share of Virgin and Recycled Materials Used in Average Vehicle, in Percentage by Weight

Material Type	Virgin Content	Recycled Content
Steel	73.6%	26.4%
Wrought Aluminum	64.9%	35.1%
Cast Aluminum	20.0%	80.0%
Lead	27.0%	73.0%
Nickel	56.0%	44.0%

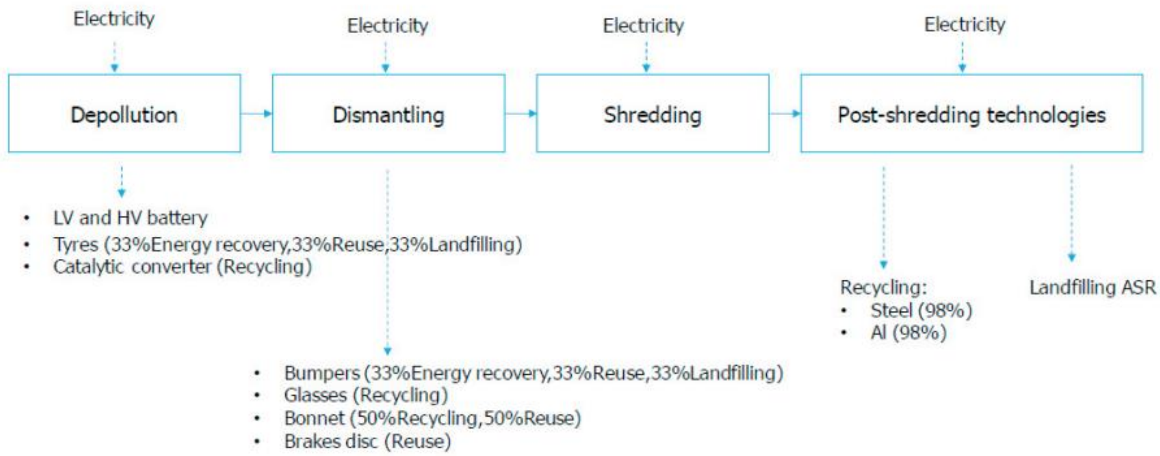
Source: ANL 2022

The 2022 GREET2 Model offers an estimate of 173,151 miles for the average lifetime vehicle miles traveled for both an ICE vehicle and an EV. Within this lifetime, an average ICE car would be expected to undergo 39 engine oil changes, 3 brake fluid changes, and 2 lead-acid battery changes. For an EV car, no replacement of lithium-ion battery is expected in this same estimated lifetime. For both car types, three tire replacements are expected during the lifetime of the vehicle.

Vehicle end of life involves various processes. A 2018 LCA study followed an approach that separates vehicle end of life into four steps of depollution, dismantling, shredding, and post-shredding, as shown in Figure 6.3-1 (Del Pero et al. 2018). The study estimated the end-of-life emissions savings related to an ICE vehicle at 95.1 kg CO_2e compared to 87.2 kg CO_2e for a comparable BEV (Del Pero et al. 2018). This end-of-life impact quantification process is using the ISO standard 22628:2002 "Road Vehicles Recyclability and Recoverability: Calculation Method," considers the energy process from each end-of-life activity, and credits all impacts generated from a recyclable material and energy flows. The end of life of car batteries are excluded from the analysis (outside of LCA boundaries) because they are assumed to be removed from the vehicle in the depollution stage and forwarded to secondary use. The study does, however, warn against evaluating the impact of a BEV versus an ICE vehicle only through the lens of one specific impact indicator (e.g., climate change) or one specific life-cycle stage because doing so may lead to erroneous overall conclusions. In particular, this study assessed EVs to evaluate higher life-cycle impacts for acidification, human toxicity,[23] particulate matter, photochemical ozone formation, and resource depletion.

[23] In this LCA, emissions involved in the mining processes of raw materials and manufacturing of chemicals and metals used in the electric drivetrain are the main drivers responsible for the human toxicological effect.

Figure 6.3-1. Allocation of Vehicle Components and Materials to End-of-Life Processes



Source : Del Pero et al. 2018

Table 6.3-2 shows the energy and emissions resulting from the end-of-life disposal phase for an average LD vehicle, in comparison to other assembly phases, based on the GREET2 2022 model. Energy and emissions related to the vehicle disposal phase are a significant portion of the average vehicle Assembly-Disposal-Recycling phases, representing 21.5 percent of total energy consumption and 21.4 percent of total GHG emissions.

Sections 6.3.1, *Non-Battery Powertrain Vehicle Disposal and Recycling*, and 6.3.2, *Battery Disposal and Recycling*, elaborate on the challenges and current state of recycling and disposal considerations for non-battery powertrain components and battery components, respectively.

Table 6.3-2. GREET2 2022 Summary of Energy Consumption and Emissions Related to Vehicle Assembly, Disposal and Recycling

	Paint Production	Vehicle Assembly						Vehicle Disposal[a]	Total
		Painting	HVAC & Lighting	Heating	Material Handling	Welding	Compressed Air		
Energy Use: MMBtu per vehicle									
Total Energy	0.595	3.511	2.052	3.32	0.425	0.566	0.848	3.101	14.416
Fossil fuels	0.472	3.313	1.628	3.318	0.337	0.449	0.672	2.46	12.649
Coal	0.209	0.336	0.722	0.003	0.149	0.199	0.298	1.09	3.007
Natural gas	0.256	2.966	0.884	3.313	0.183	0.244	0.365	1.337	9.549
Petroleum	0.006	0.011	0.022	0.001	0.004	0.006	0.009	0.033	0.092
Water consumption (gallon per vehicle)	50	87	171	10	35	47	71	259	731
Total Emissions: grams per vehicle									
VOC	4.3	1,638.3	15.0	40.7	3.1	4.1	6.2	22.6	1,734.4
CO	15.6	179.0	53.6	170.7	11.1	14.8	22.2	81.1	548.0
NO_X	28.2	250.3	97.2	231.5	20.1	26.8	40.2	146.9	841.2
PM10	4.2	75.8	14.6	11.7	3.0	4.0	6.0	22.1	141.6
PM2.5	2.3	42.7	8.0	11.6	1.7	2.2	3.3	12.1	84.0
Sulfur oxides	24.9	66.2	85.8	34.3	17.8	23.7	35.4	129.7	417.7
Black carbon	0.1	1.7	0.4	2.0	0.1	0.1	0.2	0.6	5.2
Organic carbon	0.6	4.8	2.0	5.0	0.4	0.6	0.8	3.1	17.3
CH_4	77.8	640.1	268.3	668.7	55.5	74.0	110.8	405.4	2,300.6
N_2O	0.7	6.2	2.6	6.5	0.5	0.7	1.1	3.9	22.1
CO_2	36,679	210,351	126,523	196,751	26,199	34,890	52,271	191,220	874,883
CO_2 (VOC, CO, CO_2)	36,717	215,739	126,654	197,146	26,226	34,926	52,325	191,418	881,150
GHGs	39,238	236,500	135,350	218,838	28,027	37,324	55,917	204,561	955,755

Source: ANL 2022

[a] Vehicle Disposal refers to all end-of-life operations, including landfilling and recycling assumptions.

CH_4 = methane; CO = carbon monoxide; CO_2 = carbon dioxide; MMBtu = million British thermal units; N_2O = nitrous oxide; NO_X = nitrogen oxides; PM10 = particulate matter 10 microns or less in diameter; PM2.5 = particulate matter 2.5 microns or less in diameter; VOC = volatile organic compounds

6.3.1 Non-Battery Powertrain Vehicle Disposal and Recycling

Vehicle-related disposal and recycling operations have important implications for the magnitude of total life-cycle GHG emissions for a vehicle. Proper end-of-life treatment of non-battery powertrain vehicle components through careful disposal and recycling processes can help reduce total life-cycle GHG emissions. 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). While recycling processes require energy and produce emissions, recycling vehicle components can save energy, conserve resources, and reduce emissions by displacing the production of virgin materials (e.g., ore, bauxite), reducing the total life-cycle GHG emissions for a vehicle.

The overall process for dismantling a vehicle for disposal and recycling requires an estimated energy expenditure of 1.5 MMBtu per vehicle. This estimate is based off a 3,000-pound vehicle and does not include material recovery processes or energy recovery combustion (Burnham et al. 2006). This value is also cited by Kelly et al. (2022).

In current technology for sedans and small SUVs, the powertrain, defined by NHTSA as including the engine, transmission, exhaust system, fuel systems, and cooling systems, makes up approximately 20 percent of the total weight of gasoline ICE vehicles (Kelly et al. 2022). The powertrain for BEVs, defined by NHTSA as including motors, step down gearbox, the energy storage system (battery), battery management system, and thermal system, can account for approximately 21 to 36 percent of total vehicle weight (Kelly et al. 2022). The material composition of powertrain components is shown in Table 6.3.1-1.

Table 6.3.1-1. Breakdown of Material Composition of Powertrain Components

Vehicle Type/ Powertrain Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	GFRP	Average Plastic	Rubber	Stainless Steel	CFRP	Others
Mid-size sedans										
Engine	44%	5%	39%	2%	3%	5%	2%	-	-	5%
Engine fuel storage system	30%	-	-	3%	-	63%	3%	-	-	-
Exhaust	92%	2%	4%	-	-	-	1%	-	-	-
Powertrain electrical	17%	2%	3%	28%	-	50%	1%	-	-	-
Powertrain thermal	17%	21%	7%	5%	9%	33%	9%	-	-	-
Fuel cell stack & BOP	19%	17%	-	2%	3%	17%	6%	31%	-	6%
H2 storage and BOP	9%	-	-	-	4%	8%	-	8%	66%	4%
Small SUVs										
Engine	38%	4%	40%	3%	3%	8%	2%	-	-	1%
Engine fuel storage system	20%	3%	-	3%	1%	70%	2%	-	-	-
Exhaust	77%	2%	19%	-	-	1%	1%	-	-	-
Powertrain electrical	10%	1%	2%	31%	2%	53%	1%	-	-	-

Vehicle Type/ Powertrain Component	Steel	Wrought Aluminum	Cast Aluminum	Copper	GFRP	Average Plastic	Rubber	Stainless Steel	CFRP	Others
Powertrain thermal	16%	21%	4%	4%	6%	38%	11%	-	-	-
Fuel cell stack & BOP	19%	17%	-	-	3%	17%	6%	31%		6%
H2 storage and BOP	9%	-	-	-	4%	8%	-	8%	66%	4%

Notes:
Source: Kelly et al. 2022:Tables 31 and 32
BOP = Balance of Plant; CFRP = carbon fiber reinforced plastic; GFRP = glass fiber reinforced plastic

The following subsections discuss the GHG, energy, and other environmental impacts and considerations for non-battery vehicle component materials at vehicle end of life. In addition to the materials discussed in Section 6.2.1, *Non-Battery Components*, with the exception of iron castings, this section also addresses tire disposal and recycling.

6.3.1.1 Steel

Scrap steel can be recycled by melting scrap steel using EAFs. The scrap steel is added to the furnace using an overhead crane where an electric current is used to melt the scrap materials. Limestone is often used in the process as a means of removing impurities from the scrap steel. Alloy materials are sometimes added depending on the planned end use of the recycled steel. The steel is then poured into ingot molds to prepare for shipping to be recast for specific vehicle components (Burnham et al. 2006).

A study by Sebastian and Thimons (2017) examined the impact on life-cycle GHG emissions for vehicle components manufactured with recycled inputs. It concluded that in different scenarios, high-strength steel consistently showed lower life-cycle GHG emissions compared to conventional steel with the use of recycled material inputs. They reached this conclusion in scenarios accounting for a credit from metals recycling (e.g., assuming that using scrap inputs offsets the use of virgin material inputs) and scenarios that did not include a credit for avoided use of virgin materials. However, the study found that life-cycle GHG emissions from aluminum components exceeded those of both conventional and high-strength steel vehicles when not including a credit for avoided use of virgin materials (Sebastian and Thimons 2017).

6.3.1.2 Plastics/Polymer Composites

Studies vary on whether plastics and polymer composites are viable material substitutes from a life-cycle GHG emission perspective. Some studies have acknowledged that the available data to conduct life-cycle assessments of plastics and composites is still lacking (Rikhter et al. 2022). However, with currently available data, many studies conclude that how plastics are recycled or disposed of has important implications for whether substitution of steel parts with plastic and composite alternatives can reduce total life-cycle GHG emissions. Studies that have analyzed the effects of using plastics and polymer composites in vehicles have 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 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. Incineration has lower life-cycle impacts for composite materials than landfilling because 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 frequently. If waste-to-energy disposal is not an option for composite auto body components, they are more often landfilled than their metal alternatives because of their low recyclability (Tempelman 2011). A European study found that the automotive plastic reuse and recycling rate is currently 2.6 percent but has the potential to reach 50.4 percent through innovative approaches (Cardamone et al. 2022).

6.3.1.3 Aluminum

Recycled aluminum is produced through scrap preparation, melting, ingot casting, and then parts casting. After preparing the aluminum scrap material, the scrap is melted using natural gas-fired furnaces. Similar to primary aluminum production, the melted aluminum is then poured into ingot molds. The aluminum ingots can then be shipped off to automobile parts manufacturers to cast the aluminum ingot for specific vehicle parts. Burnham et al. (2006) determined that “alloy compatibility is a major concern for producing quality parts from recycled materials. Thus, for large-scale recycling of aluminum automotive parts, the cast and wrought materials should be separated so that the chemistry of the recycled parts is predictable and desirable.”

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,[24] and location of aluminum production. 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). A recent study found that for every additional percent of end-of-life recycling of aluminum, energy demand could be reduced by 1,266 MJ and emissions reduced by 80 kg CO_2e based off 1 metric ton of aluminum (Wang 2022). 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.[25] The increased volume of aluminum scrap presents an opportunity for vehicle manufacturers to increase the recycled content of

[24] 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., kg 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 affect results, which is why many vehicle LCAs express results per kilometer or mile as a functional unit.

[25] 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. LD 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.

vehicles and reduce the energy intensity and GHG impacts of the material extraction and production phases (Zhu et al. 2021).

LCA results are also sensitive to how energy and emissions savings from recycling end-of-life aluminum vehicle components are allocated in a given study. Sebastian and Thimons (2017) found that substituting aluminum for conventional steel sheet parts reduces the total life-cycle GHG emissions when using the avoided burden method to account for a credit from metals recycling. 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 conventional and high-strength steel vehicles (Sebastian and Thimons 2017). Similar results were shown in a study by Palazzo and Geyer (2019).[26]

In practice, recycling aluminum results in the accumulation of impurities, such as 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[27] (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 conventional 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 (Raugei et al. 2015).

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

[26] 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).

[27] 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, and are 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), making an entire closed-loop system challenging. However, emerging technologies (e.g., laser-induced breakdown spectroscopy, a focus laser pulse vaporizer) can improve the process efficiency and accelerate the progress towards a closed-loop system.

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[28] difference in emissions factors depending on how and where the electricity is generated (Colett 2013).

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 2021). 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.

6.3.1.4 Fluids and Lubricants

The end-of-life treatment of vehicle fluids and lubricants is highly important given that these substances contain toxic chemicals that can have adverse impacts on the environment and human health. For example, ethylene glycol, a common substance in antifreeze, coolants, brake fluid, and other fluids, can cause respiratory issues and other negative health impacts (National Center for Biotechnology Information 2023). Many of these fluids such as engine oil, transmission fluid, and power steering fluid can be recycled. Other fluids that cannot be recycled must be disposed of properly to avoid additional negative impacts. Certain automotive fluids and lubricants may be hazardous and generally need to be disposed of in accordance with state or local laws.

6.3.1.5 Other Powertrain Metals

Other metals, such as copper, nickel, and cobalt found in non-battery powertrain components have good theoretical recycling potential and are increasingly recovered for recycling.

In the past decade, recycled sources have provided more than 30 percent of all copper consumed per year, inclusive of all sectors. According to a global copper stocks and flows model developed by the Fraunhofer Institute, it is estimated that about two-thirds of the 550 million metric tons of copper produced since 1900, or about 367 million metric tons, are still in productive use (Copper Alliance 2023; Glöser et al. 2013). In 2018, the U.S. recycling industry recovered 870,000 metric tons of old and new copper scrap, a 1 percent increase from the previous year. Of this total, 83 percent was new scrap from manufacturing operations and 17 percent was old scrap, as reported by the U.S. Geological Survey. This

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[28] The Colett (2013) study calculated a range of emissions factors (EFs) for single fuels using data from ANL's GREET model. These EFs ranged from "23.3 kg CO_2-eq/kg Al for an all-coal fueled electricity grid, 15.1 kg CO_2-eq/kg Al for natural gas, to 4.9 kg CO2-eq/kg Al for hydro and renewables. This captures the full range of production weighted EFs seen in our study (15.4 to 19.8 kg CO_2-eq per kg Al ingot)." The "479 percent difference figure" is calculated from the difference between primary aluminum production powered entirely by coal-generated electricity compared to renewable-generated electricity, which "highlights the large influence of electricity generation fuel source on the final GHG EFs of primary aluminum production."

supply met 34 percent of the domestic demand for refined copper (Copper Development Association, Inc. 2022).

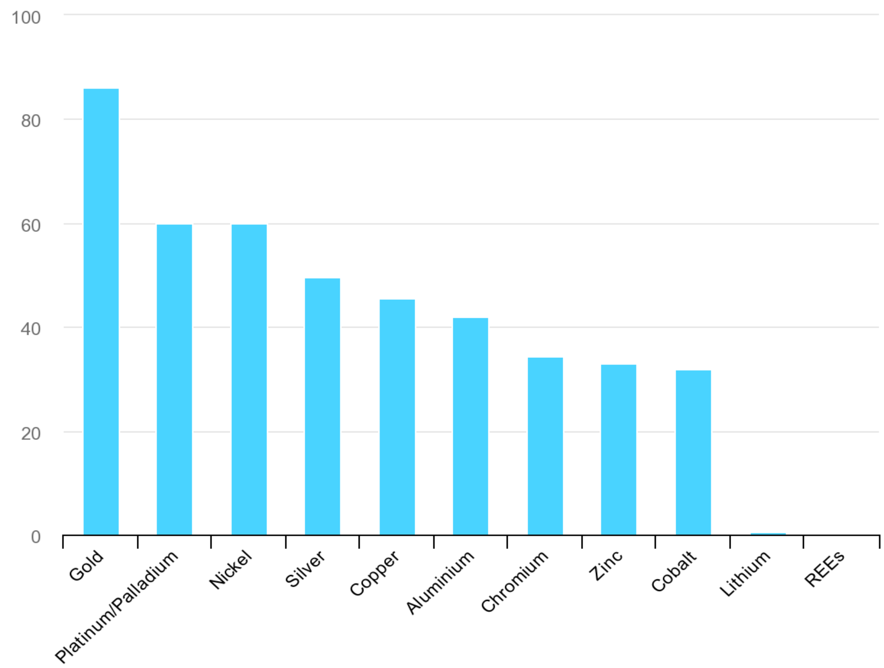
During the lifetime of products, small amounts of copper are lost due to factors such as corrosion and abrasion. Additionally, when scrap is separated and disassembled, a significant amount of copper is lost and ends up in other metal recycling loops, in the form of slags or impurities in the recycled metal. Additionally, some copper is not collected after the end of its useful lifetime and remains in place, known as *abandoned in place* (Glöser et al. 2013).

Recycled cobalt represented about 29 percent of U.S. consumption in 2018. Cobalt can be recovered from secondary sources by incorporating the recycled material into a primary refining or transformation process, resulting in final products such as cathodes, powders, oxides, salts, or solutions, depending on market demand (OECD 2019). Cobalt recycling requires 46 percent less energy and 40 percent less water than primary production. It also results in a 59 percent reduction in GHG emissions and a 98 percent reduction in sulfur oxide emissions. It is estimated that by 2050, 25 percent of the necessary cobalt could be obtained through recycling (Golroudbary et al. 2022).

Nickel, like many other metals, is a fully recyclable natural resource that can be recycled again and again without any loss of quality, making it a valuable resource for the Circular Economy model (Nickel Institute 2023). Nickel and nickel-containing alloys can be recycled and transformed into their original state or another valuable form. For example, nickel-containing stainless steel scrap can be used to create new stainless steel, and nickel from recycled batteries can be used in nickel-containing stainless steel. In 2010, about 68 percent of all available nickel from consumer products was recycled, 15 percent entered the carbon steel loop, and around 17 percent still ended up in landfills, mostly in metal goods and waste electrical and electronic equipment (Nickel Institute 2023). Production with recycled nickel uses about 5 percent as much energy as nickel from virgin inputs (ANL 2022); a comparison is shown in Section 6.2.1.6, *Other Powertrain Metals (Copper, Cobalt, Nickel)*, in Table 6.2.1-10.

Figure 6.3.1-1 shows the global recycling rates, as of 2022, of powertrain metals such as copper, cobalt, and nickel compared to recycling rates of other metals. Out of the three powertrain metals discussed, nickel has the highest recycling rate of approximately 60 percent, followed by copper at approximately 45 percent, and cobalt at approximately 30 percent (IEA 2022d).

Figure 6.3.1-1. Global Recycling Rates of Copper, Cobalt, and Nickel Compared to Other Metals



Source: IEA 2022a

6.3.1.6

The disposal and recycling of tires is another important end-of-life consideration for vehicles. Tires are an energy-intensive vehicle component to manufacture, and their chemical composition slows or prevents degradation resulting in "a potential long-term permanence in the environment" (Valentini and Pegoretti 2022). It takes approximately 90 GJ/ton to prepare the rubber compound used in tires and an additional 115 GJ/ton to manufacture the tires (Valentini 2022). As a result, reusing or recycling tires is critical to reduce vehicle life-cycle GHG emissions.

Productive end-of-life options for tires include civil engineering applications (using tires in retaining walls, drainage basins, or other civil projects), energy recovery (shredding and burning tires as fuel for cement kilns to recover some of the energy used to produce them), retreading (extending the useful life of the tire by adding a new tread), or recycling (Valentini and Pegoretti 2022). In the energy recovery process, only about 15 percent of the energy required to make a tire can be recovered. Recycling is the optimal end-of-life treatment option. The rubber can be shredded into granulated rubber that can be used to make new tires or for other purposes such as turf or asphalt/road paving. In 2019, approximately 30.9 million tons of tires were at the end of their life globally. However, only 59 percent of these tires were disposed of properly. The other 41 percent were either disposed of in landfills, stockpiled, or lost. Stockpiling tires is illegal in many countries given that the buildup of tires can create a fire hazard, pollute the surrounding environment, or accumulate still water that allows large populations of mosquitoes to form and pose potential health risks (Valentini and Pegoretti 2022).

In summary:

- The use of recycled materials offers life-cycle GHG benefits for high-strength steel compared to conventional steel; for carbon fiber compared to conventional, lightweight, and virgin material inputs; and for aluminum compared to virgin aluminum inputs.

- The magnitudes of life-cycle GHG emissions reductions and energy-use savings are influenced by the amount of recycled material used in vehicle components, recycling rates, lifetime of vehicles, and location of production.
- Composites demonstrate lower recyclability than metals, but offer high energy content for waste to energy.
- Proper end-of-life treatment of vehicle fluids and lubricants is important given that some contain toxic chemicals that can adversely affect the environment and human health.
- Tire manufacture is energy intensive; reusing or recycling tires reduces vehicle life-cycle GHG emissions and offers useful applications.

6.3.2 Battery Disposal and Recycling

6.3.2.1 Lead-Acid Batteries

Lead-acid batteries (LABs) on their own 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 (Battery Council International 2020).

In North America, the recycling rate for LABs is almost 100 percent due in large part to the Mercury-Containing and Rechargeable Battery Management Act, which requires all sellers of LABs to accept these products at their end of life for recycling (Bird et al. 2022). It is estimated that recycled lead from LABs contributes 62 percent of the total amount of lead needed for a new LAB in the United States (International Lead Association 2022). U.S. secondary lead from LABs is recycled through a smelting process and totaled almost 1.1 million metric tons in 2011. The United States exported more than 300,000 metric tons of lead contained in used LABs in 2011, where 67 percent of this went to Mexico and 25 percent to Canada (U.S. Geological Survey 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).

6.3.2.2 Lithium-Ion Batteries

Unlike LABs, lithium-ion batteries do not yet have a high recycling rate, with current estimates at less than 5 percent for end-of-life lithium-ion batteries (DOE 2019).[29] The rate is likely higher, though difficult to estimate (Gaines et al. 2021). Scrap generated during the production of lithium-ion batteries serves as another important recycling feedstock with fairly high recycling rates ranging from 5 to 30 percent (Gaines et al. 2021). A combination of a booming market for lithium-ion batteries, lagging government regulation, and still-evolving and costly recycling methods are keeping end-of-life recycling rates low across the United States. EPA currently does not designate lithium-ion batteries as hazardous waste under the Resource Conservation and Recovery Act, which outlines the legal guidelines for disposal of hazardous waste. While there are no current Federal laws on lithium-ion battery recycling, EPA does recommend contacting the automobile dealer when the battery reaches its end of life as

[29] Includes batteries from various applications in addition to automotive.

opposed to direct disposal by the consumer (EPA 2023f). The addition of lithium-ion batteries under the Resource Conservation and Recovery Act would lead to greater regulation and a legal framework for their recycling in the United States (Bird et al. 2022). In addition, some states have laws banning the disposal of lithium-ion batteries in landfills (Winslow et al. 2017), but there are no specific state or local laws addressing lithium-ion battery recycling (Bird et al. 2022). Landfill disposal bans are becoming the consensus across the world for lithium-ion batteries, driven by concerns that leachate in landfills can transport toxic elements leached from batteries to groundwater supplies off the landfill site (Winslow et al. 2017). However, due to a lack of cohesive laws in the United States and batteries often ending up back in the hands of automobile dealers at end of life, detailed information on battery disposal in these cases is largely undetermined (Mrozik et al. 2021). The Mercury-Containing and Rechargeable Battery Management Act could be used as a template for the Federal Government to follow for lithium-ion battery recycling given its success, but LABs are also designed to be recycled during production, such as consistent design and materials across batteries. Lithium-ion batteries by contrast differ in size, shape, and components, so increased forethought toward uniformity would be crucial in increasing the success of lithium-ion battery recycling in the future (Bird et al. 2022).

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 production, use, and disposal of different types of electric batteries generate different types of waste. Both solid and hazardous waste are produced during the life cycle of the batteries, including during production and after their useful life in automobiles. Of the two main materials in electric batteries, nickel is classified as a hazardous air pollutant and hazardous waste, but lithium is not listed in either category (EPA 2023g).[30] The disposal of batteries can lead to adverse impacts because of the risk of toxic chemicals being released into the environment or combustion if the batteries are internally damaged (Mrozik et al. 2021).

A 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 kg (11–63.9 pounds) CO_2e per kWh with a median of 20 kg (44.1 pounds) CO_2e per kWh (Aichberger and Jungmeier 2020). At the end of the useful life of an EV or PHEV, the battery will most likely not be fully exhausted and could be used for other purposes (EPA et al. 2010) to mitigate environmental impacts. Most of the recycling techniques and methodologies are still at the laboratory or pilot 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.

LCAs of lithium-ion battery recycling have focused on three recycling technologies: pyrometallurgy, hydrometallurgy, and direct recycling using physical processes (Dunn et al. 2012; EPA 2013c; Hendrickson et al. 2015; Zwolinski and Tichkiewitch 2019; Xu et al. 2020; ANL 2019; Sambamurthy et al. 2021). 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. This process has been largely commercialized across the United States and Europe due to its efficient process and compatibility with any type of battery (Yu et al. 2022); however, large amounts of energy are needed to handle and purify waste gases at the end of the process before they enter the environment (Winslow et al. 2017). Also, the use of toxic solvents and acids during recovery poses health risks (Costa et al. 2021).

[30] 40 CFR 261.33.

Hydrometallurgy uses chemical leaching, capable of recovering valuable metals and lithium. It is a lower-cost and less energy-intensive alternative to pyrometallurgy, but hydrometallurgy is overall more complex and time consuming and leads to complications with wastewater treatment due to the chemical usage (Yu et al. 2022). 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).

Closed-loop recycling can be set up with 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. Similarly, Rajaeifar et al. (2021) concluded that closed-loop pyrometallurgical recycling can avoid between 770 and 2,080 kg CO_2e per metric ton of batteries recycled depending on the specific recycling scenario.

A third alternative is direct recycling, which aims at maintaining chemical structures in the process of recovering the cathode materials. It involves the recovery of useful components through physical processes like disassembly, crushing, and sorting without using any chemical processes (Dunn et al. 2012). Direct recycling using physical processes offer advantages over pyrometallurgy and hydrometallurgy through lower energy use and higher recovery rates; however, it is still in the early stages of development (Harper et al. 2019) and is the focus of ANL's Advanced Battery Recycling Initiative (ANL 2019).

Of the three processes, pyrometallurgy is currently most widely used (Nealer and Hendrickson 2015), while hydrometallurgy is the preferred method in China (Yu et al. 2022). 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 MJ/kg 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). GREET summarizes material and emissions data in a life-cycle inventory for pyrometallurgy, two variations of hydrometallurgy, and direct recycling of an NMC battery in Table 6.3.2-1.[31]

Table 6.3.2-1. Life Cycle Inventory for Battery Recycling Pathways

Inventory Item	Pyrometallurgy	Hydrometallurgy: Inorganic Acid Leaching	Hydrometallurgy: Organic Acid Leaching	Direct
Energy use (MMBtu/ton cells recycled)				
Diesel	0.516	0.516	0.516	0.516
Natural gas	-	2.150	0.837	-
Electricity	4.024	0.107	0.849	2.348
Water use (gal/ton cells recycled)	-	907	-	907

[31] GREET conducted this life cycle inventory using an economic value–based allocation approach as that aligns with the incentives involved in battery recycling.

Inventory Item	Pyrometallurgy	Hydrometallurgy: Inorganic Acid Leaching	Hydrometallurgy: Organic Acid Leaching	Direct
Materials Use (ton/ton cells recycled)				
Limestone	0.300	-	-	-
Sand	0.150	-	-	-
Hydrochloric Acid	0.210	0.012	-	-
Hydrogen Peroxide	0.060	0.366	0.065	-
Ammonium Hydroxide	-	0.031	-	-
Sodium Hydroxide	-	0.561	-	-
Sulfuric Acid	0.689	1.078	0.689	-
Soda Ash	-	0.021	0.361	-
Citric Acid	-	-	0.050	-
NMP	-	-	0.000	-
Lithium Carbonate	-	-	-	0.003
Carbon Dioxide	-	-	-	2.200
Non-fuel-combustion process emissions (g/ton cells recycled)				
Carbon Dioxide[a]	1,103,418	280,334	113,253	199,584

Notes:
[a] From combustion of battery materials that contain carbon, thermal decomposition of carbonates, and loss of supercritical CO_2.
Source: ANL 2019

Depending on the cell chemistry, recycling can significantly reduce the potential environmental impacts of battery production. One LCA study found that the highest benefits are obtained via the advanced hydrometallurgical treatment for NMC and lithium nickel cobalt aluminum oxide batteries, mainly due to cobalt and nickel (Mohr et al. 2020). 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 an economy where recyclers become suppliers for manufacturers, recycling would be optimized for business considerations. For example, transportation costs can be reduced if the recycling plant is near the production plant. Additionally, upfront planning would require the production and the recovery technologies to be compatible, along with the exchange of materials. The Infrastructure Investment and Jobs Act, passed by the Biden Administration in November 2021, provided $335 million in investments for lithium-ion battery recycling to help guide this growth in the supply chain. This helps fund an expansion to an existing lithium-ion recycling facility in Ohio (DOE 2022f) and DOE's Lithium-Ion Battery Recycling Prize, which in 2022 rewarded entrepreneurs who developed processes with the potential to capture 90 percent of lithium-ion batteries for recovery (DOE 2022g). To build on this, the Inflation Reduction Act, passed in August 2022, provides tax credits for the purchase of EVs manufactured using a certain percentage of domestic materials or those sourced from countries with which the United States has a free trade agreement, including recovered materials from recycling in North America.[32] At this time, many vehicle manufacturers and battery recyclers have started long-term cooperation and a coordinated planning approach. Some manufacturers are implementing their own recycling facilities, including Volkswagen, Ford, Mercedes-Benz, and Nissan. Other efforts to recycle these batteries are conducted through partnerships and collaboration (General Motors, Honda, Hyundai), which are all dependent on factors including the region, cooperation needs, and recycling technology (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 other 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). Current projections show by 2030 that secondary lithium recovered from batteries could make up 6 percent of the total supply, but as more batteries are put into the market (with an average lifespan of 10–15 years), this number could increase with more batteries up for recycling (Azevedo et al. 2022). In 2021 alone, lithium production rose by a steep 27 percent (BP 2022), emphasizing the importance of implementing strategies to recover these materials once the product has reached its end of life.

Although the majority of components in EV batteries are recyclable, the cost associated with material recovery still poses a significant hurdle for the industry. To ensure U.S. companies have secure and reliable access to critical minerals, circularity is critical. To build circularity, a report by the Li-Bridge Project recommends "establish[ing] an industry-led waste battery end-of-life program, harmoniz[ing] regulations for transporting waste batteries, and support[ing] the recovery and use of domestically recycled content" (Arora et al. 2023). The National Blueprint for Lithium Batteries, created by the Federal Consortium for Advanced Batteries (FCAB), outlines five goals for the United States to establish a secure domestic supply chain for lithium-based batteries by 2030. The fourth goal focuses on facilitating large-scale reuse and recycling of critical materials at the end of an EV battery's life cycle, along with establishing a complete competitive value chain within the United States (FCAB 2021). Lithium-ion battery cathodes come in more than 15 chemistries. While this enables their use in diverse applications, it also increases material demand. Advanced recycling methods can significantly reduce

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[32] Section 30D New Clean Vehicle Credit; Notice of Proposed Rulemaking, 88 FR 23370 (Apr. 17, 2023). As described in this IRS proposed rule, recycling is defined as "the series of activities during which recyclable materials containing critical minerals are transformed into specification-grade commodities and consumed in lieu of virgin materials to create new constituent materials; such activities result in new constituent materials contained in the battery from which the electric motor of a new clean vehicle draws electricity."

reliance on imported critical materials. DOE's Vehicle Technologies Office is investing in early-stage research to develop recycling technologies that extract and reuse key components with minimal energy and environmental impact. The Vehicle Technologies Office is establishing the ReCell Lithium Battery Recycling R&D Center, which focuses on cost-effective recycling processes to recover critical materials from lithium batteries. The team's research encompasses four areas: Design for Recycling, Recovery of Other Materials, Direct Cathode-to-Cathode Recycling, and Reintroduction of Recycled Materials (DOE 2019).

Other end-of-life alternatives for EV batteries include reuse applications for energy storage. Currently, when EV batteries are removed from vehicle operation, significant battery capacity remains, although to an uncertain degree (Sathre et al. 2015). A procedure for assessing the battery state and the technical and economic viability for transition to a second life application—including direct use, stacking used battery packs, making a refurbished battery from used modules, and making refurbished modules from used cells—is detailed in a recent study (Montes et al. 2022). There is potential for end-of-life EV batteries to play a role in grid-attached energy storage and could help in resource conservation of vital elements like cobalt and lithium. One study estimated the use of EV batteries as energy storage as a second use could reduce lithium demand by 30,000 kg per year after 2030 (with demand peaking at 120,000 kg) and similarly reduce cobalt demand by nearly 30 percent in 2033 (Busch et al. 2017). Additional 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).

In summary:

- The rise in EV adoption will create large battery waste flows and require increased efficiency in recovering lithium-ion battery materials at end of life.
- At end of life for an EV, the battery life may not yet be exhausted; batteries can often be repurposed in applications such as energy storage.
- Recycling lithium-ion batteries, regardless of which technology is used, reduces the life-cycle GHG emissions, reduces other environmental impacts, and avoids waste flows. Pyrometallurgy is the most common recycling technology, but also the most energy intensive.
- An additional benefit of battery recycling is the recovery of high-value metals.

6.4 Conclusions

The information in this chapter helps the decision-maker understand the environmental impacts, with a focus on GHG emissions and energy use, that arise during vehicle material and battery production, vehicle assembly, and end-of-life phases. It also discusses some potential opportunities for reductions in environmental impacts in the production and end-of-life vehicle life-cycle phases. These changes in environmental impacts would be proportional to the degree to which vehicle manufacturers use the various materials or technologies in response to the action alternatives (CAFE and HDPUV FE standards) under consideration. As discussed in Section 6.1, *Introduction*, NHTSA does not know how manufacturers will rely on the different materials or technologies assessed in this chapter and fuel sources assessed in Chapter 3, *Energy*, and as a result cannot quantitatively distinguish between action alternatives.

The non-battery powertrain-specific technologies that are projected by the CAFE Model to have the highest technology penetration in the LD vehicle fleet are shown in Table 6.4-1 for MY 2032. The higher penetration of mass reduction technologies, such as those discussed in this chapter, will in most cases contribute to lowering vehicle life-cycle GHG emissions, with the largest reductions in the use phase. The use of high-strength steel, plastics and polymer composites, and aluminum, and in particular recycled versions of these materials in place of conventional steel, offer mass reduction and net life-cycle GHG and emission benefits; however, extraction of virgin inputs can lead to additional environmental impacts. As shown in Table 6.4-1, the technology with highest mass reduction for passenger cars and light trucks—Level 3 with a 15 percent reduction in glider weight—is seen in CAFE Alternatives PC1LT3 and PC2LT4 in MY 2032.

Table 6.4-1. Summary of CAFE Model's Highest Non-Battery Technology Penetration Rates for Passenger Car and Light Trucks in MY 2032

Technology Type	No-Action	CAFE Standard Action Alternative			
		PC1LT3	PC2LT4	PC3LT5	PC6LT8
TURBO0: Turbocharging and Downsizing, Baseline Level	11%	11%	10%	10%	6%
HCR: High Compression Ratio Engine	15%	14%	14%	14%	9%
ATR: 8-Speed Automatic Transmission	13%	10%	9%	5%	1%
Conventional Powertrain (Non-Electric)	11%	11%	11%	10%	8%
12-Volt Micro-Hybrid (Stop-Start)	23%	21%	20%	19%	9%
Mass Reduction Technologies					
Mass Reduction, Level 1 (5% Reduction in Glider Weight)	33%	33%	30%	30%	26%
Mass Reduction, Level 3 (10% Reduction in Glider Weight)	47%	44%	44%	42%	37%
Mass Reduction, Level 4 (15% Reduction in Glider Weight)	10%	44%	44%	42%	37%
Low-Rolling-Resistance Tires					
Low-Rolling-Resistance Tires, Level 3 (30% Reduction)	97%	97%	97%	97%	97%

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. As lightweight materials are typically more scarce (Lewis et al. 2019), mining for the minerals needed to construct lighter vehicles could shift some metal extraction activities to areas where these resources are more abundant. However, this is also the case with demand for non-lightweighting materials, such as copper and cobalt (Lewis et al. 2019). Relocating mining to new sites for these alternative resources could result in environmental impacts, such as destruction of natural habitat from altered land cover, toxic emissions, and consumption of differing regional sources of energy. 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. The CAFE Model projects a substantial penetration of mass reduction technologies in the LD vehicle fleet under the CAFE No-Action Alternative and the CAFE standard action alternatives, implying that a shift toward lighter-weight materials is likely, potentially leading to new mining sites.

CAFE and HDPUV FE action alternatives with greater shares of lithium-ion EVs projected (Table 6.4-2 and Table 6.4-3) will result in overall reduced life-cycle GHG impacts. For PHEVs and dedicated EVs, the impact would be more substantial in regions where the electric grid mixes are less carbon intensive because GHG emissions from EVs in these regions would be lower than regions with a higher carbon grid. (As discussed in Chapter 3, *Energy*, the grid mix would not affect the use phase for strong HEVs because those vehicles are not plugged in and do not depend on electricity and charging stations for power.) Chapter 3.3 of NHTSA's Technical Support Document provides detailed descriptions of the EV technologies included in the CAFE Model. LCA impacts of lithium-ion batteries are higher for action alternatives that reflect more stringent CAFE standards; for NHTSA's EIS (i.e., "unconstrained") CAFE Model runs (Chapter 2, Section 2.3.2, *Constrained versus Unconstrained CAFE Model Analysis*), the CAFE Model projects a greater penetration of vehicles with lithium-ion batteries—reaching approximately 65, 66, 70, and 83 percent, respectively, in the four CAFE standard action alternative scenarios in MY 2032, as shown in Table 6.4-2.

Table 6.4-2. Technology Penetration Rates for Passenger Cars and Light Trucks Using Batteries in MY 2032

Technology Type	No-Action	CAFE Standard Action Alternative			
		PC1LT3	PC2LT4	PC3LT5	PC6LT8
Strong HEVs	4%	4%	4%	3%	2%
PHEVs	3%	3%	3%	5%	7%
BEVs	53%	54%	56%	57%	68%
Total for Strong HEVs, PHEVs, and BEVs	**59%**	**62%**	**63%**	**65%**	**76%**

Notes:
PHEV = plug-in hybrid electric vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle
Totals may not sum due to rounding.

Table 6.4-3 shows the CAFE Model's projections of the technologies with the highest penetration rates for HDPUVs in MY 2035. BEVs are projected to account for a growing share of the vehicle fleet as the stringency increases across HDPUV action alternatives. As shown in Table 6.4-3, the Level 1 mass technology with a 5 percent reduction in glider weight is projected to be employed in the majority of HDPUVs across the alternatives in MY 2035.

Table 6.4-3. Summary of CAFE Model's Highest Technology Penetration Rates for Heavy-Duty Pickup Trucks and Vans in MY 2035

Technology Type	No-Action	HDPUV FE Standard Action Alternative		
		HDPUV4	HDPUV10	HDPUV14
SOHC: Single Overhead Camshaft Engine	17%	17%	13%	0%
ATR: 8-Speed Automatic Transmission	20%	20%	16%	4%
12V Micro-Hybrid (Stop-Start)	17%	17%	14%	6%
P2TRB0: P2 Strong Hybrid/EV with TURBO0 Engine	26%	26%	26%	27%

Technology Type	No-Action	HDPUV FE Standard Action Alternative		
		HDPUV4	HDPUV10	HDPUV14
Mass Reduction Technologies				
Mass Reduction, Level 1 (5% Reduction in Glider Weight)	79%	79%	79%	79%
Mass Reduction, Level 2 (7.5% Reduction in Glider Weight)	15%	15%	15%	15%
Low-Rolling-Resistance Tires, Level 2 (20% Reduction)	94%	94%	94%	94%
Aero Drag Reduction, Level 2 (20% Reduction)	94%	94%	94%	94%
PHEVs and BEVs	**54%**	**54%**	**58%**	**66%**
PHEV50T: 50-Mile Plug-In Hybrid/EV with Turbo Engine	13%	13%	14%	18%
BEV1: EV, Level 1 (150-/200-mile)	33%	33%	35%	41%
BEV2: EV, Level 2 (250-/300-mile)	8%	8%	8%	8%

Notes:
PHEV = plug-in hybrid electric vehicle; EV = electric vehicle; BEV = battery electric vehicle
Totals may not sum due to rounding.

The magnitude of life-cycle GHG impacts associated with materials and technologies is small in comparison with the emissions reductions from avoided fuel consumption during vehicle use. Below is a summary of some of the key findings in this chapter related to the life-cycle impacts of vehicle materials:

- **Raw material extraction.** The extraction and manufacture of vehicle materials is generally energy and GHG emissions intensive. This is the case for the materials that account for the greatest share of vehicle weight—including steel, plastics, aluminum, fluids and lubricants, iron castings, and other metals used in the vehicle powertrain. The extraction and production processes also result in other adverse environmental impacts, such as land degradation, soil contamination, and air and water pollution.
- **Vehicle assembly.** The processes involved in vehicle assembly—painting, HVAC, lighting, heating, compressed air, welding, and material handling—account for about 8 to 17 percent of energy use and 3 to 7 percent of the water use over the vehicle material life-cycle (excluding vehicle operation), depending on the vehicle type. The painting process is the most energy- and emissions-intensive part of the assembly process.
- **Net environmental benefits of materials.** Lightweight vehicle materials manufactured using aluminum, high-strength steel, and plastics and composites require more energy to produce than similar conventional steel components, but often offer overall life-cycle energy and emissions benefits through FE improvements. Although the production of weight-reducing materials requires more energy during the vehicle production phase, the operating efficiencies gained can be significant, often leading to a net decrease in environmental impacts and GHG emissions. However, mining of lightweight materials results in other environmental consequences, including adverse land and water use impacts. Consideration of multiple environmental impacts is necessary as attention to a single impact alone could miss the identification of other potentially significant impacts.
- **End-of-life practices.** Vehicle disposal processes require about 27 percent as much energy and emit about 27 percent of the GHG emissions associated with vehicle assembly. The end-of-life pathway for vehicles and component materials has important environmental implications. Recovery of scrap from vehicles and other products allows manufacturers to increase their use of recycled material

inputs in place of virgin inputs, and thereby reduces upstream impacts on the environment. The amount of recycled material used in vehicle components, end-of-life recycling rate, lifetime of vehicles in use, and location of production all influence the magnitudes of life-cycle GHG emissions reductions and energy-use savings for vehicles.

- **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. However, mining for critical minerals (also referred to as energy-transition resources) used in batteries and processing causes local adverse environmental impacts including air, soil, and water pollution, and concerns related to resource scarcity. The production process also requires high levels of water consumption. Recent research has focused on battery reuse and 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. Recovery of secondary lithium from batteries is growing, but not yet keeping pace with the rate of primary lithium production. Reuse and recycling are already playing an important role in reducing reliance on critical mineral supplies and lessening environmental impacts caused by mining.

CHAPTER 7 ENVIRONMENTAL JUSTICE

7.1 Introduction

Executive Order (E.O.) 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[1] 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. E.O. 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 E.O. as it relates to NEPA (CEQ 1997). A White House Environmental Justice Advisory Council established under E.O. 14008, *Tackling the Climate Crisis at Home and Abroad*, provided recommendations to CEQ on ways to update E.O. 12898, including the expansion of environmental justice advice and recommendations. E.O. 14008 also established the White House Environmental Justice Interagency Council, which will advise on increasing environmental justice monitoring and enforcement. In 2023, E.O. 14096, *Revitalizing Our Nation's Commitment to Environmental Justice for All*,[2] further built upon the Federal Government's commitment to strengthen environmental justice initiatives. E.O. 14096 requires that environmental reviews analyze direct, indirect, and cumulative effects of Federal actions on communities with environmental justice concerns; consider best available science on disparate health effects arising from exposure to environmental hazards; and provide opportunities for early and meaningful involvement in the environmental review process by communities with environmental justice concerns potentially affected by a proposed action.

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 of the negative human health and environmental impacts 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*,[3] describes the process for DOT agencies to incorporate environmental justice principles in programs, policies, and activities (DOT 2021b). 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 to each other or be geographically dispersed/transient.

Prior analyses associated with fuel economy and fuel efficiency rulemakings have focused on qualitative literature reviews to assess potential for impacts of the action on communities of environmental justice

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

[2] E.O. 14096, Revitalizing Our Nation's Commitment to Environmental Justice for All, 88 FR 25251 (April 21, 2023).

[3] DOT Updated Environmental Justice Order 5610.2(c) (May 14, 2021).

concern. As noted in Appendix B, *Scoping Comments*, NHTSA received comments on environmental justice from four commenters during public scoping in response to the Notice of Intent for this EIS. As part of the consideration of these comments, NHTSA considered adjustments to the environmental justice analysis to include a quantitative analysis. For the reasons discussed in this chapter, NHTSA has continued to rely on qualitative analysis for this EIS.

To expand the environmental justice analysis, NHTSA considered identifying socioeconomic characteristics of communities, by census block group, likely to be affected by the rule. NHTSA determined that communities likely to be affected by the rule are those in proximity to major highways that would be affected by tailpipe emissions, and/or those in proximity to industrial facilities that produce upstream emissions, like oil production and refinery locations and electric power plants. This would require NHTSA to identify the locations of tailpipe and upstream emissions on a nationwide scale. The analysis could then consider whether low-income and/or minority populations are more prevalent in the communities likely to be affected by the Proposed Action and alternatives in comparison to national averages and compare these characteristics to national averages.

NHTSA considered using the tool EJScreen, which is an EPA environmental justice mapping and screening tool based on nationally consistent preprocessed data on environmental and demographic socioeconomic indicators (EPA no date). EJScreen includes an environmental indicator associated with proximity to Risk Management Plan facilities, which includes petroleum refineries and power plants. However, the EJScreen dataset for locations associated with Risk Management Plan facilities does not completely represent the facilities included in NHTSA's upstream analysis of impacts of different levels of CAFE standards, and does include locations for facilities that may not have a change in emissions as a result of NHTSA's rule. Similarly, NHTSA considered that data for near roadway impacts could be assessed using 2019 DOT traffic data and consider census block groups that fall within a specified percentile. Characteristics of communities could be assessed to determine their proximity to hazard exposure and vulnerability to exposure; however, the analysis of the dataset would require assumptions not appropriately characterizing potential pollutant dispersal.

Due to the nationwide nature of this rulemaking and the assumptions needed to use the data, along with the risk of overstating certainty, NHTSA determined that this quantitative analysis would not support the decision-maker or the public in understanding environmental justice impacts and benefits. Proceeding with this additional analysis would require the agency to make several assumptions about how to use available data that could create misinformation and approximate results with limited certainty. For example, the required assumption for the quantitative analysis that radial proximity equals exposure would not be true for all facilities and pollutants. As a result, this analysis would not fully or accurately reflect communities benefiting from the rulemaking or communities likely to be adversely affected. Moreover, the proposed rule would set nationwide standards, and, although minority and low-income populations may experience some disproportionate effects or face inequities in receiving some benefits, analysis for setting more stringent standards has repeatedly shown that impacts from the Proposed Action and alternatives on human health and the environment would not be disproportionately high and adverse.

NHTSA's qualitative analysis continues to provide relevant context for the potential impacts of the Proposed Action and alternatives on low-income and minority populations. The qualitative analysis reviews recent, relevant, peer-reviewed studies, including studies requested for inclusion by scoping commenters and studies identified by recent similar rulemakings. The literature cited presents a broad range of research on environmental justice concerns related to this rulemaking, while avoiding the reliance on assumptions and misinformation that could result from quantitative analysis. For NHTSA's qualitative analysis, the following information was reviewed:

- The extent to which minority and low-income populations live in proximity to oil-refining facilities and whether these populations may be more likely to be adversely affected by the emissions of the Proposed Action and alternatives. A correlation between proximity to oil refineries and the prevalence of minority and low-income populations is suggested in the scientific literature.
- The extent to which minority and low-income populations disproportionately live or attend schools near major roadways and, as a result, whether these populations may be more likely to be adversely affected by the Proposed Action and alternatives.
- The extent to which minority and low-income populations have access to and can benefit from vehicles required by more stringent fuel economy and Clean Air Act standards.
- Impacts of climate change and whether these impacts disproportionately affect minority and low-income populations in urban areas (which are subject to the most substantial temperature increases) and areas prone to inland and coastal flooding.
- Change in health effects with the Proposed Action or alternatives and whether these changes disproportionately affect minority and low-income populations.

7.2 Affected Environment

The affected environment for environmental justice considerations of this rulemaking is nationwide, with a focus on communities that are disadvantaged due to their socioeconomic characteristics (e.g., minority or low-income) or cumulative exposure to environmental hazards and 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 where mining occurs for energy-transition metals, areas near roadways, coastal flood-prone areas, and urban areas that are subject to the heat island effect.[4] The affected environment also considers the effects of increasing sales and availability of vehicles with increasing fuel economy, to see to what extent benefits of these vehicles reach these communities.

Ambient air pollution exposure, regardless of proximity to any sources, has an increased impact on the health of minorities, individuals with lower income, and individuals with lower educational attainment (Kiomourtzoglou et al. 2016). 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). 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). Redlining across the United States is also associated with higher levels of air pollution, as nitrogen dioxide (NO_2) and particulate matter 2.5 microns or less in diameter (PM2.5) pollution levels have a consistent and nearly monotonic association with historical Home Owners' Loan Corporation (HOLC) investment risk grades (Lane et al. 2022), showing how historical racially discriminatory policies shape present-day environmental inequities.

Nationwide, studies conducted between 2013 and 2017 also show racial disparities in asthma risk, due in part to air pollution exposure (Nardone et al. 2018). EPA's 2019 Integrated Science Assessment for

[4] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas. See Chapter 5, Section 5.5.2, *Sectoral Impacts of Climate Change*, under *Urban Areas*, for further discussion of the heat island effect.

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 2019b). 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).

7.2.1 Proximity to Industrial Facilities with Vehicle-Related Upstream Emissions

Through a literature review on disproportionate proximity of marginalized populations to industrial facilities, NHTSA found that some environmental hazards related to industrial facilities are more prevalent in areas where minority and low-income populations represent a higher proportion of the population compared with the general population. Other commissioned reports and case studies (United Church of Christ 2007; National Association for the Advancement of Colored People and Clean Air Task Force 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, NHTSA believes they add important and accurate context about the evidence linking low-income and minority populations living near industrial facilities to environmental risk exposure.

Some literature shows that race is a significant predictor for exposure to environmental hazards from industrial sources (Bullard et al. 2007). For example, Mohai et al. (2009) found that survey respondents who were Black and, to a lesser degree, had lower income levels, were significantly more likely to live within 1 mile of an industrial facility listed in the EPA's 1987 Toxic Release Inventory national database. Ringquist (2005) conducted a meta-analysis of 49 environmental equity studies and concluded that evidence of race-based environmental inequities is statistically significant (although the average magnitude of these inequities is small), while evidence supporting the existence of income-based environmental inequities is substantially weaker. Considering poverty-based class effects, Ringquist (2005) found an inverse relationship between environmental risk and poverty, concluding that environmental risks are less likely to be located in areas of extreme poverty.

Overall, the body of scientific literature points to disproportionate representation of minority and low-income populations in proximity to industrial facilities that are likely to be affected by this rule, such as oil refineries and power plants, although results of individual studies may vary.

7.2.1.1 Proximity to Oil Production and Refining

Minority and low-income populations face disproportionate exposure to environmental risk associated with oil refineries specifically. 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 Black, Hispanic, Asian American/Pacific Islander, or American Indian residents, and nearly 45 percent have incomes below the poverty level (Environmental Integrity Project 2021). One study of environmental justice in the oil refinery industry (Carpenter and Wagner 2019) found evidence of environmental hazard inequities in areas around refineries correlated to unemployment levels and, to a slightly lesser extent, as a result of income inequality.

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). An EPA analysis of socioeconomic factors for populations living near petroleum refineries found that minority and Black populations face double the cancer risk burden compared to their national demographic representation. For example, Black individuals make up 13 percent of the nationwide population but 28 percent of the population with increased cancer risk. Hispanic and Latino or multiracial populations, those who live below the poverty line, adults without a high school diploma, and linguistically isolated communities also face elevated cancer risk (EC/R Incorporated 2014). 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 air multivariate regression. This study concludes that racial/ethnic minorities are among those that suffer a disparate impact from the highest-hazard facilities (primarily manufacturing plants).

While the scientific literature specific to oil refineries is limited, disproportionate exposure of air pollution from oil refineries to minority and low-income populations is suggested by other broader studies of racial and socioeconomic disparities in proximity to industrial facilities generally.

7.2.1.2 Proximity to Electric Power Plants

In 2022, fossil fuels made up 60 percent of utility-scale electricity generation in the United States, primarily from natural gas (39.8 percent of electricity generation) and coal (19.5 percent) (EIA 2023d). Based on an analysis that complemented the Clean Power Plan, EPA determined that communities that live near power plants tend to be low-income or communities of color. The analysis was based on an EPA tool and dataset (EJScreen) and evaluated the demographic and socioeconomic characteristics of populations living within 3 miles of an electric power plant. The analysis found that 52 percent of people living within a 3-mile radius of an electric power plant were minority (compared to the national average of 36 percent) and that 39 percent of people living within the same 3-mile radius were low-income (compared to the national average of 34 percent) (EPA 2015b).

Power generation from fossil fuels releases not only greenhouse gases but also co-pollutants (e.g., nitrogen oxides [NO_X], sulfur dioxide [SO_2], particulate matter 10 microns or less in diameter [PM10], PM2.5) that are associated with myocardial infarctions and respiratory and cardiovascular disease (Declet-Barreto and Rosenberg 2022). Even in areas that aim to reduce electric power plant emissions, marginalized communities receive disproportionately fewer benefits from the reduction of emissions compared to non-marginalized communities. In states that participate in the Regional Greenhouse Gases Initiative,[5] the percentage of minority populations who live within 6.2 miles of a power plant is up to 23.5 percent higher than the percentage of White people who live within the same distance band. Furthermore, the percentage of people living in poverty within 5 miles of a power plant is up to 15.3 percent higher than the percentage of people living above the poverty line (Declet-Barreto and Rosenberg 2022). A similar empirical assessment of environmental justice burdens in California's cap-and-trade program also found that facilities regulated under the trading program are disproportionately located within environmental justice communities, and that neighborhoods that saw greenhouse gas and co-pollutant emissions increases over the trading period were largely low-income communities of color (Cushing et al. 2018). Programs and policies that focus on emissions reductions have done so while mostly benefitting non-disadvantaged communities and not redressing existing pollution disparities in marginalized communities.

[5] The Regional Greenhouse Gases Initiative is the country's first market-based power sector emissions reduction program.

7.2.2 Proximity to High-Traffic Roadways

Studies have consistently found a disproportionate prevalence of minority and low-income populations living near mobile sources of pollutants across the United States (Tian et al. 2013; Boehmer et al. 2013; Rowangould 2013; Kingsley et al. 2014). In particular, Rowangould (2013) found that greater traffic volumes and densities across the United States are associated with nearby larger shares of minority and low-income populations. A 2011 study (Bailey 2011) used data reported in the 2009 American Housing Survey on whether a housing unit was located within 300 feet of a "4-or-more lane highway, railroad, or airport."[6] The study analyzed differences between households within 300 feet and more than 300 feet from these transportation facilities. 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 a non-Hispanic householder. 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 (Bailey 2011).

Studies at state and local levels also demonstrate a correlation between minority and low-income status and proximity to roadways (Hajat et al. 2013). In certain locations in the United States, there is 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 specifically, studies demonstrate that minority 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).

Students attending school in proximity to high-traffic roadways also tend to identify as minorities. To evaluate school proximity to major roadways, Pedde and Bailey (2011) used the Common Core of Data from the U.S. Department of Education[7] and mapped each school to U.S. Census Topologically Integrated Geographic Encoding and Referencing (TIGER) dataset roadways. 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. Similarly, 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. Kingsley et al. (2014) found that schools with minority and underprivileged[8] children were disproportionately located within 250 meters of a major roadway.

[6] 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 American Housing Survey.

[7] This dataset includes information on all public elementary and secondary schools and school districts nationwide (http://nces.ed.gov/ccd/).

[8] 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.

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). In California, Blacks, Latinos, and Asian Americans are on average exposed to more PM2.5 pollution from vehicles than White Californians (Reichmuth 2019). PM2.5 and NO_2 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). Furthermore, two studies using TROPospheric Ozone Monitoring Instrument (TROPOMI) satellite sensors have provided evidence that NO_2 concentrations are high in areas with a high density of highways, and that average NO_2 levels are 28 percent higher for low-income non-White people compared with high-income White populations (EPA 2023h).

The air pollutants to which marginalized populations face exposure can lead to a variety of health impacts. High exposure to PM2.5 and NO_2 in an urban setting are both linked to lung cancer risk and mortality, with PM2.5 also being positively associated with higher coronavirus disease of 2019 mortality (Letellier et al. 2022; Wu et al. 2020). Contaminants such as black carbon, NO_X, ozone, and SO_2, largely byproducts of fossil fuel combustion, can be harmful to socially vulnerable communities by exacerbating a myriad of respiratory and cardiovascular conditions (Environmental Defense Fund no date). The following studies connected exposure to traffic and the associated air pollutants and adverse health outcomes:

- 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) found that students at schools closer to major highways in Michigan had a higher risk of respiratory and neurological disease.

A study of traffic, air pollution, and socioeconomic status inside and outside the Minneapolis-St. Paul metropolitan area similarly found that low-income and minority populations are disproportionately exposed to traffic and air pollution and at higher risk for associated adverse health outcomes, such as increased cancer risk (Pratt et al. 2015).

7.2.3 Vehicle Ownership

More fuel-efficient cars, including electric vehicles (EVs), provide a range of benefits, some of which are realized by the owner of the vehicle (e.g., maintenance, fuel savings) and some are realized by society. While lower-income households are more likely to purchase used vehicles than new ones, research suggests that all income groups will benefit from improvements in fuel efficiency. A report by the National Research Council (NRC) examining the cost effectiveness of the CAFE standards in 2015 found that the standards made both new and used cars more affordable due to the value of added fuel savings realized over the lifetime of the vehicle (NRC 2015). Additionally, the net benefits extended to consumers from the standards were estimated to be greater for low-income households. This report estimated that some low-income households spent almost 50 percent more on fuel than on vehicles in 2011. The report estimated that the standards assessed in 2015 would increase vehicle prices by about 6 percent but reduce fuel consumption by one-third relative to the 2016 standards (NRC 2015). The more recent 2021 NRC report cited the 2015 report as the most up-to-date summary of literature on this topic (NRC 2021).

Fuel savings are particularly beneficial for low-income households, as fuel spending constitutes a higher percentage of their earnings. U.S. households earning less than $25,000 spend 50 percent of their income on vehicle ownership and operation annually, or about $7,400 (Bauer et al. 2021 citing U.S. Bureau of Labor Statistics 2020). Improvements in fuel economy can have distributed benefits; according to research by Greene and Welch (2018), fuel economy advancements can increase income for all income groups and will have the greatest benefit for low-income groups. This research estimates that household savings from fuel economy advancements from 1980 to 2014 were around $8,000 for the lowest income group.

A 2020 Consumer Reports analysis found that EVs typically have a higher purchase price over gasoline-powered vehicles (Consumer Reports 2020). However, these higher upfront costs are typically offset by savings over the life of the vehicle. For example, a national analysis conducted on the cost of charging EVs found that the typical driver could save between $3,000 and $10,500 compared with gasoline vehicles (over a 15-year time horizon) (Borlaug et al. 2020). However, the 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).

Realization of participant benefits by vehicle owners, including air quality benefits to low-income communities living close to air pollution hotspots such as freeways, depends on market access (Muehlegger and Rapson 2018). While 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, uptake of EVs by low-income households is still low compared to uptake by high-income households. Higher-income households have claimed the vast majority of Federal EV incentives. A study by Hardman et al. (2021)[9] suggested that policies that have stricter income caps for EV purchases, offer more progressive rebate amounts, and offer more availability to used car buyers can increase car rebate allocation in low-income communities. The ability to charge an EV at home or work is another important differential socioeconomic factor related to EV access and ownership because access to charging at multifamily residential complexes and rented homes can be challenging or limited (NREL 2021b). At the state level, California, in particular, has looked at expanding EV incentives.

Holland et al. (2020) found that, in the past decade, changes in emissions rates and shifts in power generation led to EVs being cleaner on average than gasoline-powered vehicles. However, studies show that benefits of EV adoption are not equally distributed among socioeconomic groups. Holland et al. (2019) found that air pollution reductions from vehicles and upstream power generation sources are not distributed homogeneously across geographies or populations. The distribution of benefits realized by subpopulations 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).

7.2.4 Proximity to Mining for Energy-Transition Resources

As the U.S. transition from gas-powered vehicles to EVs continues, manufacturers will require increasing amounts of key energy-transition metals such as copper, nickel, cobalt, and lithium. However, many resources for these critical metals may be within or near areas of cultural and environmental importance to Native Americans. Mining within Native American reservations could create or exacerbate existing environmental inequities; mining in lands near or upstream of Native American

[9] This study is not published in a peer-reviewed scientific journal.

territories could threaten culturally sacred areas or areas that provide significant resources for traditional lifestyles. According to the Block (2021) article (published by MSCI)[10] that analyzed 5,336 U.S. mining properties, 97 percent of nickel, 89 percent of copper, 79 percent of lithium, and 68 percent of cobalt reserves and resources in the United States are within 35 miles of Native American reservations (Block 2021).[11]

NHTSA did not find any peer-reviewed studies that provide data or information about other environmental justice communities in proximity to mining for energy-transition resources; therefore, NHTSA's analysis related to proximity to mining for energy-transition resources is focused on mining within or near areas of cultural and environmental importance to Native Americans.

7.2.5 Communities Facing Climate Change Effects

Across all climate risks, low-income communities, some communities of color, and those facing discrimination are disproportionately afflicted 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). Additionally, many marginalized communities may face more severe health consequences from climate change because access to healthcare resources may not be equally available or accessible as for nonmarginalized communities (EPA 2021d).

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 2018c). In many major cities throughout the United States, Black individuals are 40–59 percent more likely than non-Black individuals to live in areas with the highest projected increases in extreme temperature (EPA 2021d). Other groups vulnerable to extreme heat include people who are elderly, disabled, homeless, and pregnant. Minority communities are 35 percent more likely than non-minorities to live in areas with the highest projected labor hours lost due to increased heat impairing their health and cognitive abilities or preventing them from working entirely. In particular, Hispanic and Latino individuals are 43 percent more likely to live in these high-impact areas, while those with low-income or no high school diploma are 25 percent more likely to live in these areas (EPA 2021d).

Many socially vulnerable communities reside and work in areas with high risk of flooding and natural disaster (EPA 2021d). During and in the aftermath of Hurricane Katrina, over 100,000 residents of greater New Orleans did not evacuate; many of whom were low-income and Black (Eiseman et al. 2007). Low-income populations and less socially connected populations were also more likely to bear disproportionate impacts from flooding (Eisenman et al. 2007). Additionally, many marginalized communities are relegated to live in flood-prone areas. Houston, Texas is a key example of this as low-income populations, populations with limited English proficiency, and some immigrant communities are more likely to live in flood-prone areas with poorly maintained infrastructure (EPA 2021d; Collins et al. 2018). The Atlanta-Charleston megaregion is another example; non-Hispanic Black and Hispanic populations residing in this area are up to three times more likely to reside in flood-prone areas (Debbage 2019). Additionally, Hispanic and Latino communities are about 50 percent more likely to experience commuting delays due to increases in coastal flooding (EPA 2021d). Another consequence of higher average temperatures and climate change-induced drought is an increased risk of wildfires (U.S.

[10] This study is not published in a peer-reviewed scientific journal.

[11] This study is not published in a peer-reviewed scientific journal.

Geological Survey no date). The California wildfires of 2017 and 2018 posed an increased risk to low-income agricultural workers who could not afford to lose wages from not working (Roos 2018).

Indigenous communities may be harmed by reduced water availability, as a result of climate change, needed for economic development, drinking supply, and the ecological health of sacred water sources and aquatic species (Novak et al. 2018). For example, traditional small-scale farmers can be destabilized by water shortages and increased salinity of water sources (e.g., saltwater intrusion from sea-level rise into groundwater aquifers) (Altieri and Koohafkan 2008). Rising water bills due to drought also disproportionately affect low-income communities. Droughts reduce water availability and force water providers to invest in additional supplies or institute expansive emergency supply measures (Rachunok and Fletcher 2023). These costs are inequitably passed onto affected households, with low-income households often paying more or paying proportionally more than higher-income households (Rachunok and Fletcher 2023).

Appendix E, *Greenhouse Gas Emissions and Climate Change*, provides additional discussion of health and societal impacts of climate change on vulnerable populations.

7.3 Environmental Consequences

7.3.1 Direct and Indirect Impacts

As discussed in Chapter 4, *Air Quality*, total health effects of emissions from either CAFE or heavy-duty pickup truck and van (HDPUV) fuel efficiency (FE) standards would remain the same or decrease under all action alternatives relative to the No-Action Alternative. Under any CAFE standard action alternative, total emissions from passenger cars and light trucks are expected to decrease over time compared to existing (2022) conditions (Table 4.2.1-1). Under any HDPUV FE standard action alternative, total emissions from HDPUVs are expected to decrease over time compared to existing (2022) conditions (Table 4.2.1-10). As discussed in Chapter 4, Section 4.1.1.3, *Vehicle Emissions Standards*, the phase-in of Tier 3 vehicle emissions standards will decrease the average per-vehicle miles traveled (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, and from HDPUVs, are expected to decrease over time compared to existing conditions.

As discussed in Chapter 4, *Air Quality*, and Chapter 9, *Comparison of Alternatives and Mitigation*, differences in air quality parameters during the forecast period to 2050 are attributed to the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies NHTSA assumes manufacturers will incorporate to comply with the standards, upstream emissions rates, the relative proportion of gasoline and diesel in total fuel consumption, and changes in VMT from the rebound effect. Other CAFE Model inputs and assumptions, which are discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and at length in the proposed rule preamble, Technical Support Document, and PRIA issued concurrently with this EIS, 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 the forecast 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.

Therefore, there would not be disproportionately high and adverse emissions health effects on low-income or minority populations.

7.3.1.1 Proximity to Industrial Facilities with Vehicle-Related Upstream Emissions

Proximity to Oil Production and Refining

Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, discuss the connections between oil production and distribution and their health and environmental impacts. Section 7.2.1.1*, Proximity to Oil Production and Refining,* describes the extent to which minority and low-income populations could be more exposed or vulnerable to such effects.

As discussed in Chapter 3, *Energy*, all of the action alternatives for CAFE and HDPUV FE standards would decrease fuel consumption. Because this decrease in fuel consumption is likely to result in less oil extraction and refining, there would not be disproportionately high and adverse impacts on minority or low-income populations.

As shown in Chapter 4, Figure 4.2.1-2 and Figure 4.2.1-7, 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 disproportionately high and adverse. Therefore, there would not be disproportionately high and adverse impacts on minority and low-income populations.

Proximity to Electric Power Plants

As discussed in Chapter 3, *Energy*, electricity generation would increase over time, and the mix of electricity-generating fuel sources would also change over time from higher emissions to lower emissions sources (Steinberg et al. 2023). To the extent that those cleaner sources are used to provide energy for EV production and batteries, the benefits of using lower emissions fuel sources could accrue to minority and low-income populations. As discussed in Section 7.2.1.2, *Proximity to Electric Power Plants*, low-income and minority populations are disproportionately located in proximity to electric power plants and are thus exposed to pollutants associated with power generation that result in negative health impacts.

To the extent that vehicle manufacturers respond to CAFE and HDPUV FE standards by building battery electric vehicles (BEVs), there would be an increase in overall emissions due to EV charging. However, these impacts may be mitigated to the extent that the electrical grid becomes cleaner and draws more from renewable energy generation. Because these impacts are small at any one location and widespread geographically, disproportionate and adverse impacts would not result for low-income or minority populations.

7.3.1.2 Proximity to High-Traffic Roadways

Even considering VMT increases from the rebound effect from CAFE standards, there would be a reduction in most tailpipe pollutant emissions. To the extent that minority and low-income communities are located in proximity to roadways, these communities would be affected from pollutant emissions. Section 7.2.2, *Proximity to High-Traffic Roadways*, discusses how populations in proximity to roadways tend to be minority and low-income populations and the resulting impacts on their health of living close to roadways. The extent of those impacts would be offset by the overall health benefits achieved by lower emissions for both CAFE and HDPUV FE standards. Therefore, there would not be disproportionate and adverse impacts on minority and low-income populations.

As shown in Chapter 4, Table 4.2.1-2 and Table 4.2.2-2, total downstream (tailpipe) emissions of carbon monoxide, PM2.5, SO_2, and volatile organic compounds in 2035 are projected to decrease under all action alternatives compared to the No-Action Alternative. Tailpipe emissions of NO_X in 2035 are projected to increase under all action alternatives compared to the No-Action Alternative. Tailpipe emissions of acetaldehyde, acrolein, formaldehyde, benzene, diesel particulate matter, and 1,3-butadiene 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 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. Therefore, there would not be disproportionately high and adverse effects on minority and low-income populations.

7.3.1.3 Proximity to Mining for Energy-Transition Resources

Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*, discusses various impacts from mining. Mining within Native American reservations could create or exacerbate existing health and environmental inequities, particularly as Indigenous populations already face health disparities (GCRP 2018a). Moreover, mining in lands near or upstream of Native American territories could threaten culturally sacred areas or areas that provide significant resources for traditional lifestyles. To the extent that mineral resources are mined within or near these areas, Native American populations would be affected disproportionately because they would be the predominantly affected population. This discussion is focused on Native American communities because NHTSA did not find any peer-reviewed studies that provide data or information about other environmental justice communities in proximity to mining for energy-transition resources.

7.3.1.4 Vehicle Ownership

As discussed in Section 7.2.3, *Vehicle Ownership,* price discrimination and market access are not limiting new EV adoption among low-income consumers and minority ethnic groups; however, uptake of EVs by low-income households has historically been low compared to higher-income households (Muehlegger and Rapson 2021). When new fuel economy standards are implemented, lower-income households are more likely to continue owning their used vehicle rather than purchase a new one (National Academies of Sciences, Engineering, and Medicine 2021). In the absence of financial assistance for EVs, the trend towards more fuel-efficient vehicles may still provide overall cost savings and environmental benefits for low-income households by eventually increasing the fuel efficiency in the used cars market (NRC 2015).

With the addition of financial assistance for the purchase of a new or used EV, as the IRA 25E incentive provides for used vehicles and the 30D incentive could provide upon taking effect, low-income households may be more likely to purchase new EVs (Internal Revenue Service [IRS] 2023a, 2023b). Benefits of owning EVs or more fuel-efficient cars, including lower air quality impacts, would accrue to low-income and minority populations in proportion to more fuel-efficient vehicle adoption.

7.3.1.5 Communities Facing Climate Change Effects

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 not be disproportionate 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 0.6 to 16.3 percent and from HPDUVs by 0 to 4.1 percent by 2100, compared to the No-Action Alternative (Chapter 5, Table 5.4.1-1 and Table 5.4.1-2). Compared to the annual U.S. CO_2 emissions of 9,477 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) from all sources by the end of the century projected by the SSP3-7.0 (medium to high global emissions) scenario, the CAFE and HDPUV FE standard action alternatives are projected to reduce total U.S. CO_2 emissions in the year 2100 by 0.02 to 1.2 percent (Chapter 5, Section 5.4.1.1, *Greenhouse Gas Emissions*). 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 (Chapter 5, 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 GCAM Reference scenario. 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. No disproportionate and adverse impacts on minority or low-income communities would result.

7.3.1.6 Direct and Indirect Impacts Conclusion

Adverse health impacts are projected to decrease nationwide under each of the action alternatives compared to the No-Action Alternative (Chapter 4, Table 4.2.1-9 and Table 4.2.1-18). The improvements to health impacts (or decreases in health incidences) would increase from Alternative PC1LT3 to Alternative PC6LT8, as well as from Alternative HDPUV4 to HDPUV14, in 2035 and 2050.

Based on the foregoing, NHTSA has determined that the Proposed Action and alternatives would not result in disproportionately high and adverse human health or environmental effects on minority or low-income populations. The proposed rule would set 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.

7.3.2 Cumulative Impacts

Implementation of the CAFE or HDPUV FE alternatives would not result in disproportionately high and adverse effects on low-income and minority populations. Similarly, the combined alternatives would not contribute to cumulative high and adverse impacts on low-income and minority populations.

While, as noted in Chapter 3, *Energy*, the Annual Energy Outlook projects that U.S. consumption of petroleum and other petroleum, liquids will grow between 2021 and 2050, the combined CAFE and HDPUV FE standards would contribute to a reduction in fuel use. This could result in potential decreases in fuel production and consumption, and reduction in energy intensity of the U.S. LD and HDPUV fleet. 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 reduced cumulative impacts resulting from these activities in relation to the proposed CAFE and HDPUV FE alternatives. These impacts could include reduced human health impacts from reductions in criteria and hazardous air pollutant emissions, and the reduced impacts would be proportional to increases or decreases in such emissions. As noted in the sections above, 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 like oil production and refining facilities, so those communities would see the greatest benefit.

Direct land disturbance resulting from oil exploration and extraction could decrease in coordination with decreases in air pollution produced by oil refineries. On the other hand, land disturbance from mining for energy-transition materials could increase as EV sales increase, but decreases in air pollution from tailpipe emissions as EV ownership increases would also occur. Furthermore, the DOE's advancement of innovations in lithium extraction, as well as a push for more responsible and sustainable mining as described in the Biden-Harris Permitting Action Plan, are expected to further reduce environmental impacts from EV transition mining (DOE 2022h; U.S. White House 2023a). As discussed in Chapter 8, *Cultural Resources*, Federal agencies involved in permitting mining actions are required to follow laws and procedures that requires steps for Native American voices and perspectives to be solicited and considered during decision-making and planning for mining projects. Additionally, lithium projects in California will be subject to community consultation to ensure responsible development (Office of Governor Gavin Newsom 2023). Lastly, additional guidance on new White House initiatives clarifies the role of Federal agencies in implementing agency directives in permitting. Sections three, four, and five of this guidance encourage agencies to engage in early and meaningful outreach and communication with tribal nations, states, territories, and local communities, improve responsiveness and support, as well as staff programs adequately for meeting community and environmental needs (Young et al. 2023).

As discussed in Chapter 4, *Air Quality*, most tailpipe pollutant emissions (with the exception of NO_X) are projected to stay the same or decrease by 2035 under all action alternatives, even after consideration of VMT increases from the rebound effect. Increases in EV ownership could also result in decreased air pollution from tailpipe emissions. Tax incentives for purchasing used EVs are available at the time of this report with Incentive 25E, and tax incentives for purchasing new EVs have been proposed with Incentive 30D; both credits are intended to increase EV ownership in lower-income households (IRS 2023a, 2023b).

As noted in previous sections, minority and low-income populations that live or attend schools near major roadways would see improvement in reduced tailpipe pollutant emissions. Lastly, minority and low-income populations are disproportionately susceptible to the cumulative impacts of climate change (GCRP 2018a). Because minority and low-income populations are 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. 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 (EPA 2021d). Some subgroups face more health risks due to climate change impacts on air quality. 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 (EPA 2021d). 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). Additionally, 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). See Chapter 5, Section 5.4.2, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*, for a discussion of the cumulative impacts of the Proposed Action and alternatives related to climate change. Appendix E, *Greenhouse Gas Emissions and Climate Change*, has additional details.

Depending on communities' locations, energy sources, and other factors influencing distribution of air quality and climate benefits like access to vehicles with higher fuel economy, the combined cumulative effect of the CAFE and HDPUV FE Proposed Action and alternatives would not contribute to cumulative adverse impacts on low-income and minority populations. Rather, they could help to reduce disproportionate impacts on overburdened communities.

CHAPTER 8 HISTORIC AND CULTURAL RESOURCES

8.1 Affected Environment

NEPA states that Federal agencies shall take into consideration impacts on the natural and physical (e.g., built) environment with respect to an array of resources and consider alternatives. Specifically, NEPA requires consideration of historic and cultural resources.[1] The Advisory Council on Historic Preservation (ACHP) defines historic properties as "a prehistoric or historic district, site, building, structure, or object included in or eligible for inclusion in the National Register of Historic Places (NRHP). This term includes artifacts, records, and remains that are related to and located within these National Register properties. The term also includes properties of traditional religious and cultural importance to an Indian tribe or Native Hawaiian organization, so long as that property also meets the criteria for listing in the National Register."[2] CEQ and ACHP define cultural resources to include historic properties "as well as additional resources such as sacred sites, archaeological sites not eligible for the NRHP, and archaeological collections."[3]

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 proposed rule.

Other relevant Federal historic preservation laws include, but are not limited to:

- American Indian Religious Freedom Act of 1978
- Antiquities Act of 1906 and recodified in 2014[6]

[1] 23 CFR 1502.16(a)(8).

[2] Advisory Council on Historic Preservation. (updated 2021*). Protecting Historic Properties: A Citizen's Guide to Section 106 Review*. Retrieved from: https://www.achp.gov/sites/default/files/documents/2021-01/CitizenGuide2021_011321.pdf.

[3] Council on Environmental Quality and Advisory Council on Historic Preservation. (March 2013). *NEPA and NHPA, A Handbook for Integrating NEPA and Section 106*. Retrieved from https://www.achp.gov/sites/default/files/2017-02/NEPA_NHPA_Section_106_Handbook_Mar2013_0.pdf.

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

[5] 36 CFR Part 800.

[6] 16 U.S.C. 431–433 recodified pursuant to P.L. 113-287 at 54 U.S.C. 320301–320303.

- Archaeological Resources Protection Act of 1979[7]
- Executive Order (E.O.) 13007, Indian Sacred Sites[8]
- E.O. 13175, Consultation and Coordination with Indian Tribal Governments[9]
- National Trails System Act of 1968[10]
- Native American Graves Protection and Repatriation Act of 1990[11]
- Section 4(f) of the U.S. Department of Transportation Act of 1966[12]

The American Indian Religious Freedom Act and E.O. 13007 require agencies to evaluate their policies to protect the religious freedom of Native Americans, including access to sacred sites, use and possession of sacred objects, and freedom to worship through traditional ceremonies. The Native American Graves Protection and Repatriation Act also protects Native American burial sites and associated objects and access to them. E.O. 13175 affirms the Federal Government's commitment to a government-to-government relationship with Native American tribes and directs agencies to ensure that Federal undertakings and actions do not conflict with tribal rights and resources protected by the treaties. NHTSA mailed a notification of the scoping notice to Native American tribes and tribal organizations listed in Appendix H, *Distribution List*.

The analysis in this EIS chapter provides additional information in order to disclose potential impacts of the Proposed Action and alternatives under NEPA.

8.2 Environmental Consequences

8.2.1 Direct and Indirect Impacts

Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, discuss the potential environmental consequences of NHTSA's Proposed Action and alternatives related to criteria pollutant emissions and climate change. In general, the environmental consequences decrease criteria pollutant emissions and the greenhouse gas emissions that cause climate change. Some criteria pollutant emissions increase under the Proposed Action and alternatives in later years (i.e., not during the time period of the standards), as NHTSA projects potential increases in power plant emissions due to increased electric vehicle (EV) charging, though these impacts may be lessened if fossil fuel-powered plants are replaced with renewable energy to a greater extent than already assumed in NHTSA's projections. There are few potential environmental consequences to historic and cultural resources related to these criteria pollutant emissions; however, the criteria pollutant emissions that cause environmental consequences travel long distances in the atmosphere. Because the estimated effects and changes in emissions would vary by location across the country due to power plant location and wind patterns, among other factors, it is not possible to quantify specific impacts. In addition, NHTSA estimates potential ways that manufacturers could respond to more stringent fuel economy standards.

[7] 16 U.S.C. 470aa–mm.

[8] 61 FR 26771–26772.

[9] 65 FR 67249–67252.

[10] Public Law (Pub. L.) 90-543 as amended through Pub. L. 111-11, March 30, 2009.

[11] Pub. L. 101-601, 25 U.S.C. 3001 et seq., 104 Stat. 3048.

[12] 49 U.S.C. 303 and 23 U.S.C. 138 implemented by the Federal Highway Administration through 23 CFR Part 774.

Chapter 7, Section 7.2.3, *Proximity to Mining for Energy-Transition Resources*, discusses Native American tribes and Indigenous communities in relation to mining activities needed for EVs. If manufacturers do not build EVs or build a fleet that differs in technology use from the fleet projected under the assumptions of the EIS analysis, these potential environmental consequences would also differ. This section discusses potential environmental consequences of the Proposed Action and alternatives on historic and cultural resources relating to criteria pollutant emissions, greenhouse gas emissions, and environmental justice considerations discussed in previous chapters.

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 2017a). 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. This could also cause damage to sacred sites or objects that are of importance to Native American tribes. Deposition of dry acidic compounds found in acid rain can also dirty historic buildings and structures, causing visual impacts and increased maintenance costs (EPA 2017a). 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 nitrogen oxides (NO_X) from electric generating units (EPA 1995).

The potential increase in power plant emissions due to EV charging under the Proposed Action and alternatives could lead to an increase in pollutant emissions that cause acid deposition compared to the No-Action Alternative, despite the decrease in vehicle fuel production and combustion, though these impacts may be lessened if fossil fuel-powered plants are replaced with renewable energy to a great extent than already assumed in NHTSA's projections. An increase in the emissions of such pollutants could result in a corresponding increase in damage to historic properties and sacred sites or objects caused by acid deposition.

In terms of specific pollutant emissions, total SO_2 emissions are anticipated to increase (except for Alternatives PC1LT3 and HDPUV4 in 2035) under the Proposed Action and alternatives compared to the relevant No-Action Alternative, while total NO_X emissions would increase slightly under all action alternatives in 2035. In 2050, total NO_X emissions would decrease under Alternatives PC1LT3 and HDPUV4, and Alternatives PC2LT4 and HDPUV10 (Preferred Alternative for CAFE and heavy-duty pickup truck and van [HDPUV] fuel efficiency [FE] standards) but increase under Alternative PC6LT8 and HDPUV14 (Chapter 4, *Air Quality*, Table 4.2.1-3). Downstream (tailpipe) emissions of NO_X and oxides of sulfur (SO_X) are projected to decrease in 2035 and 2050, compared to the No-Action Alternative. Upstream (refinery and power plant) emissions of NO_X and SO_X are projected to increase under all action alternatives in 2035 and 2050 (Appendix A, *Modeling Results Reported Separately by Vehicle Class*, Tables A-2 and A-3). Since these effects and change in emissions would vary by location across the country, the impacts of the Proposed Action and alternatives would vary by location. Additionally, 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) or sacred site or object.

As described in Appendix B, *Scoping Comments,* during the scoping period, NHTSA received a comment requesting NHTSA to consider the impacts of mining and energy extraction on Native American tribes and Indigenous communities. As discussed in Chapter 7, Section 7.2.3, *Proximity to Mining for Energy-*

Transition Resources, and Section 7.3.1.3, *Proximity to Mining for Energy-Transition Resources*, metals critical to energy transition from gas-powered vehicles to EVs including copper, nickel, cobalt, and lithium may be located within or near areas of cultural and environmental importance to Native Americans. To the extent that mining in these areas takes place, that mining could threaten culturally sacred areas and access to them, or areas that provide significant resources for traditional lifestyles. However, advances in lithium mining are being researched to reduce the scale of potential environmental impact in future mining, and the Federal Government is incentivizing such research (DOE 2022i). NHTSA's Proposed Action is setting CAFE and FE standards; however, manufacturers may choose to respond to NHTSA's standards with increasing production of EVs, resulting in mining activities and with potential to indirectly affect Native American tribes and Indigenous communities. Energy use, including needed resources for EVs, is further discussed in Chapter 3, *Energy*, and vehicle materials is further discussed in Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*.

8.2.2 Cumulative Impacts

Cumulative impacts could result from the Proposed Action and alternatives. As noted above, the main impact on historic and cultural resources, as well as sacred sites and objects associated with the Proposed Action and alternatives, is the potential for increased acid rain and deposition that results from fuel production and consumption, including from increased power plant emissions due to EV charging, if manufacturers choose to respond to the standards by building EVs. Acid rain and deposition corrodes metals and other building materials, reducing their historic and cultural value.

Increases in CAFE standards have the potential to reduce fuel production and consumption impacts, reducing pollutant emissions that cause acid rain and deposition and decreasing impacts on historic and cultural resources as well as sacred sites and objects. However, if fuel production and consumption is not reduced—because of, as an example, increased vehicle miles traveled as vehicles become more fuel efficient—an increase in emissions that contributes to acid rain and deposition from fuel production and consumption could occur, which may affect historic and cultural resources. Regardless of the action alternative, acid rain would continue to occur and contribute to degradation of historic and cultural resources.

Emissions that contribute to acid rain from power plants that increase as a result of increased EV charging could also be lessened if fossil fuel-powered plants are replaced with renewable energy to a greater extent than already assumed in NHTSA's projections. For example, other Federal actions could incentivize the adoption of more power plants fueled by renewable energy (Steinberg et al. 2023); however, as discussed above, the criteria pollutant emissions that cause environmental consequences for historic and cultural resources travel long distances in the atmosphere. Because the estimated effects and changes in emissions would vary by location across the country due to power plant location and wind patterns, among other factors, it is not possible to quantify any particular benefit from the proposed standards.

During scoping, the Mille Lacs Band of Ojibwe asserted that the EIS should discuss the impacts of mining and energy extraction on Native American tribes and Indigenous communities. Cumulative increase in EV usage could lead to increased mining of metals critical to energy transition to EVs within or near areas of cultural and environmental importance to Native Americans, which could threaten culturally sacred areas and access to them. As worldwide demand for energy-transition metals grows, land pressure on Indigenous lands over time could increase. However, advances in lithium mining are being researched to reduce the scale of potential environmental impact in future mining, and the Federal

Government is incentivizing such research (DOE 2022i). NHTSA is not responsible for permitting actions related to mining projects near areas of cultural and environmental importance to Native Americans. To the extent that other Federal agencies are involved in permitting mining actions, those agencies would be required to follow laws and procedures outlined in Section 8.1, *Affected Environment*, which requires steps for Native American voices and perspectives to be solicited and considered during decision-making and planning for mining projects.

CHAPTER 9 COMPARISON OF ALTERNATIVES AND 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 must 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, *Comparison of Alternatives*) 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*), as well as short-term commitments of resources, implications for long-term productivity, and commitments of resources to comply with the standards (Section 9.4, *Short-Term Uses, Long-Term Productivity, and Irretrievable Commitments of Resources*).

9.1 Comparison of Alternatives

The CEQ NEPA implementing regulations direct Federal agencies to present in an EIS "the environmental impacts of the proposed action 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.[5] NHTSA has presented the environmental impacts of the Proposed Action and alternatives in comparative form through each of the substantive chapters that follow in this EIS. To supplement that information, this section summarizes and compares the direct, indirect, and cumulative impacts of the CAFE and HDPUV fuel efficiency (FE) standard action alternatives on energy, air quality, and climate, as presented in Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and*

[1] 40 CFR 1502.14(e).

[2] 40 CFR 1502.16(a)(9).

[3] 40 CFR 1508.1(s).

[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).

[5] 40 CFR 1502.14.

Climate Change. No quantifiable, alternative-specific impacts were identified for the other resource areas discussed in Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*, Chapter 7, *Environmental Justice*, and Chapter 8, *Historic and Cultural Resources,* so they are not summarized here.

Under the alternatives analyzed in this EIS for both the CAFE and HDPUV FE standards, fuel efficiency is expected to improve compared to current levels under the relevant No-Action Alternative, more than offsetting the growth in the number of passenger cars, light trucks, and HDPUVs 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, light trucks, and HDPUVs 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, light trucks, and HDPUVs. NHTSA estimates that the Preferred Alternative for CAFE standards (Alternative PC2LT4), the Preferred Alternative for HDPUV FE standards (Alternative HDPUV10), and each of the action alternatives would decrease fuel consumption and CO_2 emissions from the future levels that would otherwise occur under the relevant No-Action Alternative.

9.1.1 Direct and Indirect Impacts

This section compares the direct and indirect impacts of the relevant No-Action Alternative and the CAFE or HDPUV FE standard action alternatives on energy, air quality, and climate (Table 9.1.1-1 for CAFE standards and Table 9.1.1-2 for HDPUV FE standards). Under NEPA, direct effects “are caused by the action and occur at the same time and place.”[6] Indirect effects “are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable.”[7] For detailed discussions of the assumptions and methods used to estimate the direct and indirect impacts, see Chapter 2, Section 2.3, *Standard-Setting and EIS Methods and Assumptions*, Chapter 3, Section 3.4, *Environmental Consequences* (energy), Chapter 4, Section 4.1.2, *Methods* (air quality), and Chapter 5, Section 5.3, *Analysis Methods* (climate). Table 9.1.1-1 summarizes the direct and indirect effects of the CAFE standard action alternatives on each resource. Table 9.1.1-2 summarizes the direct and indirect effects of the HDPUV FE standard action alternatives on each resource.

[6] 40 CFR 1508.1(g)(1)40 CFR 1508.14(g)(1).

[7] 40 CFR 1508.1(g)(2)40 CFR 1508.14(g)(2).

Table 9.1.1-1. Direct and Indirect Impacts of CAFE Standards

No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Energy: Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2022–2050 (billion gasoline gallon equivalent)				
2,761	2,744	2,727	2,688	2,548
Energy: Combined U.S. Passenger Car and Light Truck Decrease in Fuel Consumption for 2022–2050 (billion gallons)				
--	-17	-34	-73	-212
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)				
--	Decrease: CO (-28,695) and VOCs (-4,593). Increase: NO_X (713), PM2.5 (35), and SO_2 (1,477).	Decrease: CO (-43,800) and VOCs (-7,203), emissions smaller than Alt. PC1LT3. Increase: NO_X (1,039), PM2.5 (48), and SO_2 (2,256), emissions larger than Alt. PC1LT3.	Decrease: CO (-88,750) and VOCs (-14,878), emissions smaller than Alts. PC1LT3 and PC2LT4. Increase: NO_X (2,701), PM2.5 (156), and SO_2 (5,087), emissions larger than Alts. PC1LT3 and PC2LT4.	Decrease: CO (-236,876) and VOCs (-40,350), emissions smaller than Alts. PC1LT3, PC2LT4, and PC3LT5. Increase: NO_X (8,009), PM2.5 (505), and SO_2 (14,338), emissions larger than Alts. PC1LT3, PC2LT4, and PC3LT5.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)				
--	Decrease: Acetaldehyde (-16), acrolein (-1), benzene (-58), 1,3-butadiene (-6), DPM (-121), and formaldehyde (-13). Increase: None.	Decrease: Acetaldehyde (-25), acrolein (-2), benzene (-91), 1,3-butadiene (-10), DPM (-207), and formaldehyde (-21), emissions smaller than Alt. PC1LT3. Increase: None.	Decrease: Acetaldehyde (-52), acrolein (-3), benzene (-189), 1,3-butadiene (-22), DPM (-373), and formaldehyde (-44), emissions smaller than Alts. PC1LT3 and PC2LT4. Increase: None.	Decrease: Acetaldehyde (-146), acrolein (-10), benzene (-520), 1,3-butadiene (-60), DPM (-951), and formaldehyde (-120), emissions smaller than Alts. PC1LT3, PC2LT4, and PC3LT5. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035				
--	Premature mortality: -4 cases Work loss: -902 days	Premature mortality: -7 cases Work loss: -1,507 days	Premature mortality: -10 cases Work loss: -2,719 days	Premature mortality: -27 cases Work loss: -7,400 days
Climate: Total Carbon Dioxide Emissions from U.S. Passenger Cars and Light Trucks for 2027–2100 ($MMTCO_2$)				
52,800	52,500	51,700	50,000	44,200
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)				
838.31	838.29	838.21	838.04	837.48

No-Action	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)				
4.340°C (7.812°F)	4.339°C (7.810°F)	4.339°C (7.810°F)	4.338°C (7.808°F)	4.336°C (7.805°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)				
83.24 (32.77)	83.24 (32.77)	83.23 (32.77)	83.22 (32.76)	83.16 (32.74)
Climate: Global Mean Precipitation Increase by 2100				
7.42%	7.42%	7.42%	7.42%	7.41%
Climate: Ocean Acidification in 2100 (pH)				
8.1933	8.1933	8.1933	8.1934	8.1937

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 9.1.1-2. Direct and Indirect Impacts of HDPUV FE Standards

No-Action	HDPUV4	HDPUV10	HDPUV14
Energy: HDPUV Fuel Consumption for 2022–2050 (billion gasoline gallon equivalent)			
412.2	412.1	410.3	403.3
Energy: HDPUV Decrease in Fuel Consumption for 2022–2050 (billion gallons)			
--	-0.1	-1.9	-8.9
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)			
--	No change: PM2.5 (0). Decrease: CO (-28) and VOCs (-14). Increase: NO_X (3) and SO_2 (4).	Decrease: CO (-587) and VOCs (-331), emissions smaller than Alt. HDPUV4. Increase: NO_X (72), PM2.5 (2), and SO_2 (95), emissions larger than Alt. HDPUV4.	Decrease: CO (-3,181) and VOCs (-1,674), emissions smaller than Alts. HDPUV4 and HDPUV10. Increase: NO_X (324), PM2.5 (9), and SO_2 (469), emissions larger than Alts. HDPUV4 and HDPUV10.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)			
--	No change: Acetaldehyde (0), acrolein (0), benzene (0), 1,3-butadiene (0), DPM (0), and formaldehyde (0).	No change: Acrolein (0) and 1,3-butadiene (0).	No change: Acrolein (0). Decrease: Acetaldehyde (-3), benzene (-16), 1,3-butadiene (-1), DPM (-21), and

No-Action	HDPUV4	HDPUV10	HDPUV14
	Decrease: None. Increase: None.	Decrease: Acetaldehyde (-1), benzene (-3), DPM (-4), and formaldehyde (-1), emissions smaller than Alt. HDPUV4. Increase: None.	formaldehyde (-3), emissions smaller than Alts. HDPUV4 and HDPUV10. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035			
--	Premature mortality: No change Work loss: -1 day	Premature mortality: No change Work loss: -22 days	Premature mortality: No change Work loss: -141 days
Climate: Total Carbon Dioxide Emissions from All HDPUVs for 2027–2100 ($MMTCO_2$)			
9,800	9,800	9,600	9,300
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
838.31	838.31	838.30	838.27
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
4.340°C (7.812°F)	4.340°C (7.812°F)	4.339°C (7.810°F)	4.339°C (7.810°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
83.24 (32.77)	83.24 (32.77)	83.24 (32.77)	83.24 (32.77)
Climate: Global Mean Precipitation Increase by 2100			
7.42%	7.42%	7.42%	7.42%
Climate: Ocean Acidification in 2100 (pH)			
8.1933	8.1933	8.1933	8.1933

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

9.1.2 Cumulative Impacts

Table 9.1.2-1 summarizes the cumulative impacts of the CAFE and HDPUV FE standard action alternatives on energy, air quality, and climate, as presented in Chapter 3, Section 3.4.2, *Cumulative Impacts,* Chapter 4, Section 4.2.2, *Cumulative Impacts,* and Chapter 5, Section 5.4.2*, Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*. These cumulative impacts are presented as the impacts of three specific combinations of CAFE standard and HDPUV FE standard action alternatives, which represent the full range of cumulative impacts of the two sets of standards that NHTSA is proposing in its rulemaking.

Table 9.1.2-1. Cumulative Impacts of MY 2027–2032 CAFE Standards and MY 2030–2035 HDPUV FE Standards

No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Energy: Fuel Consumption of LD Vehicles and HDPUVs (billion gasoline gallon equivalent total for calendar years 2022–2050)			
3,173	3,156	3,138	2,952
Energy: Decrease in Fuel Consumption of LD Vehicles and HDPUVs (billion gasoline gallon equivalent total for calendar years 2022–2050)			
--	-17	-36	-221
Air Quality: Criteria Air Pollutant Emissions Changes in 2035 (tons per year)			
--	Decrease: CO (-28,722) and VOCs (-4,607). Increase: NO_X (716), PM2.5 (35), and SO_2 (1,481).	Decrease: CO (-44,388) and VOCs (-7,535), emissions smaller than Alt. PC1LT3 + HDPUV4. Increase: NO_X (1,111), PM2.5 (51), and SO_2 (2,352), emissions larger than Alt. PC1LT3 + HDPUV4.	Decrease: CO (-240,057) and VOCs (-42,025), emissions smaller than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10. Increase: NO_X (8,334), PM2.5 (514), and SO_2 (14,807), emissions larger than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035 (tons per year)			
--	Decrease: Acetaldehyde (-16), acrolein (-1), benzene (-58), 1,3-butadiene (-7), DPM (-121), and formaldehyde (-14). Increase: None.	Decrease: Acetaldehyde (-26), acrolein (-2), benzene (-94), 1,3-butadiene (-11), DPM (-211), and formaldehyde (-22), emissions smaller than Alt. PC1LT3 + HDPUV4. Increase: None.	Decrease: Acetaldehyde (-149), acrolein (-10), benzene (-536), 1,3-butadiene (-62), DPM (-972), and formaldehyde (-124), emissions smaller than Alts. PC1LT3 + HDPUV4 and PC2LT4 + HDPUV10. Increase: None.
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035			
--	Premature mortality: -4 cases Work loss: -903 days	Premature mortality: -7 cases Work loss: -1,529 days	Premature mortality: -28 cases Work loss: -7,541 days
Climate: Total Carbon Dioxide Emissions from All LD Vehicles and HDPUVs for 2027–2100 ($MMTCO_2$)[a]			
62,500	62,200	61,300	53,500
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)			
587.78	587.76	587.68	587.00
Climate: Increase in Global Mean Surface Temperature by 2100 in °C (°F)			
2.826°C (5.087°F)	2.826°C (5.087°F)	2.826°C (5.087°F)	2.822°C (5.080°F)

No-Action	PC1LT3 + HDPUV4	PC2LT4 + HDPUV10	PC6LT8 + HDPUV14
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)			
67.12 (26.43)	67.11 (26.42)	67.11 (26.42)	67.03 (26.39)
Climate: Global Mean Precipitation Increase by 2100			
6.11%	6.10%	6.10%	6.10%
Climate: Ocean pH in 2100			
8.3328	8.3328	8.3329	8.3333

Notes:
[a] Total greenhouse gas emissions from the combined impacts of all LD vehicles and HDPUVs are the same as the additive sum presented 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 an intermediate global emissions scenario (SSP2-4.5) as opposed to the high emissions scenario (SSP3-7.0) used in the direct and indirect effects analysis. NHTSA chose the SSP2-4.5 scenario as plausible global emissions baseline for the cumulative analysis because this scenario is more aligned with reasonably foreseeable global actions that will result in a moderate level of emissions reductions (although it does not explicitly include any particular policy or program).
EV = electric vehicle; 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

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 EIS 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 2022k). Also, vehicle manufacturers can choose which technologies to employ to reach the new CAFE and HDPUV FE standards. Some of their technology choices could result 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 EIS) 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. 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 purposes only. Examples of mitigation measures include further EPA criteria pollutant emissions standards for passenger cars and light trucks and for electricity generation, incentives for the purchase of more fuel-efficient vehicles and for cleaner electricity generation (e.g., tax credits and deductions available under the Inflation Reduction Act of 2022), mechanisms to encourage the reduction of VMT (e.g., 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, 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).

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, 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, because 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 EVs), fluctuations in the energy market, or other future activities.

9.4 Short-Term Uses, Long-Term Productivity, and Irreversible and Irretrievable Commitments of Resources

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 and HDPUV FE standards, manufacturers may apply various fuel-saving technologies during the production of passenger cars, light trucks, and HDPUVs. NHTSA cannot predict with certainty which specific technologies and materials manufacturers would apply or in what order. As noted in Chapter 6, *Life-Cycle Assessment Implications of Vehicle Materials*, some vehicle manufacturers may commit additional resources to existing, redeveloped, or new production facilities to meet the fuel economy and FE standards. NHTSA cannot predict with certitude what actions manufacturers may take. In some cases, this could represent an irreversible and irretrievable commitment of resources. The specific amounts and types of irretrievable resources (e.g., electricity or other forms of energy) that manufacturers would expend in meeting the CAFE and HDPUV FE standards would depend on the technologies and materials manufacturers select. For further discussion of the costs and benefits of the final rule, consult Chapter 4 of NHTSA's Preliminary Regulatory Impact Analysis.