Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2

Draft Regulatory Impact Analysis

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Draft Regulatory Impact Analysis

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

and

Office of International Policy, Fuel Economy, and Consumer Programs
National Highway Traffic Safety Administration
U.S. Department of Transportation

EPA-420-D-15-900
June 2015

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List of Acronyms

µg	Microgram
µm	Micrometers
2002$	U.S. Dollars in calendar year 2002
2009$	U.S. Dollars in calendar year 2009
A/C	Air Conditioning
ABS	Antilock Brake Systems
ABT	Averaging, Banking and Trading
AC	Alternating Current
ACES	Advanced Collaborative Emission Study
ALVW	Adjusted Loaded Vehicle Weight
AEO	Annual Energy Outlook
AES	Automatic Engine Shutdown
AHS	American Housing Survey
AMOC	Atlantic Meridional Overturning Circulation
AMT	Automated Manual Transmission
ANL	Argonne National Laboratory
APU	Auxiliary Power Unit
AQ	Air Quality
AQCD	Air Quality Criteria Document
AR4	Fourth Assessment Report
ARB	California Air Resources Board
ASL	Aggressive Shift Logic
ASPEN	Assessment System for Population Exposure Nationwide
AT	Automatic Transmissions
ATA	American Trucking Association
ATIS	Automated Tire Inflation System
ATRI	Alliance for Transportation Research Institute
ATSDR	Agency for Toxic Substances and Disease Registry
ATUS	American Time Use Survey
Avg	Average
BAC	Battery Air Conditioning
BenMAP	Benefits Mapping and Analysis Program
bhp	Brake Horsepower
bhp-hrs	Brake Horsepower Hours
BLS	Bureau of Labor Statistics
BSFC	Brake Specific Fuel Consumption
BTS	Bureau of Transportation Statistics
BTS	Bureau of Labor Statistics
BTU	British Thermal Unit
CAA	Clean Air Act

CAAA	Clean Air Act Amendments
CAD/CAE	Computer Aided Design And Engineering
CAE	Computer Aided Engineering
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CBI	Confidential Business Information
CCP	Coupled Cam Phasing
CCSP	Climate Change Science Program
Cd	Coefficient of Drag
C_dA	Drag Area
CDC	Centers for Disease Control
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CH4	Methane
CILCC	Combined International Local and Commuter Cycle
CITT	Chemical Industry Institute of Toxicology
CMAQ	Community Multiscale Air Quality
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2eq	CO2 Equivalent
COFC	Container-on-Flatcar
COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
CoV	Coefficient of Variation
CPS	Cam Profile Switching
CRC	Coordinating Research Council
CRGNSA	Columbia River Gorge National Scenic Area
CRR	Rolling Resistance Coefficient
CS	Climate Sensitivity
CSI	Cambridge Systematics Inc.
CSS	Coastal Sage Scrub
CSV	Comma-separated Values
CVD	Cardiovascular Disease
CVT	Continuously-Variable Transmission
CW	Curb Weight
D/UAF	Downward and Upward Adjustment Factor
DCP	Dual Cam Phasing
DCT	Dual Clutch Transmission
DE	Diesel Exhaust
DEAC	Cylinder Deactivation
DEER	Diesel Engine-Efficiency and Emissions Research
DEF	Diesel Exhaust Fluid
DHHS	U.S. Department of Health and Human Services

Diesel HAD	Diesel Health Assessment Document
DMC	Direct Manufacturing Costs
DO	Dissolved Oxygen
DOC	Diesel Oxidation Catalyst
DOD	Department of Defense
DOE	Department of Energy
DOHC	Dual Overhead Camshaft Engines
DOT	Department of Transportation
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
DR	Discount Rate
DRIA	Draft Regulatory Impact Analysis
DVVL	Discrete Variable Valve Lift
EC	European Commission
EC	Elemental Carbon
ECU	Electronic Control Unit
ED	Emergency Department
EERA	Energy and Environmental Research Associates
EFR	Engine Friction Reduction
EGR	Exhaust Gas Recirculation
EHPS	Electrohydraulic Power Steering
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EISA	Energy Independence and Security Act
EMS-HAP	Emissions Modeling System for Hazardous Air Pollution
EO	Executive Order
EPA	Environmental Protection Agency
EPS	Electric Power Steering
ERG	Eastern Research Group
ESC	Electronic Stability Control
EV	Electric Vehicle
F	Frequency
FEL	Family Emission Limit
FET	Federal Excise Tax
FEV1	Functional Expiratory Volume
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
FMCSA	Federal Motor Carrier Safety Administration
FOH	Fuel Operated Heater
FR	Federal Register
FTP	Federal Test Procedure
FVC	Forced Vital Capacity
g	Gram

g/s	Gram-per-second
g/ton-mile	Grams emitted to move one ton (2000 pounds) of freight over one mile
gal	Gallon
gal/1000 ton-mile	Gallons of fuel used to move one ton of payload (2,000 pounds) over 1000 miles
GCAM	Global Change Assessment Model
GCW	Gross Combined Weight
GDP	Gross Domestic Product
GEM	Greenhouse gas Emissions Model
GEOS	Goddard Earth Observing System
GHG	Greenhouse Gases
GIFT	Geospatial Intermodal Freight Transportation
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GSF1	Generic Speed Form one
GUI	Graphical User Interface
GVWR	Gross Vehicle Weight Rating
GWP	Global Warming Potential
HABs	Harmful Algal Blooms
HAD	Diesel Health Assessment Document
HC	Hydrocarbon
HD	Heavy-Duty
HDUDDS	Heavy Duty Urban Dynamometer Driving Cycle
HEG	High Efficiency Gearbox
HEI	Health Effects Institute
HES	Health Effects Subcommittee
HEV	Hybrid Electric Vehicle
HFC	Hydrofluorocarbon
HFET	Highway Fuel Economy Dynamometer Procedure
HHD	Heavy Heavy-Duty
HHDDT	Highway Heavy-Duty Diesel Transient
hp	Horsepower
hrs	Hours
HRV	Heart Rate Variability
HSC	High Speed Cruise Duty Cycle
HTUF	Hybrid Truck User Forum
hz	Hertz
IARC	International Agency for Research on Cancer
IATC	Improved Automatic Transmission Control
IC	Indirect Costs
ICCT	International Council on Clean Transport
ICD	International Classification of Diseases
ICF	ICF International

ICM	Indirect Cost Multiplier
ICP	Intake Cam Phasing
IMAC	Improved Mobile Air Conditioning
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPCC	Intergovernmental Panel on Climate Change
IRFA	Initial Regulatory Flexibility Analysis
IRIS	Integrated Risk Information System
ISA	Integrated Science Assessment
JAMA	Journal of the American Medical Association
k	Thousand
kg	Kilogram
KI	kinetic intensity
km	Kilometer
km/h	Kilometers per Hour
kW	Kilowatt
L	Liter
lb	Pound
LD	Light-Duty
LHD	Light Heavy-Duty
LLNL	Lawrence Livermore National Laboratory's
LRR	Lower Rolling Resistance
LSC	Low Speed Cruise Duty Cycle
LT	Light Trucks
LTCCS	Large Truck Crash Causation Study
LUB	Low Friction Lubes
LUC	Land Use Change
m^2	Square Meters
m^3	Cubic Meters
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MCF	Mixed Conifer Forest
MD	Medium-Duty
MDPV	Medium-Duty Passenger Vehicles
mg	Milligram
MHD	Medium Heavy-Duty
MHEV	Mild Hybrid
mi	mile
min	Minute
MM	Million
MMBD	Million Barrels per Day
MMT	Million Metric Tons
MOVES	Motor Vehicle Emissions Simulator
mpg	Miles per Gallon
mph	Miles per Hour

MSAT	Mobile Source Air Toxic
MRL	Minimal Risk Level
MT	Manual Transmission
MY	Model Year
N2O	Nitrous Oxide
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards
NAFA	National Association of Fleet Administrators
NAICS	North American Industry Classification System
NAS	National Academy of Sciences
NATA	National Air Toxic Assessment
NCAR	National Center for Atmospheric Research
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network
NEC	Net Energy Change Tolerance
NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NESCAUM	Northeastern States for Coordinated Air Use Management
NESCCAF	Northeast States Center for a Clean Air Future
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NiMH	Nickel Metal-Hydride
NIOSH	National Institute of Occupational Safety and Health
Nm	Newton-meters
NMHC	Nonmethane Hydrocarbons
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO_X	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Oxides of Nitrogen
NPRM	Notice of Proposed Rulemaking
NPV	Net Present Value
NRC	National Research Council
NRC-CAN	National Research Council of Canada
NREL	National Renewable Energy Laboratory
NTP	National Toxicology Program
NVH	Noise Vibration and Harshness
O&M	Operating and maintenance
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OC	Organic Carbon

OE	Original Equipment
OEHHA	Office of Environmental Health Hazard Assessment
OEM	Original Equipment Manufacturer
OHV	Overhead Valve
OMB	Office of Management and Budget
OPEC	Organization of Petroleum Exporting Countries
ORD	EPA's Office of Research and Development
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation and Air Quality
Pa	Pascal
PAH	Polycyclic Aromatic Hydrocarbons
PEF	Peak Expiratory Flow
PEMS	Portable Emissions Monitoring System
PGM	Platinum Group Metal
PHEV	Plug-in Hybrid Electric Vehicles
PM	Particulate Matter
PM_{10}	Coarse Particulate Matter (diameter of 10 µm or less)
$PM_{2.5}$	Fine Particulate Matter (diameter of 2.5 µm or less)
POM	Polycyclic Organic Matter
Ppb	Parts per Billion
Ppm	Parts per Million
Psi	Pounds per Square Inch
PTO	Power Take Off
R&D	Research and Development
RBM	Resisting Bending Moment
REL	Reference Exposure Level
RESS	Rechargeable Energy Storage System
RFA	Regulatory Flexibility Act
RfC	Reference Concentration
RFS2	Renewable Fuel Standard 2
RIA	Regulatory Impact Analysis
RPE	Retail Price Equivalent
Rpm	Revolutions per Minute
RSWT	Reduced-Scale Wind Tunnel
S	Second
SAB	Science Advisory Board
SAB-HES	Science Advisory Board - Health Effects Subcommittee
SAE	Society of Automotive Engineers
SAR	Second Assessment Report
SAV	Submerged Aquatic Vegetation
SBA	Small Business Administration
SBAR	Small Business Advocacy Review
SBREFA	Small Business Regulatory Enforcement Fairness Act

SCC	Social Cost of Carbon
SCR	Selective Catalyst Reduction
SER	Small Entity Representation
SET	Supplemental Emission Test
SGDI	Stoichiometric Gasoline Direct Injection
SHEV	Strong Hybrid Vehicles
SI	Spark-Ignition
SIDI	Spark Ignition Direct Injection
SO_2	Sulfur Dioxide
SOx	Sulfur Oxides
SOA	Secondary Organic Aerosol
SOC	State of Charge
SOHC	Single Overhead Cam
SO_X	Oxides of Sulfur
SPR	Strategic Petroleum Reserve
STB	Surface Transportation Board
Std.	Standard
STP	Scaled Tractive Power
SUV	Sport Utility Vehicle
SVOC	Semi-Volatile Organic Compound
SwRI	Southwest Research Institute
TAR	Technical Assessment Report
TC	Total Costs
TCp	Total Cost package
TDS	Turbocharging And Downsizing
THC	Total Hydrocarbon
TIAX	TIAX LLC
TMC	Technology & Maintenance Council
TOFC	Trailer-on-Flatcar
Ton-mile	One ton (2000 pounds) of payload over one mile
TPM	Tire Pressure Monitoring
TRBDS	Turbocharging and Downsizing
TRU	Trailer Refrigeration Unit
TSD	Technical Support Document
TSS	Thermal Storage
TTMA	Truck Trailer Manufacturers Association
TW	Test Weight
U/DAF	Upward and Downward Adjustment Factor
UCT	Urban Creep and Transient Duty Cycle
UFP	Ultra Fine Particles
URE	Unit Risk Estimate
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program

UV	Ultraviolet
UV-b	Ultraviolet-b
VHHD	Vocational Heavy Heavy-Duty
VIN	Vehicle Identification Number
VIUS	Vehicle Inventory Use Survey
VLHD	Vocational Light Heavy-Duty
VMHD	Vocational Medium Heavy-Duty
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VSL	Vehicle Speed Limiter
VTRIS	Vehicle Travel Information System
VVL	Variable Valve Lift
VVT	Variable Valve Timing
WACAP	Western Airborne Contaminants Assessment Project
WBS	Wide Base Singles
WHR	Waste Heat Recovery
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle
WRF	Weather Research Forecasting
WTP	Willingness-to-Pay
WTVC	World Wide Transient Vehicle Cycle
WVU	West Virginia University

Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA), on behalf of the Department of Transportation, are each proposing changes to our comprehensive Heavy-Duty National Program that would further reduce greenhouse gas emissions (GHG) and increase fuel efficiency for on-road heavy-duty vehicles, responding to the President's directive on February 18, 2014, to take coordinated steps toward the production of even cleaner vehicles. NHTSA's fuel consumption standards and EPA's carbon dioxide (CO_2) emissions standards would be tailored to each of the three current regulatory categories of heavy-duty vehicles: (1) Combination Tractors; (2) Heavy-duty Pickup Trucks and Vans; and (3) Vocational Vehicles, as well as gasoline and diesel heavy-duty engines. In addition, the agencies would be adding new standards for combination trailers. EPA's hydrofluorocarbon emissions standards that currently apply to air conditioning systems in tractors, pickup trucks, and vans, would also be applied to vocational vehicles.

Table 1 and Table 2 present the rule-related fuel savings, costs, benefits and net benefits in both present value terms and in annualized terms as calculated by NHTSA and EPA, respectively. Table 3 presents the proposed rule's fully phased-in (MY 2027) numeric standards by vehicle (and engine) subcategory, along with the agencies' projected per vehicle incremental cost and incremental improvement in fuel efficiency and CO_2 emissions.

For HD pickups and vans, the agencies are proposing performance-based standards under which, as for Phase 1, the average fuel consumption and CO_2 emission rates required of a manufacturer depend on the mix of vehicles produced by the manufacturer for sale in the U.S. For each vehicle, the agencies are again proposing to define the work factor as the sum of (a) 75% of the vehicle's maximum payload, 25% of the vehicles maximum towing capacity, and (c) 375 lbs. if the vehicle has four-wheel drive. The agencies are further proposing that fuel consumption and CO_2 emission rate targets will apply to each vehicle based on the vehicle's work factor and fuel type, and that the average fuel consumption and CO_2 emission rates required of the manufacturer will be defined as the production-weighted average of these targets. The proposed fuel consumption targets are linear functions defined by the slopes and intercepts shown below in Figure 1, Figure 2, and Table 4.

Table 1 NHTSA's Estimated 2018-2029 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits using Method A and Relative to the More Dynamic Baseline and Assuming the 3% Discount Rate SCC Value[a]
(Billions of 2012 Dollars)

Lifetime Present Value – 3% Discount Rate	
Vehicle Program	-$25.2
Maintenance	-$1.1
Fuel Savings	$170.1
Benefits	$93.8
Net Benefits	$238
Annualized Value – 3% Discount Rate	
Vehicle Program	-$1.0
Maintenance	-$0.04
Fuel Savings	$6.7
Benefits	$3.7
Net Benefits	$9.4
Lifetime Present Value - 7% Discount Rate	
Vehicle Program	-$17
Maintenance	-$0.6
Fuel Savings	$91.7
Benefits	$66.1
Net Benefits	$140
Annualized Value – 7% Discount Rate	
Vehicle Program	-$1.2
Maintenance	-$0.04
Fuel Savings	$6.7
Benefits	$4.8
Net Benefits	$10.2

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 2 EPA's Estimated 2018-2029 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits using Method B and Relative to the Less Dynamic Baseline and Assuming the 3% Discount Rate SCC Value[a]
(Billions of 2012 Dollars)

Lifetime Present Value[c] – 3% Discount Rate	
Vehicle Program	-$25
Maintenance	-$1.1
Fuel Savings	$171
Benefits [b]	$97

Net Benefits[d]	$242
Annualized Value[e] – 3% Discount Rate	
Vehicle Program	-$1.3
Maintenance	-$0.1
Fuel Savings	$8.7
Benefits [b]	$4.9
Net Benefits[d]	$12.3
Lifetime Present Value[c] - 7% Discount Rate	
Vehicle Program	-$17
Maintenance	-$0.6
Fuel Savings	$90
Benefits [b]	$65
Net Benefits[d]	$138
Annualized Value[e] – 7% Discount Rate	
Vehicle Program	-$1.3
Maintenance	$0.0
Fuel Savings	$7.3
Benefits [b]	$4.2
Net Benefits[d]	$10.1

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] EPA estimated the benefits associated with four different values of a one ton CO_2 reduction (model average at 2.5% discount rate, 3%, and 5%; 95[th] percentile at 3%), which each increase over time. For the purposes of this overview presentation of estimated costs and benefits, however, the benefits shown here use the marginal value deemed to be central by the interagency working group on this topic: the model average at 3% discount rate, in 2012 dollars. Chapter 8.5 provides a complete list of values for the 4 estimates. Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section Chapter 8.5 for more detail.

[c] Present value is the total, aggregated amount that a series of monetized costs or benefits that occur over time is worth now (in year 2012 dollar terms), discounting future values to the present over the lifetime of each model year vehicle.

[d] Net benefits reflect the fuel savings plus benefits minus costs.

[e] The annualized value is the constant annual value through a 30 year lifetime whose summed present value equals the present value from which it was derived. Annualized SCC values are calculated using the same rate as that used to determine the SCC value, while all other costs and benefits are annualized at either 3% or 7%.

TABLE 3 SUMMARY OF PROPOSED 2027 STANDARDS INCLUDING AVERAGE PER VEHICLE COSTS AND PROJECTED IMPROVEMENTREGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE (FOR ENGINES, CO_2 GRAMS PER BRAKE HORSEPOWER-HOUR; FOR HD PUV, GRAMS PER MILE)	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE (FOR ENGINES, GALLONS PER 100 BRAKE HORSEPOWER-HOUR; FOR HD PUV, GALLONS PER 100 MILES)	AVERAGE INCREMENTAL COST PER VEHICLE OR ENGINE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2027 [a]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2027 RELATIVE TO MY 2017
Tractors				
Class 7 Low Roof Day Cab	87	8.5462	$10,140	19%
Class 7 Mid Roof Day Cab	96	9.4303	$10,140	19%
Class 7 High Roof Day Cab	96	9.4303	$10,099	21%
Class 8 Low Roof Day Cab	70	6.8762	$10,204	19%
Class 8 Mid Roof Day Cab	76	7.4656	$10,204	18%
Class 8 High Roof Day Cab	76	7.4656	$10,209	20%
Class 8 Low Roof Sleeper Cab	62	6.0904	$12,744	22%
Class 8 Mid Roof Sleeper Cab	69	6.7780	$12,744	21%
Class 8 High Roof Sleeper Cab	67	6.5815	$12,842	24%
Trailers				
Long Dry Box Trailer	77	7.5639	$1,409	8%
Short Dry Box Trailer	140	13.7525	$1,280	7%
Long Refrigerated Box Trailer	80	7.8585	$1,253	5%
Short Refrigerated Box Trailer	144	14.1454	$1,253	5%

Notes:
[a] Engine costs are included in average vehicle costs.

Table 3 (cont.) Summary of Proposed 2027 Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE (FOR ENGINES, CO_2 GRAMS PER BRAKE HORSEPOWER-HOUR; FOR HD PUV, GRAMS PER MILE)	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE (FOR ENGINES, GALLONS PER 100 BRAKE HORSEPOWER-HOUR; FOR HD PUV, GALLONS PER 100 MILES)	AVERAGE INCREMENTAL COST PER VEHICLE OR ENGINE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2027 [a]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2027 RELATIVE TO MY 2017
Vocational Diesel				
LHD Urban	272	26.7191	$3,489	16%
LHD Multi-Purpose	280	27.5049	$3,490	16%
LHD Regional	292	28.6837	$1,407	16%
MHD Urban	172	16.8959	$4,696	16%
MHD Multi-Purpose	174	17.0923	$4,696	16%
MHD Regional	170	16.6994	$1,395	16%
HHD Urban	182	17.8782	$7,422	16%
HHD Multi-Purpose	183	17.9764	$7,422	16%
HHD Regional	174	17.0923	$4,682	16%
Vocational Gasoline				
LHD Urban	299	33.6446	$3,086	12%
LHD Multi-Purpose	308	34.6574	$3,087	12%
LHD Regional	321	36.1202	$1,004	12%
MHD Urban	189	21.2670	$4,327	13%
MHD Multi-Purpose	191	21.4921	$4,327	13%
MHD Regional	187	21.0420	$1,026	13%
HHD Urban	196	22.0547	$7,053	12%
HHD Multi-Purpose	198	22.2797	$7,053	12%
HHD Regional	188	21.1545	$4,313	12%
Diesel Engines[a]				
LHD Vocational	553	5.4322	$471	4%
MHD Vocational	553	5.4322	$437	4%
HHD Vocational	533	5.2358	$437	4%
MHD Tractor	466	4.5776	$1,698	4%
HHD Tractor	441	4.3320	$1,698	4%
Class 2b and 3 HD Pickups and Vans[b]				
HD Pickup and Van	458	4.8608	$1,357	18%

Notes:

[a] Engine costs are included in average vehicle costs. Costs shown for diesel engines are not additive to vehicle costs.

[b] For HD pickups and vans, Table 3 shows results for MY2029, assuming continuation of proposed MY2027 standard.

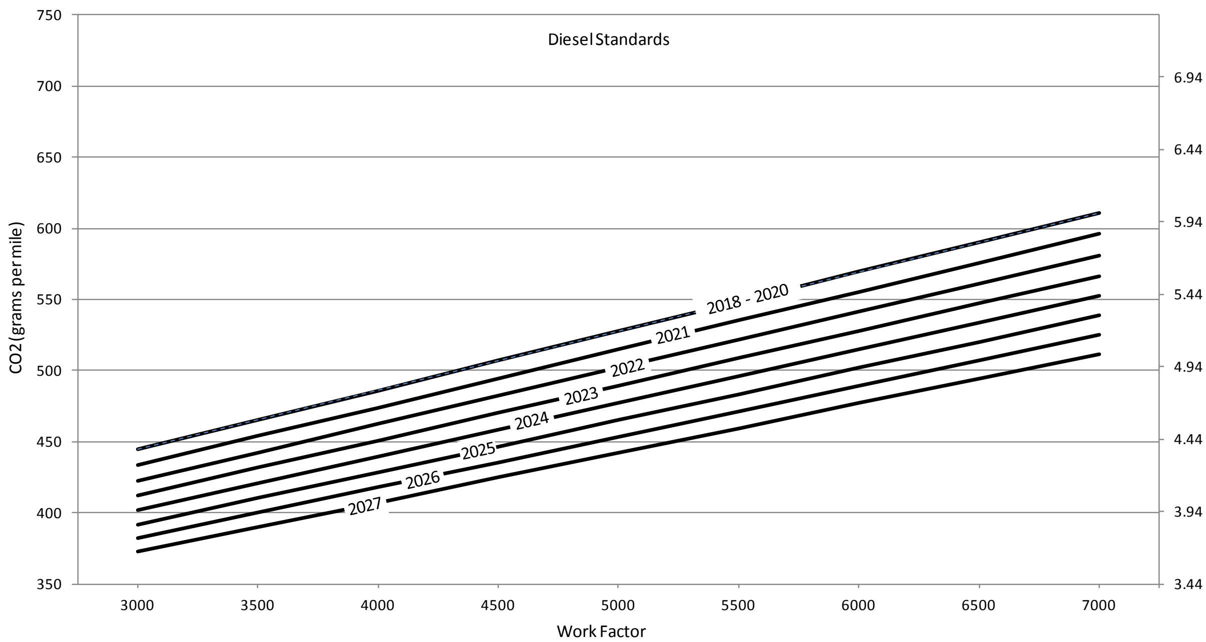


Figure 1 EPA Proposed CO_2 Target Standards and NHTSA Proposed Fuel Consumption Target Standards for Diesel HD Pickups and Vans

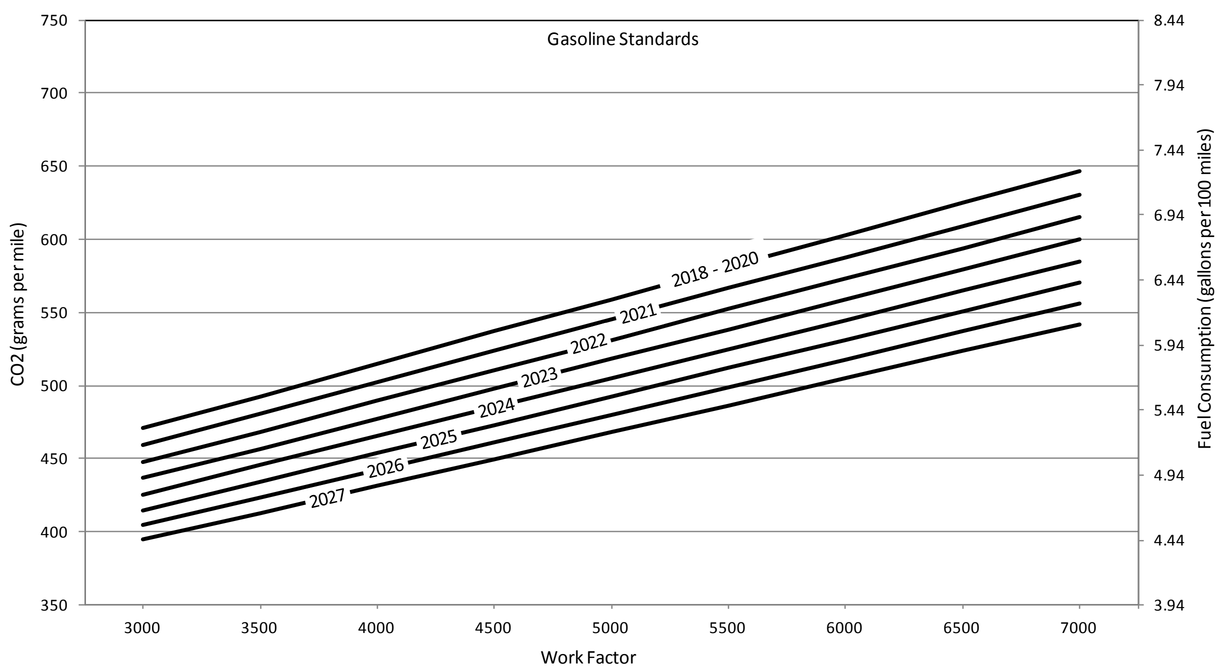


Figure 2 EPA Proposed CO_2 Target Standards and NHTSA Proposed Fuel Consumption Target Standards for Gasoline HD Pickups and Vans

Described mathematically, EPA's and NHTSA's proposed target standards are defined by the following formulas:

EPA CO_2 Target (g/mile) = [a x WF] + b

NHTSA Fuel Consumption Target (gallons/100 miles) = [c x WF] + d

Where:

WF = Work Factor = [0.75 x (Payload Capacity + xwd)] + [0.25 x Towing Capacity]

Payload Capacity = GVWR (lb) – Curb Weight (lb)

xwd = 500 lb if the vehicle is equipped with 4wd, otherwise equals 0 lb.

Towing Capacity = GCWR (lb) – GVWR (lb)

Coefficients a, b, c, and d are taken from Table 1.

Table 4. Proposed Phase 2 Coefficients for HD Pickup and Van Target Standards

DIESEL VEHICLES				
Model Year	a	b	c	d
2018-2020 [a]	0.0416	320	0.0004086	3.143
2021	0.0406	312	0.0003988	3.065
2022	0.0395	304	0.0003880	2.986
2023	0.0386	297	0.0003792	2.917
2024	0.0376	289	0.0003694	2.839
2025	0.0367	282	0.0003605	2.770
2026	0.0357	275	0.0003507	2.701
2027 and later	0.0348	268	0.0003418	2.633
Gasoline Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.044	339	0.0004951	3.815
2021	0.0429	331	0.0004827	3.725
2022	0.0418	322	0.0004703	3.623
2023	0.0408	314	0.0004591	3.533
2024	0.0398	306	0.0004478	3.443
2025	0.0388	299	0.0004366	3.364
2026	0.0378	291	0.0004253	3.274
2027 and later	0.0369	284	0.0004152	3.196

Note:

[a] Phase 1 primary phase-in coefficients. Alternative phase-in coefficients are different in MY2018 only.

This Draft Regulatory Impact Analysis (RIA) provides detailed supporting documentation to EPA and NHTSA joint proposal under each of their respective statutory authorities. Because there are slightly different requirements and flexibilities in the two authorizing statutes, this Draft RIA provides documentation for the primary joint provisions as well as for provisions specific to each agency.

This RIA is generally organized to provide overall background information, methodologies, and data inputs, followed by results of the various technical and economic analyses. A summary of each chapter of the RIA follows.

Chapter 1: Industry Characterization. In order to assess the impacts of greenhouse gas (GHG) and fuel consumption regulations upon the affected industries, it is important to understand the nature of the industries impacted by the regulations. The heavy-duty vehicle industries include the manufacturers of Class 2b through Class 8 trucks, engines, trailers and some other equipment. Of these categories, trailers are the only industry that would be newly regulated under the proposed standards. This chapter provides market information for the trailer industry, as well as the variety of ownership patterns, for background purposes.

Chapter 2: Technology and Cost. This chapter presents details of the vehicle and engine technologies and technology packages for reducing greenhouse gas emissions and fuel consumption. These technologies and technology packages represent potential ways that the industry could meet the CO_2 and fuel consumption stringency levels, and they provide the basis for the technology costs and effectiveness analyses.

Chapter 3: Test Procedures. Laboratory procedures to physically test engines, vehicles, and components are a crucial aspect of the heavy-duty vehicle GHG and fuel consumption program. The rulemaking would establish some new test procedures for both engine and vehicle compliance and would revise existing procedures. This chapter describes the relevant test procedures, including methodologies for assessing engine emission performance, the effects of aerodynamics and tire rolling resistance, as well as procedures for chassis dynamometer testing and their associated drive cycles.

Chapter 4: Vehicle Simulation Model. An important aspect of a regulatory program is its ability to accurately estimate the potential environmental benefits of heavy-duty truck technologies through testing and analysis. Most large truck manufacturers employ various computer simulation methods to estimate truck efficiency for purposes of developing and refining their products. Each method has advantages and disadvantages. This section will focus on the use of a type truck simulation modeling that the agencies have developed specifically for assessing tailpipe GHG emissions and fuel consumption for purposes of this rulemaking. The agencies are proposing to revise the existing simulation model -- the "Greenhouse gas Emissions Model (GEM)" -- as the primary tool to certify vocational vehicles, combination tractor, and combination trailers, Class 2b through Class 8 heavy-duty vehicles that are not heavy-duty pickups or vans) and discuss the model in this chapter.

Chapter 5: Impacts on Emissions and Fuel Consumption. This program estimates anticipated impacts from the CO_2 emission and fuel efficiency standards. The agencies quantify fuel use and emissions from the GHGs carbon dioxide (CO_2), methane (CH_4), nitrous oxide

(N_2O) and hydrofluorocarbons (HFCs). In addition to reducing the emissions of greenhouse gases and fuel consumption, this program would also influence the emissions of "criteria" air pollutants, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SO_X) and the ozone precursors hydrocarbons (VOC) and oxides of nitrogen (NO_X); and several air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein), as described further in Chapter 5.

The agencies used EPA's Motor Vehicle Emission Simulator (MOVES2014) to estimate downstream (tailpipe) emission impacts for combination tractors and vocational vehicles, and a spreadsheet model based on emission factors the "GREET" model to estimate upstream (fuel production and distribution) emission changes resulting from the decreased fuel. For HD pickups and vans, the agencies used DOT's CAFE model to estimate manufacturer responses to the proposed standards. NHTSA used the CAFE model to estimate emission impacts, and EPA used the CAFE model technology penetration outputs as an input to MOVES to calculate emission impacts. Based on these analyses, the agencies estimate that this program would lead to 183.4 million metric tons (MMT) of CO_2 equivalent (CO_2EQ) of annual GHG reduction and 13.4 billion gallons of fuel savings in the year 2050, as discussed in more detail in Chapter 5.

Chapter 6: Health and Environmental Impacts. This chapter discusses the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants would not be directly regulated by the standards, but the standards would affect emissions of these pollutants and precursors. Reductions in these pollutants are the co-benefits of the rulemaking (that is, benefits in addition to the benefits of reduced GHGs). This chapter also discusses GHG-related impacts, such as changes in atmospheric CO_2 concentrations, global mean temperature, sea level rise, and ocean pH associated with the program's GHG emissions reductions.

Chapter 7: Vehicle-Related Costs of the Program. In this chapter, the agencies present our estimate of the costs associated with the proposed program. The presentation summarizes the costs associated with new technology expected to be added to meet the GHG and fuel consumption standards, including hardware costs to comply with the air conditioning (A/C) leakage program. The analysis discussed in Chapter 7 provides our best estimates of incremental costs on a per truck basis and on an annual total basis. We also present the fuel savings and maintenance costs in this chapter, along with a detailed payback analysis for various vehicle segments.

Chapter 8: EPA's Economic and Other Impacts Analysis. This chapter provides EPA's description of the net benefits of the proposed HD National Program. To reach these conclusions, the chapter discusses each of the following aspects of the analyses of benefits:

Rebound Effect: The VMT rebound effect refers to the fraction of fuel savings expected to result from an increase in fuel efficiency that is offset by additional vehicle use.

Energy Security Impacts: A reduction of U.S. petroleum imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risk is a measure of improved U.S. energy security.

Monetized CO_2 Impacts: The agencies estimate the monetized benefits of GHG reductions by assigning a dollar value to reductions in CO_2 emissions using recent estimates of the social cost of carbon (SCC). The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year.

Other Impacts: There are other impacts associated with the GHG emissions and fuel efficiency standards. Lower fuel consumption would, presumably, result in fewer gallons being refilled and, thus, less time spent refueling. The increase in vehicle-miles driven due to a positive rebound effect may also increase the societal costs associated with traffic congestion, crashes, and noise. However, if drivers drive those additional rebound miles, there must be a value to them which we estimate as the value of increased travel. The agencies also discuss the impacts of safety standards and voluntary safety improvements on vehicle weight.

Chapter 8 also presents a summary of the total costs, total benefits, and net benefits expected under the program.

Chapter 9: NHTSA and EPA considered the potential safety impact of technologies that improve HD vehicle fuel efficiency and GHG emissions as part of the assessment of regulatory alternatives. This chapter discusses the literature and research considered by the agencies, which included two National Academies of Science reports, an analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and agency-sponsored safety testing and research.

Chapter 10: NHTSA CAFE Model. This chapter describes NHTSA's CAFE modeling system. The agencies used DOT's CAFE model to estimate manufacturer responses to the proposed standards for HD pickups and vans, and NHTSA also used the CAFE model to estimate emission impacts for this sector.

Chapter 11: Results of Preferred and Alternative Standards. The heavy-duty truck segment is very complex. The sector consists of a diverse group of impacted parties, including engine manufacturers, chassis manufacturers, truck manufacturers, trailer manufacturers, truck fleet owners and the public. The agencies have largely designed this program to maximize the environmental and fuel savings benefits, taking into account the unique and varied nature of the regulated industries. In developing this program, we considered a number of alternatives that could have resulted in fewer or potentially greater GHG and fuel consumption reductions than the program we are proposing. Chapter 9 section summarizes the alternatives we considered.

Chapter 12: Small Business Flexibility Analysis. This chapter describes the agencies' analysis of the small business impacts due to the joint program.

Chapter 13: Natural Gas Vehicles and Engines. This chapter describes EPA's lifecycle analysis for natural gas used by the heavy-duty truck sector.

Chapter 1: Industry Characterization

1.1 Introduction

The proposed fuel consumption and CO_2 emissions standards described in the preamble of this NPRM would be applicable to three currently-regulated categories of heavy-duty vehicles: (1) Combination Tractors; (2) Heavy-duty Pickup Trucks and Vans; and (3) Vocational Vehicles, as well as gasoline and diesel heavy-duty engines. The industry characterization for these sectors can be found in the RIA for the HD Phase 1 rulemaking.[1] With this proposed rulemaking, the agencies would be setting standards for combination trailers for the first time. The characterization laid out in this chapter focuses solely on trailers as this subcategory would be the only newly-regulated industry.

1.2 Trailers

A trailer is a vehicle designed to haul cargo while being pulled by another powered motor vehicle. The most common configuration of large freight trucks consists of a Class 7 or 8 tractor hauling one or more trailers. Vehicles in these configurations are called “combination tractor-trailers” or simply “tractor-trailers”. A trailer may be constructed to rest upon the tractor that tows it, or be constructed so part of its weight rests on an auxiliary front axle called a “converter dolly” between two or more trailers. Trailers are attached to tractors by a *coupling pin* (or *king pin*) on the front of the trailer and a horseshoe-shaped coupling device called a *fifth wheel* on the rear of the towing vehicle or on the converter dolly. A tractor can also pull international shipping or domestic *containers* mounted on open-frame chassis, which when driven together on the road function as trailers.

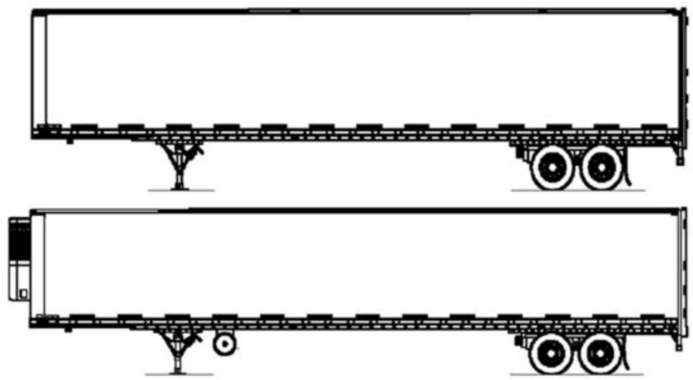
The Truck Trailer Manufacturers Association, an industry trade group primarily for manufacturers of Class 7 and 8 truck trailers, offers publications of recommended practices, technical bulletins and manuals that cover many aspects of trailer manufacture, and serves as a liaison between the industry and government agencies.[2] To date, federal regulations for the trailer industry are limited to those issued by the Department of Transportation (See 49 CFR). These regulations govern trailer dimensions and weight, as well as trailer safety requirements (e.g., lights, reflective materials, bumpers, etc.). In addition, DOT requires that each trailer, like other on-road vehicles, must have a Vehicle Identification Number (VIN)[3]. The VIN is displayed on a label that is permanently-affixed to the trailer. It is required to contain the manufacturer identification, make and type of vehicle, model year, type of trailer, body type, length, and axle configuration. Trailer manufactures are responsible for reporting each trailer’s VIN information to NHTSA prior to the sale of the trailer.

1.2.1 **Trailer Types**

Class 7 and 8 tractors haul a diverse range of trailer types. The most common trailer type is the box trailer, which is enclosed and can haul most types of mixed freight. The general rectangular shape of these trailers allows operators to maximize freight volume within the regulated dimensional limits, since the majority of freight shipped by truck cubes-out (is volume-limited) before it grosses-out (is weight-limited). Despite considerable improvements in suspension, material, safety, durability, and other advancements, the basic shape of the box trailer has not changed much over the past decades, although its dimensions have increased incrementally from what used to be the industry's standard length of 40' to today's standard 53' long van trailer. Today, box vans are commonly found in lengths of 28', 48', and 53'and widths of 102" or 96". The 28' vans ("pups") are often driven in tandem and connected by a dolly. Current length restrictions for the total combination tractor-trailer vehicle limit tandem operation to 28' trailers. However, some members of the trucking industry are pushing to increase the length limits to allow trailers as long as 33' to be pulled in tandem, and arguing that these "less than truckload" (LTL) operations could increase capacity per truckload, reduce the number of trucks on the road, reduce the fuel consumption and emissions of these tractor-trailers, and remain within the current weight limits.[4,5]

Trailers are often highly customized for each order. The general structure of the box trailer type is common and consists of vertical support posts in the interior of the trailer covered by a smooth exterior surface. However the exterior of the trailer may be constructed of aluminum or a range of composite materials. Historically, floors were constructed of wood, however many trailer customers are requesting aluminum floors to reduce weight. Semi-trailer axles are commonly a dual tandem configuration, but can also be single, spread tandem (i.e., two axles separated to maximize axle loads), tridem (i.e., three axles equally spaced), tri axles (i.e., three axles consisting of a tandem and a third axle that may be liftable), or multi-axles to distribute very heavy loads. Axles can be fixed in place, or allowed to slide to adjust weight distribution. Doors are commonly located at the rear of the trailer. The most common door is the side-by-side configuration, in which each door opens outward. Roll-up doors, which are more costly, allow truck drivers to pull up to loading docks without first stopping to open the doors. Roll-up doors are common on trailers with temperature-sensitive freight. Additional variations in trailers include side-access doors, or use the underside of the trailer for belly boxes or to store on-demand items such as ladders or spare tires.

The most common box trailer is the standard dry van, which transports cargo that does not require special environmental conditions. In addition to the standard rectangular shape, dry vans come in several specialty variants, such as drop floor, expandable, and curtain-side. Another type of specialty box trailer is the refrigerated van trailer (reefer). This is an enclosed, insulated trailer that hauls temperature sensitive freight, with a transportation refrigeration unit (TRU) or heating unit mounted in the front of the trailer powered by a small (9-36 hp) diesel engine. Figure 1-1 shows an example of the standard dry and refrigerated vans.



Adapted from http://www.wbmcguire.com/links/Guides/TruckTrailerGuide.pdf

Figure 1-1 Examples of dry and refrigerated van

Many other trailer types are uniquely designed to transport a specific type of freight. Platform trailers carry cargo that may not be easily contained within or loaded and unloaded into a box trailer, such as large, nonuniform equipment or machine components. Platforms come in different configurations including standard flatbed, gooseneck, and drop deck. Tank trailers are pressure-tight enclosures designed to carry liquids, gases or bulk, dry solids and semi-solids. Tank trailers are generally constructed of steel or aluminum. The plumbing for intake and discharge of the contents could be located below the tank or at the rear. There are also a number of other specialized trailers such as grain (with and without hoppers), dump (frameless, framed, bottom dump, demolition), automobile hauler (open or enclosed), livestock trailers (belly or straight), construction and heavy-hauling trailers (tilt bed, hydraulic).

A sizable fraction of U.S. freight is transported in large, steel containers both internationally via ocean-going vessels and domestically via rail cars. Containers are constructed with steel sidewalls and external support beams, which results in a corrugated exterior. These containers haul mixed freight and are designed with similar dimensions to box trailers. Ocean-going international shipping containers are typically 20-feet or 40-feet in length. Domestic containers, which often travel by rail, are 53-feet in length. Transport of these containers from ports or rail to their final destination requires the container to be loaded on a specialty piece of equipment called a chassis. The chassis, which is attached to the fifth wheel of a Class 7 or 8 tractor, consists of a frame, axles, suspension, brakes and wheel assemblies, as well as lamps, bumpers and other required safety components. Fixed chassis vary in length according to the type of container that will be attached, though some chassis adjust to accommodate different sizes. When the chassis and container are assembled the unit serves the same function as a road trailer.[6] However, under customs regulations, the container itself is not considered part of a road vehicle.[7]

ACT Research compiles factory shipment information from a Trailer Industry Control Group that represents 80 percent of the U.S. trailer industry. Figure 1-2 shows the distribution of trailers sold in the U.S. based on ACT Research's 2013 factory shipment data. The most common type of trailer in use today is the dry van trailer, followed by the refrigerated van. Together, these box vans make up greater than 70 percent of the industry. Trailer Body Builders' annual trailer output report estimates there were over 240,000 trailers sold in North America 2013.

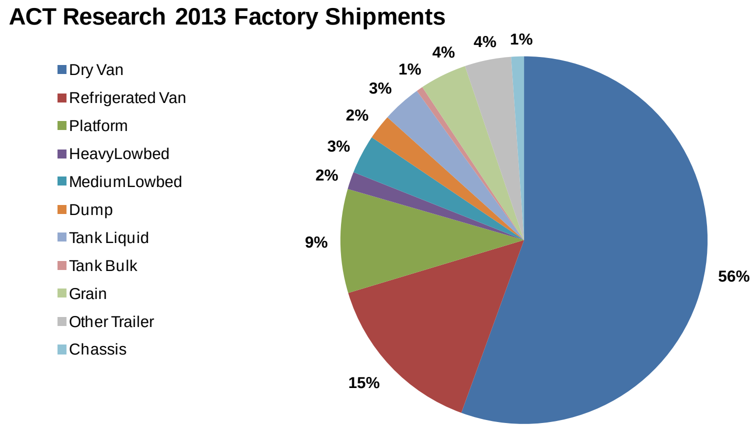


Figure 1-2 ACT Research's 2013 U.S. factory shipments

1.2.2 **Trailer Manufacturers**

Trailer Body Builders' annual trailer output report estimates there were over 240,000 trailers sold in North America in 2013. The diverse van, platform, tank and specialty trailers are produced by a large number of trailer manufacturers. EPA estimates there are 114 trailer manufacturers. Trailers are far less mechanically complex than the tractors that haul them, and much of trailer manufacturing is done by hand. This relatively low barrier to entry for trailer manufacturing accounts, in part, for the large number of trailer manufacturers. Figure 1-3 shows that over 70 percent of the manufacturing output of the industry comes from just five manufacturers.

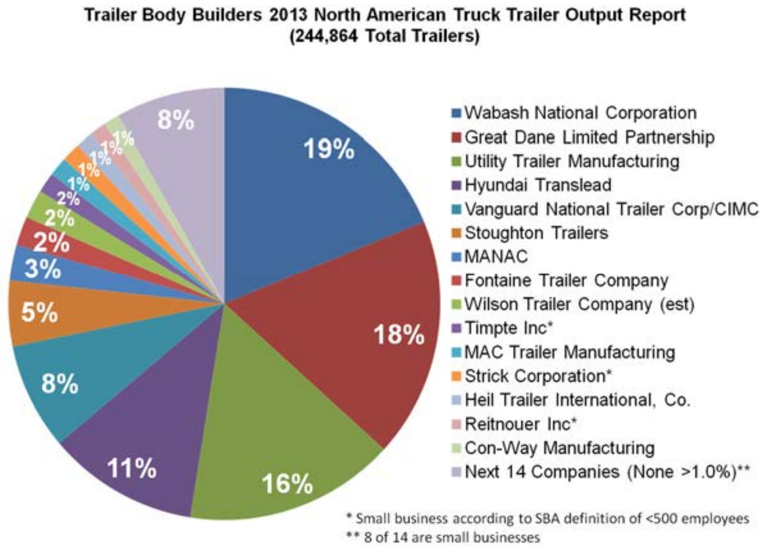


Figure 1-3 2013 Trailer Output Report from Trailer Body Builders

Table 1-1 Illustrates the varying revenue among trailer manufacturers and further distinguishes the very different roles in that market played by small and large manufacturers. The revenue numbers were obtained from Hoovers online company database.[8] Over 80 percent of trailer manufacturers meet the Small Business Administration's (SBA) definition of a small business (i.e., less than 500 employees), yet these manufacturers make up less than 25 percent of the overall revenue from the industry. In fact, a majority of the small business trailer manufacturers make less than $10 million in revenue per year.

Table 1-1 Summary of 2013 Trailer Industry Revenue by Business Size

Revenue Range	Business Size		
	All Sizes	Large	Small[a]
> 1000M	1	1	0
$500M - $999M	0	0	0
$400M - $499M	1	1	0
$300M - $399M	0	0	0
$200M - $299M	3	3	0
$100M - $199M	3	3	0
$50M - $99M	13	7	6
$40M - $49M	14	2	12
$15M - $19M	9	1	8
$10M - $14M	3	0	3
$5M - $9M	26	0	26
< $5M	41	1	40
Total Companies	114	19	95
Total Revenue ($M)	4965	3799	1166
Average Revenue ($M)	44	200	12

Box Trailer Mfrs	14	9	5
Non-Box Trailer Mfrs	109	17	92

Note:

[a] The Small Business Administration (SBA) defines a trailer manufacturer as a "small business" if it has fewer than 500 employees

The trailer industry was particularly hard hit by the recent recession. Trailer manufacturers saw deep declines in new trailer sales of 46 percent in 2009; some trailer manufacturers saw sales drop as much as 71 percent. This followed overall trailer industry declines of over 30 percent in 2008. The 30 largest trailer manufacturers saw sales decline 72 percent from 282,750 in 2006, to only 78,526 in 2009. Several trailer manufacturers shut down entire production facilities and a few went out of business altogether. Trailer production has steadily grown across the industry since 2010 and, although historic production peaks have not been repeated to date, it has now returned to levels close to those seen in the mid-2000s. Figure 1-4 shows the ACT Research's annual factory shipments, which illustrates the unsteady production over the past 17 years.

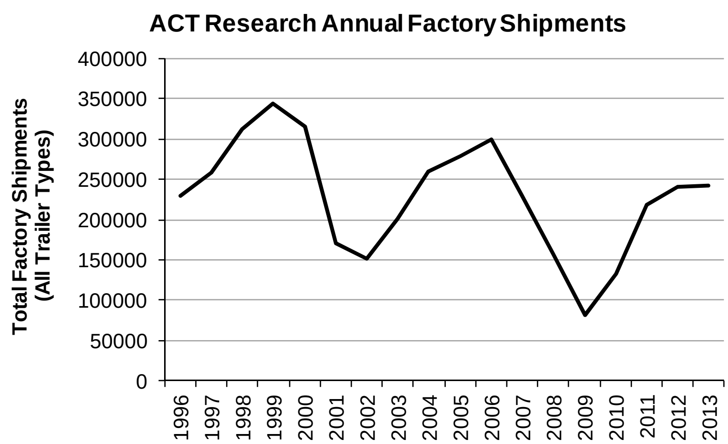


Figure 1-4 Annual Factory Shipments Tracked by ACT Research

1.2.3 **Trailer Use**

In order to determine the appropriate tractor type for each trailer, the agencies investigated "primary trip length" results from the Vehicle Inventory and Use Survey database to determine the distribution of trailers in short- and long-haul applications.[9] Using a primary trip length of 500 miles or less to represent short-haul use, the agencies found that, of the reported vehicles, over 50 percent of the 53-feet and longer dry vans were used in long-haul and over 80 percent of the shorter vans were used in short-haul applications. Over 70 percent of the reported 53-feet and longer refrigerated vans were long-haul trailers, with 65 percent of the shorter refrigerated vans used in short-haul applications. The survey found that non-box trailers are most frequently used for short-haul. Figure 1-5 summarizes these findings.

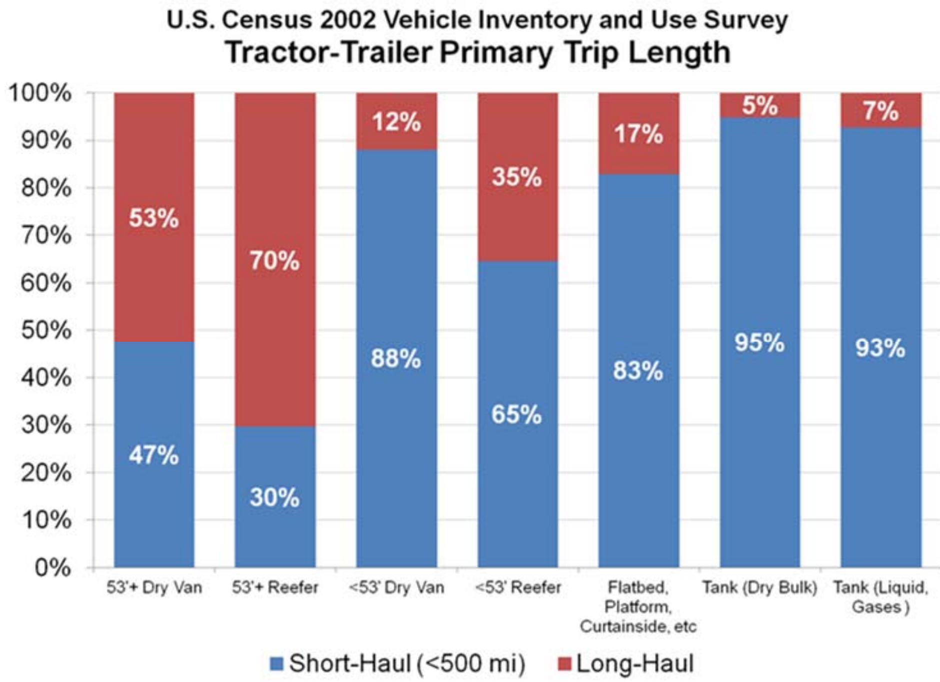


Figure 1-5 2002 Vehicle Inventory and Use Survey Considering Primary Trip Length for Tractor-Trailers

Truck drivers and trucking fleets frequently do not control all or even any of the trailers that they haul. Trailers can be owned by freight customers, large equipment leasing companies, third party logistics companies, and even other trucking companies. Containers on chassis, which function as trailers, are rarely owned by truck operators. Rather, they are owned or leased by ocean-going shipping companies, port authorities or others. This distinction between who hauls the freight and who owns the equipment in which it is hauled means that truck owners and operators have limited ability to be selective about the trailers they carry, and very little incentive or ability to take steps to reduce the fuel use of trailers that they neither own or control.

For refrigerated trailers, the story is slightly different. These trailers are used more intensely and accumulate more annual miles than other trailers. Over time, refrigerated trailers can also develop problems that interfere with their ability to keep freight temperature-controlled. For example, the insulating material inside a refrigerated trailer's walls can gradually lose its thermal capabilities due to aging or damage from forklift punctures. The door seals on a refrigerated trailer can also become damaged or loose with age, which greatly affects the insulation characteristics of the trailer, similar to how the door seal on a home refrigerator can reduce the efficiency of that appliance. As a result of age-related problems and more intense usage, refrigerated trailers tend to have shorter procurement cycles than dry van trailers, which means a faster turnover rate, although still not nearly as fast as for trucks in their first use.

Tractor-trailers are often used in conjunction with other modes of transportation (e.g., shipping and rail) to move goods across the country, known as intermodal shipping. Intermodal traffic typically begins with containers carried on ships, and then they are loaded onto railcars, and finally transported to their end destination via truck. Trucks that are used in intermodal applications are of two primary types. Trailer-on-flatcar (TOFC) involves lifting the entire trailer or the container attached to its chassis onto the railcar. In container-on-flatcar (COFC) applications, the container is removed from the chassis and placed directly on the railcar. The use of TOFCs allows for faster transition from rail to truck, but is more difficult to stack on a vessel; therefore the use of COFCs has been increasing steadily. Both applications are used throughout the U.S. with the largest usage found on routes between West Coast ports and Chicago, and between Chicago and New York.

1.2.4 Trailer Fleet Size Relative to the Tractor Fleet

In 2013, over 800,000 trailers were owned by for-hire fleets and almost 300,000 were owned by private fleets. Trailers that are purchased by fleets are typically kept much longer than are the tractors, so trucks and trailers have different purchasing cycles. Also, many trailers are owned by shippers or by leasing companies, not by the trucking fleets. Because of the disconnect between owners, the trailer owners may not benefit directly from fuel consumption and GHG emission reductions.

The industry generally recognizes that the ratio of the number of dry van trailers in the fleet relative to the number of tractors is typically three-to-one.[10] Typically at any one time, two trailers are parked while one is being transported. Certain private fleets may have ratios as high as six-to-one and owner-operators may have a single trailer for their tractor. The ratio of refrigerated vans to tractors is closer to two-to-one. This is partly due to the fact that it is more expensive to purchase and operate refrigerated vans compared to dry vans. Specialty trailers, such as tanks and flatbeds are often attached to a single trailer throughout much of their life. This characteristic of the trailer fleet impacts the cost effectiveness of trailer technologies. The annual savings achieved due to these technologies are proportional to the number of miles traveled in a year and the analysis for many of the trailers must account for some amount of inactivity, which will reduce the benefits.

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[6] Per 46 CFR § 340.2.
[7] 19 CFR 115.3
[8] Dun & Bradstreet. Hoover’s Inc. Online Company Database. Available at: http://www.hoovers.com.
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[10] TIAX. LLC. “Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles,” Final Report to the National Academy of Sciences, November 19, 2009. Page 4-49.

Chapter 2: Technology and Cost

2.1 Overview of Technologies

In discussing the potential for CO_2 emission and fuel consumption reductions, it can be helpful to think of the work flow through the system. The initial work input is fuel. Each gallon of fuel has the potential to produce some amount of work and will produce a set amount of CO_2 (about 22 pounds (10 kg) of CO_2 per gallon of diesel fuel). The engine converts the chemical energy in the fuel to useable work to move the truck. Any reductions in work demanded of the engine by the vehicle or improvements in engine fuel conversion efficiency will lead directly to CO_2 emission and fuel consumption reductions.

Current diesel engines are around 40 percent efficient over a range of operating conditions depending on engine sizes and applications, while gasoline engine efficiency is much lower than that of diesel engines. This means that approximately one-third of the fuel's chemical energy is converted to useful work and roughly two-thirds is lost to friction, gas exchange, and waste heat in the coolant and exhaust. In turn, the truck uses this work delivered by the engine to overcome overall vehicle-related losses such as aerodynamic drag, tire rolling resistance, friction in the vehicle driveline, and to provide auxiliary power for components such as air conditioning and lights. Lastly, the vehicle's operation, such as vehicle speed and idle time, affects the amount of total energy required to complete its activity. While it may be intuitive to look first to the engine for CO_2 emission and fuel consumption reductions given that only about one-third of the fuel is converted to useable work, it is important to realize that any improvement in vehicle efficiency proportionally reduces both the work demanded and the energy wasted.

Technology is one pathway to improve heavy-duty truck GHG emissions and fuel consumption. Near-term solutions exist, such as those being deployed by SmartWay partners in heavy-duty truck long haul applications. Other solutions are currently underway in the light-duty vehicle segment, especially in the large pickup sector where some of the technologies can apply to the heavy-duty pickup trucks covered under this rulemaking. Long-term solutions are currently under development to improve efficiencies and cost-effectiveness. While there is not a "silver bullet" that will significantly eliminate GHG emissions from heavy-duty trucks like the catalytic converter has for criteria pollutant emissions, significant GHG and fuel consumption reductions can be achieved through a combination of engine, vehicle system, and operational technologies.

The following sections will discuss technologies in relation to each of the proposed regulatory subcategories – Heavy-Duty Pickup Trucks and Vans, Heavy-Duty Engines, Class 7 and 8 Combination Tractors, Trailers, and Class 2b-8 Vocational Vehicles. In each of these sections, information on technological approaches, costs, and percent improvements is provided. Depending on the segment, the vehicle-level technologies available for consideration may include idle reduction, improved tire rolling resistance, improved transmissions, improved axles, weight reduction, improved accessories, and aerodynamic technologies. Depending on the segment, the engine-level technologies available for consideration may include friction reduction, variable valve timing, cylinder deactivation, turbocharging, downsizing, combustion optimization, aftertreatment optimization, and waste heat recovery. The agencies are not projecting that all of the technologies discussed in these sections would be used for compliance with the engine and vehicle standards, for reasons that are also discussed in each section. Nevertheless, the *potential* for there to be technologies other than those which form the basis for the compliance pathway set forth by the agencies, or which can be used in different combinations or penetration rates than that projected compliance pathway, is an important consideration in assessing the feasibility of the proposed standards. Summaries of all of the technologies, along with the corresponding costs, fuel consumption and GHG emissions improvement percentages are provided in this chapter. A summary of engine and vehicle technologies, effectiveness, and costs for HD pickup trucks and vans is provided in Chapter 2.5. Summaries of engine technologies, effectiveness, and costs are provided in Chapters 2.6 and 2.7. A summary of technologies, effectiveness, and costs for tractors is provided in Chapter 2.8. A summary of technologies, effectiveness, and costs for vocational vehicles is provided in Chapter 2.9. A summary of technologies, effectiveness, and costs for trailers is provided in Chapter 2.10. A detailed analysis of technology costs is found in Chapters 0 and 2.13.

EPA and NHTSA collected information on the cost and effectiveness of fuel consumption and CO_2 emission reducing technologies from several sources. The primary sources of information were the 2010 National Academy of Sciences report on Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles (NAS)[1], TIAX's assessment of technologies to support the NAS panel report (TIAX)[2], EPA's Heavy-Duty Lumped Parameter Model[3], the analysis conducted by NESCCAF, ICCT, Southwest Research Institute and TIAX for reducing fuel consumption of heavy-duty long haul combination tractors (NESCCAF/ICCT)[4], and the technology cost analysis conducted by ICF for EPA (ICF).[5] In addition, the agencies relied on NHTSA's technology assessment report under contract with SwRI and Tetra Tech.[6,7,8] In addition, the agencies used the vehicle simulation model (the Greenhouse gas Emissions Model or GEM) to quantify the effectiveness of various technologies on CO_2 emission and fuel consumption reductions in terms of vehicle performance as they are evaluated in determining compliance with the HD program. The simulation tool is described in draft RIA Chapter 4 in more detail.

2.2 Technology Principles – SI Engines

The engine technology principles described in this chapter for SI and CI engines are typically described as applying for gasoline and diesel-fueled engines, respectively. Even so, these technology principles generally also apply for engines powered by other fuels, including natural gas. In Section II of the preamble to these rules, the agencies describe regulatory provisions that differ between SI and CI engines. Technologies related to closed crankcases for natural gas engines are described below in Chapter 2.11 and in the Preamble Section II. The agencies describe technologies and test procedures related to minimizing evaporative emissions from natural gas fuel systems in Chapter 2.11 as well as in Section XI of the preamble to these rules. The agencies' approach in this document is to first describe the principles of how technologies can work for an engine, without specifying the type of vehicle into which it will be installed, or the test cycle over which it will be certified. Later, in Chapter 2.5, the agencies describe a subset of these technologies as they apply specifically to complete HD pickup trucks and vans. In Chapter 2.6, the agencies describe a subset of these technologies as they apply to SI engines intended for vocational vehicles.

2.2.1 **Engine Friction Reduction**

In addition to low friction lubricants, manufacturers can reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. The 2010 NAS Report, NESCCAF[9] and EEA[10] reports as well as confidential manufacturer data used in the light-duty vehicle rulemaking suggested a range of effectiveness for engine friction reduction to be between 1 to 3 percent. Reduced friction in bearings, valve trains, and the piston-to-liner interface would improve efficiency. Any friction reduction must be carefully developed to avoid issues with durability or performance capability.

2.2.2 **Variable Valve Timing**

Variable valve timing (VVT) classifies a family of valve-train designs that alter the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control the level of residual gases in the cylinder. VVT reduces pumping losses when the engine is lightly loaded by controlling valve timing closer to the optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used to alter (and optimize) the effective compression ratio where it is advantageous for certain engine operating modes (*e.g.*, in the Atkinson Cycle).

VVT has now become a widely adopted technology in the light duty fleet: in MY 2014, most of all new cars and light trucks had engines with some method of variable valve timing.[11] Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. Therefore, the degree of further improvement across the fleet is limited by the level of valvetrain technology already implemented on the vehicles. The three major types of VVT are listed below.

Each implementation of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as “camshaft phasing.” This phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

2.2.2.1 Coupled Cam Phasing for Overhead Valve (OHV) and Single Overhead Camshaft (SOHC) Engines

Valvetrains with coupled (or coordinated) cam phasing (CCP) can modify the timing of both the inlet valves and the exhaust valves an equal amount by varying the phasing of the camshaft across an engine’s range of operating speeds; also known as VVT. For engines configured as an overhead valve (OHV) or as a single overhead camshaft (SOHC) only one cam phaser is required per camshaft to achieve CCP.

Based on the heavy-duty Phase 1 vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent over average driving patterns.

2.2.2.2 Intake Cam Phasing (ICP) for Dual Overhead Camshaft Engines (DOHC)

Valvetrains with ICP, which is the simplest of the cam phasing technologies, can modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed. This requires the addition of a cam phaser on each bank of intake valves on the engine. An in-line 4-cylinder engine has one bank of intake valves, while V-configured engines have two banks of intake valves.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the heavy-duty 2014-2018 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 2 percent reduction in fuel consumption over average driving patterns, for this technology.

2.2.2.3 Dual Cam Phasing (DCP) for Dual Overhead Camshaft Engines (DOHC)

The most flexible VVT design is dual (independent) cam phasing, where the intake and exhaust valve opening and closing events are controlled independently. This option allows the option of controlling valve overlap, which can be used as an internal EGR strategy. At low engine loads, DCP creates a reduction in pumping losses, resulting in improved fuel consumption. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved depends on the residual tolerance of the combustion system. Additional improvements are observed at idle, where low valve overlap may result in improved combustion stability, potentially reducing idle fuel consumption. DCP requires two cam phasers on each bank of the engine.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the light-duty 2012-2016 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 3 percent reduction in fuel consumption over average driving patterns, for this technology.

2.2.2.4 Variable Valve Lift (VVL)

Controlling the lift of the valves provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVL into their fleets (Toyota, Honda, and BMW), but overall this technology is still available for most of the fleet. There are two major classifications of variable valve lift, described below:

2.2.2.5 Discrete Variable Valve Lift (DVVL)

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. By optimizing the cam profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. This increases the efficiency of the engine. These cam profiles consist of a low and a high-lift lobe, and may include an inert or blank lobe to incorporate cylinder deactivation (in the case of a 3-step DVVL system). DVVL is normally applied together with VVT control. DVVL is also known as Cam Profile Switching (CPS). DVVL is a mature technology in LD applications with low technical risk.

Based on the light-duty MY 2017-2025 final rule, previously-received confidential manufacturer data, 2015 NHTSA Technology Study, and report from the Northeast States Center for a Clean Air Future (NESCCAF), the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent over average driving patterns.

2.2.3 **Cylinder Deactivation**

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part cylinder" mode. Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently. Cylinder deactivation is less effective on heavily-loaded vehicles because they require more power and spend less time in areas of operation where only partial power is required. The technology also requires proper integration into the vehicles which is difficult in the vocational vehicle segment where often the engine is sold to a chassis manufacturer or body builder without knowing the type of transmission or axle used in the vehicle or the precise duty cycle of the vehicle. The cylinder deactivation requires fine tuning of the calibration as the engine moves into and out of deactivation mode to achieve acceptable NVH. Additionally, cylinder deactivation would be difficult to apply to vehicles with a manual transmission because it requires careful gear change control. NHTSA and EPA adjusted the 2017-2025 MY light-duty rule estimates using updated power to weight ratings of heavy-duty trucks and confidential business information and downwardly adjusted the effectiveness to 0 to 3 percent over average driving patterns for these vehicles to reflect the differences in drive cycle and operational opportunities compared to light-duty vehicles.

2.2.4 **Stoichiometric Gasoline Direct Injection (SGDI)**

Stoichiometric gasoline direct injection (SGDI) engines inject fuel at high pressure directly into the combustion chamber (rather than into the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures, and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance, and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers have recently introduced vehicles with SGDI engines, including GM and Ford, who have announced their plans to increase dramatically the number of SGDI engines in their vehicle portfolios.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of SGDI to be between 1 and 2 percent over average driving patterns.

2.2.5 **Turbocharging and Downsizing (TRBDS)**

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

Almost every major manufacturer currently markets a vehicle with some form of boosting. While boosting has been a common practice for increasing performance for several decades, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common “turbo lag”) while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios for example a very small displacement engine in a vehicle with significant curb weight, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of gasoline direct injection (GDI) systems with turbocharged engines and charge air cooling also reduces the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios. Ford's "EcoBoost" downsized, turbocharged GDI engines introduced on MY 2010 vehicles allow the replacement of V8 engines with V6 engines with improved in 0-60 mph acceleration and with fuel economy improvements of up to 12 percent as documented in their technical paper.[12]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines. Confidential manufacturer data suggest an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system;[13] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[14] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[15] These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

The agencies reviewed estimates from the 2017-2025 final light-duty rule, the TSD, and existing public literature. The previous estimate from the MYs 2017-2025 suggested a 12 to 14 percent effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over baseline fixed-valve engines, similar to the estimate for Ford's EcoBoost engine, which is already in LD production. Additionally, the agencies analyzed Ricardo vehicle simulation data and the 2015 NHTSA Technology Study for various turbocharged engine packages.

2.3 Technology Principles – CI Engines

2.3.1 Low Temperature Exhaust Gas Recirculation

Most LHDD, MHDD, and HHDD engines sold in the U.S. market today use cooled EGR, in which part of the exhaust gas is routed through a cooler (rejecting energy to the engine coolant) before being returned to the engine intake manifold. EGR is a technology employed to reduce peak combustion temperatures and thus NO_X. Low-temperature EGR uses a larger or secondary EGR cooler to achieve lower intake charge temperatures, which tend to further reduce NO_X formation. For a given NO_X requirement, low-temperature EGR can allow changes such as more advanced injection timing that would increase engine efficiency slightly more than one percent. Because low-temperature EGR reduces the engine's exhaust temperature, it has not been considered as part of a technology package that also includes exhaust energy recovery systems such as turbocompounding or a bottoming cycle.

2.3.2 Combustion System Optimization

Improvements on the fuel injection system that allow more flexible fuel injection capability with higher injection pressure can improve engine fuel efficiency, while maintaining the same emission level. Combustion system optimization, featuring piston bowl, injector tip and the number of holes, in conjunction with the advanced fuel injection system, is able to further improve engine performance and fuel efficiency. Manufacturers have been working to improve engines these areas for some time. At this point, all engine manufacturers have substantial development efforts underway that we project would be translated into production in the near future. Some examples include the combustion development programs conducted by Cummins[16], Detroit Diesel[17], and Navistar[18] funded by Department of Energy as part of Supertruck program. These manufacturers found the improvement due to combustion alone during this program was 1 to 2 percent. While their findings are still more towards research environment, specifically targeting one optimal operating point, the results of these research programs do support the possibility that some of technologies they are developing could be applied to production in the time frame of 2027. The agencies have determined that it is feasible that fuel consumption and CO_2 emissions could be reduced by as much as 1.0 percent in the agencies' certification cycles in the 2027 time frame through the use of these technologies.

Some technologies were evaluated but not included in the agencies' technical feasibility analysis for the Phase 2 regulation since the agencies do not anticipate these technologies will be commercially available by 2027. For example, alternative combustion processes such as homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI), low-temperature combustion (LTI), and reactivity controlled compression ignition (RCCI) technologies were not included in the feasibility analysis for Phase 2. While these technologies show good indicated thermal efficiency, fuel savings over the entire range of engine operation is still a major challenge. At the current level of development it is not clear that the technologies will be in commercial production by 2027. This, however, does not preclude the use of these technologies for compliance should manufacturers develop and commercialize these alternative combustion or other approaches.

2.3.3 Model Based Control

Another important area of potential improvement is advanced engine control incorporating model based calibration to reduce losses of control during transient operation. Improvements in computing power and speed would make it possible to use much more sophisticated algorithms that are more predictive than today's controls. Because such controls are only beneficial during transient operation, they would reduce emissions over the Federal Test Procedure (FTP) cycle, but not over the Supplemental Emission Test (SET) cycle. Detroit Diesel introduced the next generation model based control concept, achieving 4 percent thermal efficiency improvement while simultaneously reducing emissions in transient operations in their earlier report.[19] More recently, this model based control technology was put into their one of vehicles for final demonstration under DOE's Supertruck program.[20] Their model based concept features a series of real time optimizers with multiple inputs and multiple outputs. This controller contains many physical based models for engine and aftertreatment. It produces fully transient engine performance and emissions predictions in a real-time manner. Although we do not project that this control concept would be in 2017 production, it would be a realistic estimate that this type of real time model control could be in production during the Phase 2 time frame, thus significantly improving engine fuel economy.

2.3.4 **Turbocharging System**

Many advanced turbocharger technologies can be potentially added into production in the time frame between 2021 and 2027 and some of them are already in production, such as mechanical or electric turbocompound, more efficiency variable geometry turbine, and Detroit Diesel patented asymmetric turbocharger. A turbocompound system extracts energy from the exhaust to provide additional power. Mechanical turbocompounding includes a power turbine located downstream of the turbine which in turn is connected to the crankshaft to supply additional power. On-highway demonstrations of this technology began in the early 1980s. It has been first used in heavy duty production by Detroit Diesel for their DD15 and DD16 engines and they claim a 3 to 5 percent fuel consumption reduction due to the system.[21] Results are duty cycle dependent, and require significant time at high load to see a fuel efficiency improvement. Light load factor vehicles can expect little or no benefit. Volvo reports two to four percent fuel consumption improvement in line haul applications, which would be likely in production even before 2020.[22]

Electric turbo-compound is another potential area that can improve engine brake efficiency. These are attained through better vehicle integration and lower backpressure impacts. Since the electric power turbine speed is no longer linked to crankshaft speed, this allows more efficient operation of the turbine. Navistar reports on the order of a 1 to 1.5 percent efficiency improvement over mechanical turbocompound systems at 0.5 to 0.7 gm/hp-hr engine-out NO_X levels, but dropping at lower engine-out NO_X.[23] However, this concept may not work well with lower engine out NO_X as indicated in this report, showing zero benefit is reported at 0.3 to 0.4 gm/hp-hr engine-out NO_X, due to lower available temperature. Navistar reports a 1.6 percent fuel efficiency improvement, again as compared to a mechanical turbocompound system.[24]

Two-stage turbocharger technology has been used in production by Navistar and other manufacturers. Ford's new developed 6.7L diesel engine features a twin-compressor turbocharger. Higher boost with wider range of operations and higher efficiency can further enhance engine performance, thus fuel economy. It is expected that this type of technology will continue to be improved by better matching with system and developing higher compressor and turbine efficiency.

Furthermore, improved turbocharger efficiency when combined with turbocompounding was shown in the SwRI study to reduce fuel consumption while maintaining criteria emissions limits. Findings show that there is limited scope for improved turbocharger efficiency on engines which do not use turbocompound, because an increase in turbocharger efficiency would result in reduced or eliminated EGR flow which in turn would cause the engine to exceed NOx emissions requirements.

2.3.5 Engine Breathing System

Various high efficiency air handling (air and exhaust transport) processes could be produced in the 2020 and 2024 time frame. To maximize the efficiency of such processes, induction systems may be improved by manufacturing more efficiently designed flow paths (including those associated with air cleaners, chambers, conduit, mass air flow sensors and intake manifolds) and by designing such systems for improved thermal control. Improved turbocharging and air handling systems must include higher efficiency EGR systems and intercoolers that reduce frictional pressure loss while maximizing the ability to thermally control induction air and EGR. EGR systems that often rely upon an adverse pressure gradient (exhaust manifold pressures greater than intake manifold pressures) must be reconsidered and their adverse pressure gradients minimized. "Hybrid" EGR strategies which rely upon pressure gradients and EGR pumps may provide pathways for improvement. Other components that offer opportunities for improved flow efficiency include cylinder heads, ports and exhaust manifolds to further reduce pumping losses. Cummins reports 1.4 percent through optimization.[25] Detroit Diesel projects a two percent fuel efficiency improvement through air handling system development.[26] Navistar predicts almost four percent through a combination of variable intake valve closing timing (IVC), turbocharger efficiency and match improvements.[24] A few plots in this reference show another four percent, but these are not explained.

Variable air breathing systems such as variable valve actuation may provide additional gains at different loads and speeds. The primary gain in diesel engines is achieved by varying the EVO event versus engine speed and load, in conjunction with turbocharger optimization to minimize blowdown losses. Navistar reports a 1.25 percent fuel consumption improvement.[23] Again, all these reference points are referred to a single optimal point conducted at DOE Supertruck program.

2.3.6 Engine Parasitic and Friction Reduction

Engine parasitic and friction reduction is another key technical area that can be further improved in production moving to the 2020 and 2027 time frame. Reduced friction in bearings, valve trains, and the piston-to-liner interface can improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. The piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offers opportunities for friction reduction. Use of more advanced oil lubricant that could be available for production in the future can also play a key role in reducing friction. Any friction reduction must be carefully developed to avoid issues with durability or performance capability. Lube pump as well water pump are another areas that improve efficiency. Navistar identifies a combined improvement of up to two percent through reduced bearing friction, reduced piston and ring friction, and unspecified lube pump improvements.[27] In his 2012 paper he reports 5.5 percent through a combination of friction reduction and both lube and cooling system improvements.[23] Later in the same presentation he specifies 0.45 percent demonstrated through water pump improvements and 0.3 percent through lube pump improvements. The total number of 5.5 percent seems optimistic, even for a single optimal point. Cummins reports a combined number of 3 percent.[25]. Detroit Diesel reports a combined number of two percent, with 0.5 percent coming from improved water pump efficiency. [26] Navistar shows a 0.9 percent benefit for a variable speed water pump and variable displacement oil pump; piston/ring/liner friction reduction as 0.5 percent; bearing friction reduction as 0.6 percent.[24] In addition, Federal-Mogul recently announced new piston ring coatings that can lead to a 20 percent reduction in engine friction and looking to the future sees an opportunity to reduce friction by an additional 30 percent, equivalent to 1.2 percent reduction in brake specific fuel consumption at road load conditions.[28] It should be noted that water pump improvements include both pump efficiency improvement and variable speed or on/off controls. Lube pump improvements are primarily achieved using variable displacement pumps and may also include efficiency improvement. All of these results shown in this paragraph are demonstrated through DOE Supertruck program under single optimal point.

2.3.7 **Integrated Aftertreatment System**

All manufacturers now use diesel particulate filter (DPF) to reduce particulate matter (PM) and use SCR to reduce NO_X emissions, and these types of technologies are likely to be deployed for many years to come. Three areas are considered to improve integrated aftertreament systems. The first is to have better combustion system optimization through increased aftertreatment efficiency. The second is to reduce backpressure through further development of the devices themselves. The third is to reduce ammonia slip out of SCR during transient operation, thus reducing the urea consumption. This is in turn translated into reduced fuel consumption. Navistar reports a seven to eight percent improvement projected through a combination of higher cylinder pressure, injection optimization, and engine/aftertreatment optimization.[23] Cummins reports a 0.5 percent improvement through improved aftertreatment flow (catalyst size optimization and improved NO_X surface utilization).[25] Detroit Diesel projects a two percent fuel efficiency improvement through reduced EGR (thinner wall DPF, improved SCR cell density, and catalyst material optimization).[26]

2.3.8 **Engine Downsizing**

Engine downsizing can be more effective if it is combined with the down speeding. This is due to increased vehicle efficiency resulting in lower power demand. This lower power demand shifts the vehicle operating points to lower load zones, which moves the engine away from some of the optimum operation points. In order to compensate for this loss, down speeding allows the engine to move back into the optimum operating points resulting in reduced fuel consumption. Increasing power density by reducing the engine size allow the vehicle operating points move back to the optimum operating points, thus further improving fuel economy. Both Detroit Diesel and Volvo show the same methodology of how downsizing should be properly used.[29,30] Detroit Diesel also shows that engine downsizing can reduce the friction due to smaller surface area as opposed to bigger bore engine.[26]

2.3.9 **Waste Heat Recovery**

Organic Rankine Cycle waste heat recovery (WHR) systems have been studied for many years. The agencies’ overall assessment of WHR as a fuel saving technology is that it offers great promise in the long term. However, it would take several years to develop, and initially, it would be viable primarily in line-haul applications. The agencies recognize the many challenges that would need to be overcome, but believe with enough time and development effort, this can be done. The discussion below highlights these challenges to show why the agencies currently believe WHR would not achieve a substantial market penetration until 2027.

The basic approach of these systems is to use engine exhaust waste heat from multiple sources to evaporate a working fluid through a heat exchanger, which is then passed through a turbine or equivalent expander to create mechanical or electrical power. The working fluid is then condensed back to the fluid tank, and pulled back to the flow circuit through a pump to continue the cycle. With support of the Department of Energy, three major engine and vehicle manufacturers have developed the WHR technology under the Supertruck program. Cummins' WHR system is based on an organic Rankine cycle using refrigerant as the working fluid.[31,32] The system recovers heat from the EGR cooler, as well as from the exhaust gas downstream of the aftertreatment system. It converts that heat to power through a mechanical gear train coupled to the engine output shaft. Some iterations of the system also sought gains from low-temperature coolant and lubricant heat rejection via a parallel loop. The system includes a recuperator that transfers post-turbine energy back into the working fluid loop prior to the condenser. This recuperator reduces condenser heat rejection requirements and improves overall system efficiency. Volvo has developed a similar system to Cummins' with variations in terms of hardware components, but uses ethanol as the working fluid instead of a refrigerant.[33] Daimler, on the other hand, has developed a different system to recover heat from the exhaust gas using an electrical generator to provide power to charge a high-voltage battery, where this battery system is primarily used to drive a hybrid system. Daimler uses ethanol as the working fluid, similar to Volvo's system.

Pre-prototype WHR systems have proven to be very efficient under right conditions. In demonstrations where operation occurred at a single optimal engine operating point, Cummins reports potential efficiency gains from WHR on the order of 2.8 percent points from the engine without WHR[31]. Volvo reports around 2.5 percent points[33]. Daimler reports 2.3 percent points.[29] All of these manufacturers use the type of WHR just described (including both mechanisms of mechanical work transfer to crankshaft and electric generator) in vehicle demonstrations for the DOE Supertruck program. It is important to note that all of these WHR systems are still in the pre-prototype stage of research and development. Despite the promising performance of pre-prototype WHR systems, the cost and complexity of these packages from Cummins, Volvo and Daimler remain high. The agencies believe manufacturers will improve these systems over time just as they have for other advanced technologies that initially had high cost and complexity at a comparable stage of development.

The technology also poses issues relating to package size and transient response challenges. Thus, the agencies believe that WHR would be less effective in urban traffic and would most likely be applied to line haul vehicles, consistent with the technology path on which the proposed standards are premised.

WHR may offer the benefit of replacing the EGR cooler and decrease cooling system heat rejection requirements by converting some heat into work. To the extent that WHR systems use exhaust heat, they may increase the overall cooling system heat rejection requirement, thus increasing radiator size, which can have negative impacts on cooling fan power needs, as well as on vehicle aerodynamics. Significant challenges could arise if the space under the vehicle hood happens to be tight, leaving little or no room for increased radiator size, which would necessitate a redesign of the vehicle front face, sacrificing potential aerodynamic improvements. This issue becomes more challenging for those truck cooling systems that are already at cooling capacity design limits.

Current pre-prototype systems are heavy, estimated to be on the order of 300-500 lbs depending on system design. Without time to optimize designs, any efforts to reduce weight by simply reducing the size of the key components, such as boilers and condensers, would likely negatively reduce the system efficiency. However, with enough lead time, the agencies believe manufacturers may be able to improve materials and designs to reduce overall system weight without compromising efficiency.

Manufacturers have not yet arrived at a consensus on which working fluid(s) to be used in WHR systems to balance concerns regarding performance, global warming potential (GWP), and safety. Current working fluids have a high GWP (conventional refrigerant), are expensive (low GWP refrigerant), are hazardous (ammonia, etc.), are flammable (ethanol/methanol), or can freeze (water). One of the challenges is determining how to seal the working fluid properly under the vacuum condition with high temperature to avoid safety issues for flammable/hazardous working fluids. Addressing leaks would also be an important issue with respect to greenhouse gas emission for a high GWP working fluid. Because of these challenges, choosing a working fluid will be an important factor for system safety, efficiency, and overall production viability.

Other key challenging issues in the WHR system are its reliability, durability, and market acceptance. Durability concerns that have been raised include: boiler fouling and cracking issues associated with high thermal gradients, thermal shock, condenser fouling, and various sensor and actuator durability under harsh temperature and pressure conditions. It can be reasonably estimated that of the current WHR systems under development by the major manufacturers consists of at least two hundred parts including all major components, such as expanders, boilers, condensers, and fluid pumps, together with many fasteners, wiring cables, sensors, actuators, and piping. Determining overall system efficacy and reliability involves rigorous testing in support of comprehensive Failure Modes and Effects Analysis (FEMA). These parts, as well as the entire WHR system as a whole, must undergo severe winter and summer tests. Multiple trucks equipped with the same WHR system must be run on the road, accumulating multiple millions of miles. During these tests, all failures must be recorded, which are associated with specific failure modes or error codes. Root causes must be determined. Warranty costs for each failure mode based on the part cost and labor must be assigned. Due to the large number of components of WHR, some of the failure modes might not be identified during the road tests even with multiple extreme weather tests. It would be a high risk for any manufacturers to put their new technology into the market without careful WHR system validations and proof of on-the-road tests. Similarly, purchasers might be unlikely to risk early adoption of such complex technology if deployed prematurely (without substantial testing) due to significant concerns and costs related to potential down time.

Based on the literature and preceding discussion, WHR technology can be characterized as being in the technology demonstration stage for purposes such as the DOE Supertruck program. Even though a few trucks with WHR technology have been tested on the road,[33,34,35] many of the components used in the trucks and product-acceptable packaging are still years away from production. Figure 2-1 shows a generic form of product process flow. As can be seen from this figure, it would take 5-15 years from applied research/development to a prototype depending on the complexity of the technology. During the prototype stage, all prototype components must be available and extensive engine and vehicle tests with WHR must be conducted. The production start-up phase would follow. After that, significant efforts must be made from a prototype to a commercial product, which typically takes about five years for a complex system like WHR. During this approximate five-year period, multiple vehicles should go through all weather condition tests, which would help to detect possible failure modes and determine warranty cost associated with them. In addition, long lead-time parts and tools should be identified; market launch and initial results on operating stability should be completed. Furthermore, designs should be released to production, and all product components should be available. Finally, production parts on customer fleets and all weather road testing should be verified before finally launching production, and distributing parts to the vehicle service network for maintenance and repair should be ready.

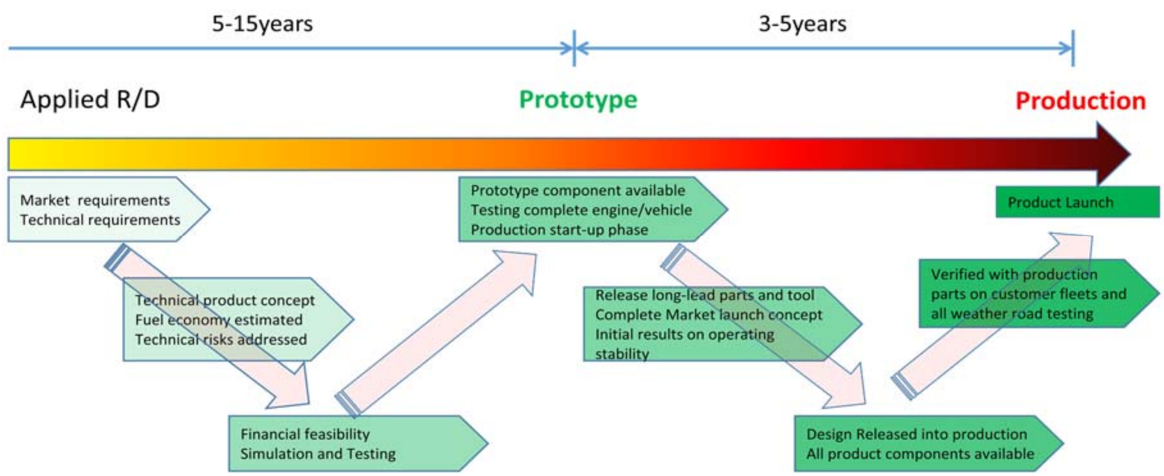


Figure 2-1 Product Process Flow

The standards the agencies are proposing can provide an effective incentive for manufacturers to reach commercial product stage earlier than would otherwise occur. It can motivate manufacturers to shorten the period for advancing from a complicated prototype system to a commercial product. It can also help to ensure the market penetration after launching a product. Nevertheless, in order for WHR to be produced commercially, several things are needed. First, it is critical to optimize the WHR package volume, cooling capability, and aero drag at typical cruise speeds on highway since the most significant benefits of WHR technology would be in line-haul applications. Removal of the exhaust heat exchangers located at the exhaust pipe could reduce the total system volume and weight. Working fluids could be selected with reasonable low GWP and high performance potential. One approach could be to put a few hundred trucks into fleets for trial in the next several years, so that a comprehensive FEMA can be thoroughly identified and warranty cost analyses can be more precisely conducted before launching into full volume production. Manufacturers have shown in the past that a robust FEMA process can address most problems before a technology is more widely introduced. Therefore, the lead time appears to be one of the most noticeable constraints. We believe that all the issues and hurdles discussed could be resolved with adequate lead time.

2.4 Technology Principles - Vehicles

2.4.1 Aerodynamics

The aerodynamic efficiency of heavy-duty vehicles has gained increasing interest in recent years as fuel prices, competitive freight markets, and overall environmental awareness has focused owners and operators on getting as much useful work out of every gallon of diesel fuel as possible. Up to 25 percent of the fuel consumed by a line-haul tractor traveling at highway speeds is used to overcome aerodynamic drag forces, making aerodynamic drag a significant contributor to a Class 7 or 8 tractor's GHG emissions and fuel consumption.[36] Because aerodynamic drag varies by the square of the vehicle speed, small changes in the tractor aerodynamics can have significant impacts on GHG emissions and fuel efficiency of that vehicle. With much of their driving at highway speed, the benefits of reduced aerodynamic drag for Class 7 or 8 tractors can be significant.[37]

The common measure of aerodynamic efficiency is the coefficient of drag (Cd). The aerodynamic drag force (*i.e.*, the force the vehicle must overcome due to air) is a function of the Cd, the area presented to the wind (*i.e.*, the projected area perpendicular to the direction of travel or frontal area), and the square of the vehicle speed. Cd values for today's line-haul fleet typically range from greater than 0.80 for a classic body tractor to approximately 0.58 for tractors that incorporate a full package of widely, commercially available aerodynamic features on both the tractor and trailer.

While designers of heavy-duty vehicles and aftermarket products try to aerodynamically streamline heavy-duty vehicles, there are some challenges. Aerodynamic design must meet practical and safety needs such as providing for physical access and visual inspections of vehicle equipment. Since weight added to the vehicle can impact its overall fuel efficiency, GHG emissions and, in limited cases, the amount of freight the vehicle can carry, aerodynamic design and devices must balance the aerodynamic benefit with the contribution to the vehicle weight. In addition, aerodynamic designs and devices must balance being as light and streamlined as possible with in-use application durability to withstand the rigors a working freight vehicle encounters while traveling or loading and unloading.

However, there are some macro and micro scale techniques that can be employed to reduce vehicle drag such as reducing vehicle size, especially, the frontal area; smoothing the shape to make it more aerodynamically efficient, thus reducing the Cd; and/or re-directing air to prevent entry into areas of high drag (e.g., wheel wells) or to maintain smooth air flow in certain areas of the vehicle. Reducing the size of the vehicle can reduce the frontal area; which reduces the pressure building up on the lateral surface area exposed to the airflow. Improving the vehicle shape may include revising the fore components of the vehicle such as rearward canting/raking or smoothing/rounding the edges of the front end components (e.g., bumper, headlights, windshield, hood, cab, mirrors) or integrating the components at key interfaces (e.g., windshield/glass to sheet metal) to alleviate fore vehicle drag. Finally, redirecting the air to prevent areas of low pressure and slow moving air; thus eliminating areas where air builds creating turbulent vortices and increasing drag. Techniques such as blocking gaps in the sheet metal, ducting of components, shaping or extending sheet metal to reduce flow separation and turbulence are methods being considered to direct air from areas of high drag (e.g., underbody, tractor-trailer gap, underbody and/or rear of trailer).

The issue for heavy-duty vehicles is that the cab and/or passenger compartment is designed for a specific purpose such as accommodating an inline cylinder engine or allowing for clear visibility given the size of the vehicle. Consequently, a reduction in vehicle size and/or frontal area may not be realistic for some applications. This also may necessitate an expensive, ground-up vehicle redesign and, with a tractor model lifecycle of up to 10 years, may mean that a mid-cycle tractor design is not feasible. In addition, the frontal area is also defined by the shape behind the cab so reducing just the cab frontal area/size reduction may not be effective. Thus, this approach is something that may occur in a long-term timeframe of 10-15 years from today.

Instead, most heavy-duty tractor manufacturers have explored, or are exploring, the latter two techniques in the short-term. Compared to previous generation tractors, every high roof tractor today has a roof fairing directing air over the top of the cab, fuel tank/chassis fairings that prevent side air from flowing underneath the vehicle, and cab side extenders that prevent flow from being trapped in the tractor-trailer gap. As a compliance strategy for HD Phase 1, many manufacturers refined the aerodynamic shape of their front end components and other components (e.g., curving or further extending side extenders) resulting in efficiency difference between pre- and post-HD Phase 1, model year tractor aerodynamic performance. Further, manufacturers have developed new tractor designs that are taking advantage of sealing gaps in sheet metal to redirect the flow and introducing some hard edges to induce turbulent flow on certain surfaces to prevent premature flow separation and downstream turbulent flow. For HD Phase 2, we anticipate manufacturers would continue to apply these techniques across their models and continue to explore refinements and re-designs in other areas of the tractor.

In addition to tractor improvements, there has been growth in the market for trailer aerodynamic devices encouraged by our successful SmartWay Partnership and Technology Verification Program. These devices function similar to components on the tractor by preventing air intrusion into areas of the trailer prone to high aerodynamic drag including the tractor-trailer gap, the trailer underbody, and the rear of the trailer as shown in Figure 2-2 and Figure 2-3 below.

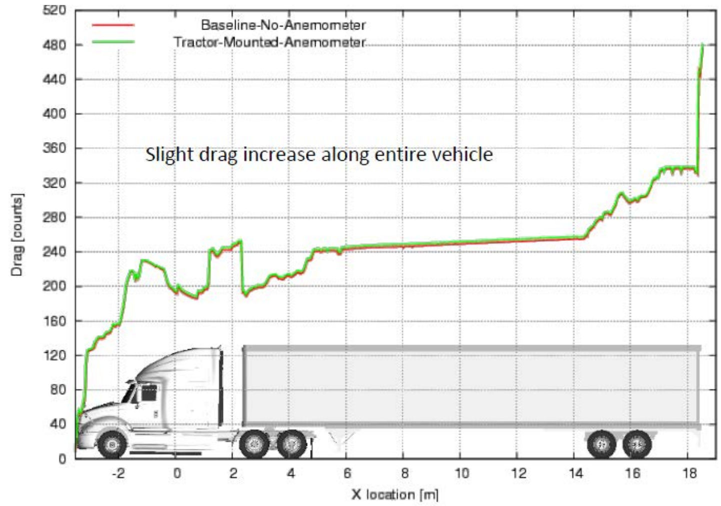


Figure 2-2 Progression of total drag along a typical line-haul tractor-trailer vehicle

Figure 2-3 Low pressure regions contributing to aerodynamic drag along a typical line-haul tractor-trailer vehicle

To address this, trailer front/nose devices are being used to round the front end and edges of the trailer while also reducing the tractor-trailer gap; skirts on the side of the trailer prevent air entering the underside of the trailer and becoming turbulent on the various underbody structure components; and trailer aft/rear treatments reduce separation of air flow of the rear edge of the trailer to reduce the large wake of turbulent air behind the trailer. Based on current SmartWay Technology Verification, these devices can reduce fuel consumption from one to nine percent, depending on the technology, and if it is employed individually or in combination.

As a result, we believe there is an opportunity within HD Phase 2 to promote continual improvement of tractor aerodynamics and capitalize on the potential improvement that aerodynamic trailer devices can provide for trailers, and overall combination tractor-trailer efficiency.

2.4.2 **Advanced Aerodynamic Concepts**

For HD Phase 2, we are proposing standards that would be fully phased in by the 2027 model year. This represents a significant amount of time from today's action. As such, it is possible that by the time the Phase 2 standards are implemented, the state of heavy-duty aerodynamic technology and performance may have significantly advanced. Thus, there may be a need to have standards to adequately address future tractor-trailer aerodynamic advances.

Accordingly, we are considering aerodynamic concepts that can achieve aerodynamic performance beyond that of the HD Phase 2 aerodynamic standards. There are many approaches applicable to today's tractors and trailers that are not considered in the HD Phase 2 aerodynamic standards and advanced research aimed at creating a completely new design paradigm for tractor-trailer combinations.

The advanced aerodynamic standards would not be required but would rather serve as a marker for future aerodynamic concepts and/or as a metric for HD Phase 2 advanced/innovative aerodynamic technologies.

2.4.2.1 Aerodynamic Improvements to Current Tractor-Trailer Combinations Based on Existing Technology

2.4.2.1.1 ***Manufacturer Commercial Initiatives***

In order to anticipate technology advancement, it is important to benchmark current technology improvements based on today's tractors and trailers. A number of Class 8 tractor OEM's have incorporated the technologies requested by their customers to improve fuel economy and to meet the HD Phase 1 standards. These technologies include side skirts, boat tails and roof fairings as well as some driver monitoring tools. Recently Jack Roberts released an article on the internet titled: "Photo, video: Western Star introduces re-designed on-highway tractor." [38]

Figure 2-4 Pictures of the Western Star Class 8 Tractors

In addition to providing photos and videos of Western Star's redesigned on-highway tractor, the article describes a multitude of new features that define the new tractor. These features include:

- A new sweptback four piece bumper with an under bumper valance that contributes to aerodynamic efficiency.
- New halogen headlights that are optimized for aerodynamic performance and excellent visibility.
- A state-of-the-art visor specifically engineered to work with the impressive slope in the hood's rear air ramp to direct airflow over the cab without an aerodynamic penalty.
- Roof and cab fairings that sweep back for tighter trailer gap and help direct air flow over and around the trailer.
- Optional chassis side fairings that reduce drag by up to 6 percent while still providing easy access to batteries and DEF tank.
- The Western Star Twin Force dual air intake, which feeds a massive centrally mounted air filter to improve efficiency.

This example demonstrates that manufacturers are continuing to find ways to improve tractors and are continually exploring concepts, such as those in used in the SuperTruck initiative, to improve commercially-available products.

2.4.2.1.2 ***Supplier Research: SABIC Roof Fairing Technology and Manufacturing***

Developments in aerodynamics have long been assumed to yield advancements in vehicle fuel efficiency. SABIC Innovative Plastics US LLC (SABIC) evaluated a variety of injection moldable thermoplastic roof fairing designs for a heavy tractor day cab to quantify efficiencies that could be obtained through advanced aerodynamics. Computational Fluid Dynamic (CFD) modeling was performed by Exa Corporation, an industry recognized leader in CFD. Multiple designs exhibited significant reductions in drag compared to a baseline roof fairing (Figure 1 of Figure 2-5). The baseline represented a top performing roof fairing on the market today. The best performing SABIC concept (Figure 2) achieved a 5.8 percent reduction in drag and fuel use compared to the baseline. Under the well-established 2:1 relationship between delta drag and fuel use, the fuel efficiency improved by nearly 3 percent from the baseline design.

The design concept optimized the shape to manage the airflow over the vehicle and enable reduced drag and increased fuel economy. Air channels – developed for injection molding processes – limit the air stagnation on the front of the trailer as well as accelerate and control the direction of the air flow. This innovative concept has been validated using state of the art CFD methods. On vehicle tests are suggested to validate findings from these studies. (from Matthew D. Marks, Senior Business Manager, Regulatory Automotive and Mass Transportation, November 14, 2014).

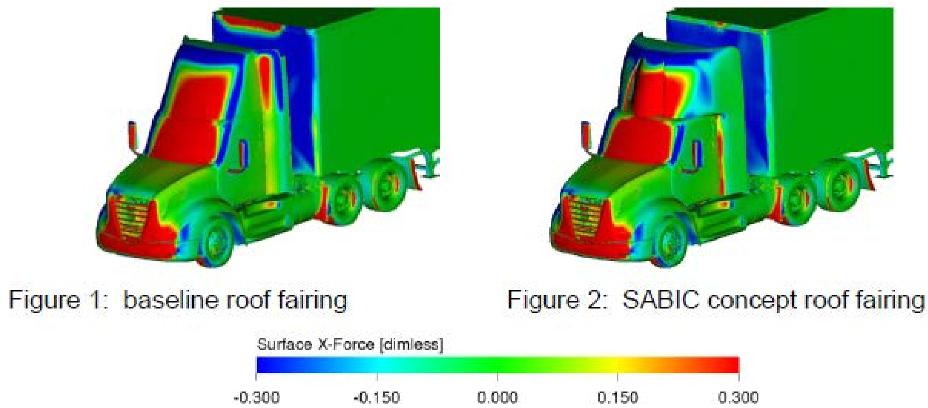


Figure 2-5 Surface X-Force (dimensionless) on Baseline and SABIC Concept Roof Fairing

Aerodynamic (surface) force is the force exerted on a body whenever there is a relative velocity between the body and the air. These plots represent this force in the direction of the vehicle travel at highway speeds. Red indicates a 'pushing' of the vehicle rearward, while blue indicates a 'pulling' of the vehicle forward.

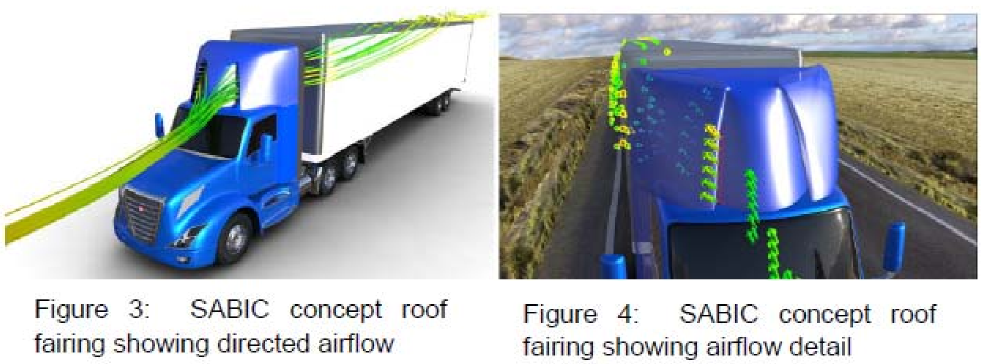


Figure 2-6 SABIC Concept Roof Fairing Operation

We are currently coordinating with SABIC on future efforts to determine feasibility and capability of this concept on additional areas of the tractor (e.g., bumper, hood, fuel tank/chassis skirt fairings, cab side extenders).

2.4.2.1.3 *HD Phase 1 Research: External Active Grille Shutter Potential on Heavy-Duty Tractors*

During HD Phase 1 aerodynamic assessment, we looked at several trends to understand some of the aerodynamic trends such as removal of tractor chassis fairings and side extenders, different tractor-trailer gap widths, and different trailer leading edge radii. However, one trend of particular relevance to advanced aerodynamic improvements for current tractors is the case of open versus closed grille.

We evaluated the open vs. closed grille trend in the full and reduced scale wind tunnel. Below in Figure 3-7 is picture of a 1/8th scale tractor model in the reduced scale wind tunnel with the grille covered with aluminum tape to simulate a fully closed grille.

Figure 2-7 Photo of 1/8th scale model of a tractor with the front, external grille covered with aluminum tape to simulate a closed grill configuration.

Below in Table 2-1 and Table 2-2 are the results of our open versus closed grille evaluations in the full and reduced scale wind tunnel separately. The tables provide the deltas for an open grille C_D minus the closed grille C_D; where the C_Ds have been corrected for blockage, in the case of the full scale wind tunnel, and normalized for differences in measured frontal area between the full and reduced scale wind tunnels using a nominal frontal area of 10.4 m^2 (111.95 in^2). For the full scale wind tunnel, only one tractor OEM was tested. In contrast, for the reduced scale wind tunnel, three tractor OEMs were tested.

Table 2-1 Full Scale Wind Tunnel Results for Open verses Close Grille Configurations

TRACTOR MODEL	DELTA WACD @55MPH	% DELTA CD VS. OPEN GRILLE CD
1	0.003	0.60%

Table 2-2 Reduced Scale Wind Tunnel Results for Open versus Close Grille Configurations

TRACTOR MODEL	DELTA WACD @55MPH	% DELTA CD VS. OPEN GRILLE CD
A	0.010	1.69%
B	0.012	1.89%
C	0.009	1.45%

Based on the data in these tables, there is a potential wind-average drag improvement of 0.6 percent to 1.45 percent from closing off the external, front grille of the tractor. This indicates the potential of active grille shutter systems on heavy-duty tractors. These systems are currently being applied on light duty vehicles behind the external grille to improve aerodynamics.

However, a recent SAE paper determined that the optimal position for active grille shutter systems was the external grille flush with the vehicle sheet metal.[39] This technique could be implemented on the external grille designs for current-design, heavy-duty tractors as well.

2.4.2.1.4 *National Research Council of Canada Historical Research on Improving Heavy-Duty Tractors*

The National Research Council of Canada (NRC-Can) performed an assessment of the drag benefit or detriment of various tractor components[40] and found the following in Table 2-3.

Table 2-3 Reduced Scale Wind Tunnel Results for Open versus Close Grille Configurations

COMPONENT	DELTA WACD
OEM Side Mirrors	-0.0156
OEM Fender Mirrors	-0.0098
Wheel Covers (Tractor and Trailer)	0.0020
Tractor Drive Axle Wrap-Around Splash Guards	0.0049
Roof Fairing Rear-Edge Filler	0.0137

Based on this table, there is the potential to improve tractor aerodynamics by 206 counts (0.0206 WAC_D) with the addition of wheel covers, drive axle wrap around splash guards, and roof fairing rear edge filler, and up to 460 counts (0.0460) if the OEM side and fender mirrors are replaced with a camera system, as suggested by the study, and combined with the wheel covers, drive axle wrap around splash guards, and roof fairing rear edge filler. Therefore, considering the current wind-average drag performance of current heavy-duty tractors, this study demonstrates the possibility to improve tractors an additional ~1 percent with some simple changes.

2.4.2.2 Aerodynamic Improvements to Current Tractor-Trailer Combinations Based on Complete Vehicle Redesign

This section contains summaries of ongoing work from various DOE efforts as well as individual efforts such as Airflow Truck Company to develop improved aerodynamic Class 8 vehicles. In addition to aerodynamics, there are other technologies such as driver awareness and ability to drive for maximum fuel economy with increased aerodynamics. Overall it is expected that the research being performed over the next year or two will reveal drastic improvements in C_dA and fuel economy. DOE's Lawrence Livermore National Laboratory is also looking at the aerodynamics of tankers.

2.4.2.2.1 *Collaborative, Government-Industry Advanced Aerodynamic Research: SuperTruck Program*

DOE's SuperTruck project is one of several initiatives that are part of the 21st Century Truck Partnership. The partnership is a public-private initiative to stimulate innovation in the trucking industry through sponsorship from government agencies, companies, national laboratories and universities. DOE's Vehicle Technologies Program provided matching funds to the program.

Cummins, Peterbilt and their program partners invested $38.8 million in private funds for the first four years of the project with additional funding provided for future research beyond 2014.

The goal of the SuperTruck Initiative was to develop a tractor that could meet or exceed 10 mpg – where tractors at this point are averaging between 5.5 and 6.5 mpg. Advances in engines, aerodynamics and more helped the tractor project increase its fuel economy. The SuperTruck objectives included development and demonstration of a highly efficient and clean diesel engine, an advanced waste heat recovery system, an aerodynamic tractor and trailer combination and a lithium ion battery auxiliary power unit, to reduce engine idling. Eaton Corp, also part of the Cummins-Peterbilt SuperTruck project team, contributed technologies including the design, development and prototyping of an advanced automated transmission that facilitated reduced engine-operating speeds. Cummins and Eaton jointly designed shift schedules and other features to yield further improved fuel efficiency.

Details of the SuperTruck that achieved 10.7 mpg are in video on the todaystrucking.com website and are presented in four videos.[41] Aerodynamic features of the tractor include the following: airflow into the engine compartment (through the front bumper, through the radiator and under the vehicle), less clearance between the road and the bottom of the tractor (rubber skirt under steps), close gaps on tractor/trailer (between hood and bumper, etc.), minimized gap between the trailer and tractor with a ball and socket design, full trailer skirt, roof fairing, smaller mirrors, minimized gap between wheels and wheel wells, wheel covers, boat tail, air foil on rear bumper design, single wide tires, and perforated mud flaps that allow air to bypass through them and reduce drag. A picture of this truck based on a Peterbilt tractor is shown in Figure 2-7 below.

Even with the addition of these aerodynamic features, overall the tractor mass was reduced by over 1,300 lbs. The article states that the CFD analysis of the tractor showed a 50 percent reduction in drag and with a 2:1 drag reduction the aero improvements resulted in a 25 percent improvement in fuel economy. In the 300 mile test course shown on the video, it was stated that the tractor achieved 10.7-11.1 mpg.

Figure 2-7 Peterbilt SuperTruck Concept (Picture from: http://www.peterbilt.com/about/media/2014/396/)

This effort represents the first step in the evolution of improving the aerodynamic efficiency of tractor-trailer by radically redesigning today's tractor-trailer combination, as a wholly integrated system rather each component, tractor and trailer, independently.

2.4.2.2.2 *Government Sponsored Advanced Aerodynamic Research: Lawrence Livermore National Laboratory*

Lawrence Livermore National Laboratory's (LLNL) Kambiz Salari presented information at the 2014 DOE Annual Merit Review on "DOE's Effort to Improve Heavy Duty Vehicle Fuel Efficiency through Improved Aerodynamics". A joint project with Wabash, Navistar, Michelin, Safeway, Frito Lay, Praxair, Freight Wing Inc, ATDynamics, Kentucky Trailer and Spirit with funding for work in 2013 and 2014, the objective was to develop a new integrated tractor-trailer design from ground up by: first, designing the first generation of an integrated tractor-trailer geometry called Generic Speed Form one (GSF1); and second performing wind tunnel tests of selected aero devices for tractor-trailers and tankers to improve fuel efficiency. The goal was to reduce aerodynamic drag of Class 8 tractor-trailers by approximately 25 percent leading to a 10-15 percent increase in fuel efficiency at 65 mph. In addition, the group developed an aerodynamic tractor-trailer prototype designed to achieve 50 percent reduced aerodynamic drag as shown in Figure 2-8. This effort represents the next generation of tractors and trailers: a completely redesigned, fully integrated, optimized shape for the tractor-trailer combination.

Figure 2-8 Pictures showing future heavy-duty tractor trailer concept to achieve >50% aerodynamic improvement for Class 8 line haul heavy-duty vehicles

2.4.2.2.3 *Independent Advanced Aerodynamic Research: Airflow Truck Company Bullet Truck Concept*

In addition to the work being performed by the OEMs and consortiums mentioned above, there are also independent commercial initiatives underway to radically redesign the tractor-trailer combination similar to the concept by Lawrence Livermore National Laboratories discussed above.

The Class 8 tractor and trailer modifications in Figure 2-9 were designed, built, and tested in 2012 by Mr. Robert Sliwa of the Airflow Truck Company. Mr. Sliwa built his first aerodynamic tractor in the 1983 when he was an owner-operator. After that, Mr. Sliwa became interested in computers and used his computer background along with his truck driver and race car driver experience to create the Bullet Truck. His current design is described at www.airflowtruck.com and his tractor design modifications are similar in appearance to the bullet looking trains used in Europe. The tractor uses a 1999 engine and the test was conducted in the manner in which the tractor was driven at 55 mph by an experienced driver throughout its test while loaded at 65,000 lbs from Newington, Connecticut to Tracy, California.

The website shows that the vehicle achieved 13.4 mpg during this trip and included traveling through the Rocky Mountains. CFD analyses of the design after the vehicle was built found a modest decrease in C_dA, thus giving credence to the design work under the hood (most of which are outlined at airflowtruck.com) and driving techniques. Several new technologies were developed during this work which included retractable tractor steps, all electric air conditioning, crankshaft mounted cooling fan, computer-controlled fan hub, waterless engine coolant, reduced engine parasitic losses, full tractor and trailer side skirts, 4 axle ATIS, and an engine feedback information display.

Figure 2-9 Figure of the Bullet Truck by Airflow Truck Company[9]

Another prototype is in development and it will include further aerodynamic optimization of the tractor and trailer, and the combination thereof, as well as the addition of a boat tail. These technologies and more are expected to result in higher mpg under similar test conditions. Other changes in the vehicle makeup and test would include a more modern engine and testing at higher speeds (>55 mpg (60-65mpg)) may influence the end results.

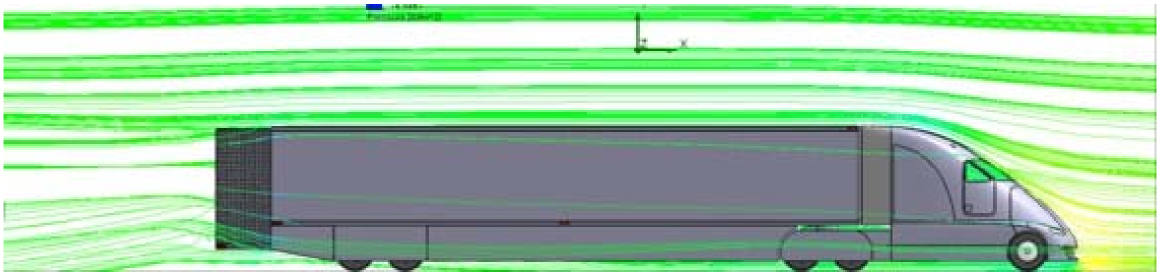


Figure 2-10 Figure of a Highly Aerodynamic Concept Class 8 Tractor

Although it is difficult to separate the aerodynamic factors from the engine and operational factors that lead to the claimed 13.4 mpg, the designs being explored and built by Mr. Sliwa are indicative of the type of tractor-trailer combinations we anticipate will be built in the future.

2.4.3 **Tires**

2.4.3.1 Improved Rolling Resistance

Research indicates that a tire's contribution to overall vehicle fuel efficiency is approximately proportional to the vehicle weight on it.[42] Energy loss associated with tires is mainly due to deformation of the tires under the load of the vehicle, known as hysteresis, but smaller losses result from aerodynamic drag, and other friction forces between the tire and road surface and the tire and wheel rim. Collectively the forces that result in energy loss from the tires are referred to as rolling resistance. Tires with higher rolling resistance lose more energy, thus using more fuel and producing more CO_2 emissions in operation, while tires with lower rolling resistance lose less energy, and use less fuel and produce less CO_2 emissions in operation.

A tire's rolling resistance is a factor considered in the design of the tire, and is affected by the tread and casing compound materials, the architecture of the casing, tread design, and the tire manufacturing process. It is estimated that 35 to 50 percent of a tire's rolling resistance is from the tread and the other 50 to 65 percent is from the casing.[42] Tire inflation can also impact rolling resistance in that under-inflated tires can result in increased deformation and contact with the road surface. In addition to the effect on CO_2 emissions and fuel consumption, these design and use characteristics of tires also influence durability, traction (both wet and dry grip), vehicle handling, ride comfort, and noise. Tires that have higher rolling resistance are likely designed to address one or more of these other tire attributes.

EPA's SmartWay program identified test methods and established criteria to designate certain tires as having lower rolling resistance (LRR) for use in the program's emissions tracking system, verification program, and SmartWay vehicle specifications. To measure a tire's efficiency, the vertical load supported by the tire must be considered, because rolling resistance is a function of the load on a tire. EPA uses a tire's rolling resistance coefficient (CRR) to characterize LRR tires. CRR is measured using the ISO 28850 test method (see 40 CFR 1037.520(c),) and reported as the rolling resistance force over vertical load (kg/metric ton). Differences in rolling resistance of up to 50 percent have been identified for tires designed to equip the same vehicle.[43]

LRR tires are commercially available from most tire manufacturers and can be applied to vehicles in all MD/HD classes. According to an energy audit conducted by Argonne National Lab, tires were shown to be the second largest contributor to energy losses for a Class 6 delivery truck at 50 percent load and speeds up to 35 mph (a typical average speed of urban delivery vehicles).[44] For Class 8 tractor-trailers, the share of vehicle energy required to overcome rolling resistance is estimated at nearly 13 percent.[45]

NHTSA, EPA, and ARB met with stakeholders from the tire industry (Bridgestone, Continental, Cooper, Goodyear, and Michelin) in 2014 to discuss the next generation of LRR tires for the Phase 2 timeframe for all segments of Class 2b-8 vehicles, including trailers. Manufacturers discussed forecasts for rolling resistance levels and production availability in the Phase 2 timeframe, as well as their plans for improving rolling resistance performance while maintaining other performance parameters such as traction, handling, wear, mass reduction, retreadability, and structural durability.

The meetings included specific discussions of the impacts of the current generation of LRR tires on vehicle stopping distance and handling. Manufacturers indicated no known safety disbenefit in the current on-road fleet from use of LRR tires. While the next generation of tires may require some tradeoffs in wear performance and costs over the next 10 years to achieve better tire rolling resistance performance, manufacturers said they will not trade off safety for performance. They also emphasized that keeping tires inflated (through proper maintenance or automatic systems) was the best way to assure long term fuel efficiency and safety during vehicle operation.

2.4.3.2 Wide Base Singles

Low rolling resistance tires can be offered for dual assembly tires and as wide base singles (WBS). Wide base singles are primarily intended for combination tractor-trailers, but some vocational vehicles are able to accommodate them. In the early years of this technology, some states and local governments restricted use of WBS, but many of these restrictions have since been lifted. As of December 2010, NACFE reports that there is virtual acceptance in North America with only a few provinces in Canada that disallow or require special permitting for the use of wide base tires.[46] A wide base single is a larger tire with a lower profile. The common wide base single sizes include 385/65R22.5, 425/65R22.5, 445/65R22.5, 435/50R22.5 and 445/50R22.5. Generally, a wide base single tire has less sidewall flexing compared to a dual assembly and therefore less hysteresis occurs. Compared to a dual tire assembly, wide base singles also produce less aerodynamic resistance or drag. Wide base singles can contribute to improving a vehicle’s fuel efficiency through design as a low rolling resistance tire and/or through vehicle weight reduction.

According to one study, the use of fuel efficient wide base singles can reduce rolling resistance by 3.7 to 4.9 percent compared to the most equivalent dual tire.[47] An EPA study with a tractor-trailer demonstrated an improvement in fuel consumption of 6 percent at 55 mph on the highway, 13 percent at 65 mph on the highway and 10 percent on a suburban loop[48] using wide base singles on the drive and trailer axles. EPA attributed the fuel consumption improvement to the reduction in rolling resistance and vehicle weight reduction from using wide base singles. In 2008 the Department of Energy (DOE) compared the effect of different combinations of tires on the fuel efficiency of Class 8 tractors. The data collected based on field testing indicates that tractors equipped with wide base singles on the drive axle experience better fuel efficiency than tractors equipped with dual tires, independent of the type of tire on the trailer.[49] This study in particular indicated a 6.2 percent improvement in fuel efficiency from wide base singles.

There is also a weight savings associated with wide base singles compared to dual tires. Wide base singles can reduce a tractor and trailer's weight by as much as 1,000 lbs. when combined with aluminum wheels. Bulk haulers of gasoline and other liquids recognize the immediate advantage in carrying capacity provided by the reduction in the weight of tires and have led the transportation industry in retrofitting their tractors and trailers[50].

New generation wide base singles, which were first introduced in 2000, are designed to replace a set of dual tires on the drive and/or trailer positions. They are designed to be interchangeable with the dual tires without any change to the vehicle[51]. If the vehicle does not have hub-piloted wheels, there may be a need to retrofit axle components.[50, 52] In addition to consideration of hub / bearing / axle, other axle-end components may be affected by use of wide base singles. To assure successful operation, suitable components should be fitted as recommended by the vehicle manufacturer.[53]

Current wide base singles are wider than earlier models and legal in all 50 states for a 5-axle, 80,000 GVWR truck[47]. Wide base singles meet the "inch-width" requirements nationwide, but are restricted in certain states up to 17,500 lbs. on a single axle at 500 lbs/inch width limit, and are not allowed on single axle positions on certain double and triple combination vehicles[51]. An inch-width law regulates the maximum load that a tire can carry as a function of the tire width. Typically wide base singles are optimized for highway operation and not for city or on/off highway operation. However, newer wide base singles are being designed for better scrub resistance, which would allow an expansion of their use. The current market share of wide base singles in combination tractor applications is 5 percent and the potential market is all combination tractors.[47] New generation wide base singles represent an estimated 0.5 percent of the 17.5 million tires sold each year in the U.S.[51]

2.4.3.3 Tire Pressure Systems

Proper tire inflation is critical to maintaining proper stress distribution in the tire, which reduces heat loss and rolling resistance. Tires with reduced inflation pressure exhibit more sidewall flexing and tread shearing, resulting in greater rolling resistance than a tire operating at its optimal inflation pressure. Bridgestone tested the effect of inflation pressure and found a 2 percent variation in fuel consumption over a 40 psi range.[42] Tractor-trailers operating with all tires under-inflated by 10 psi have been shown to increase fuel consumed by up to 1 percent.[54] Tires can gradually lose pressure from small punctures, leaky valves or simply diffusion through the tire casing. Changes in ambient temperature can also have an effect on tire pressure. Trailers that remain unused for long periods of time between hauls may experience any of these conditions. To achieve the intended fuel efficiency benefits of low rolling resistance tires, it is critical that tires are maintained at the proper inflation pressure.

Although most truck fleets understand the importance of keeping tires properly inflated, it is likely that a substantial proportion of trucks on the road have one or more underinflated tires.

An industry survey conducted in 2002 at two truck stops found that fewer than half of the tires checked were within 5 pounds per square inch (psi) of their recommended inflation pressure. Twenty-two percent of the vehicles checked had at least one tire underinflated by at least 20 psi, and 4 percent of the vehicles were running with at least one flat tire, defined as a tire underinflated by 50 psi or more. The survey also found mismatches in tire pressure exceeding 5 percent for dual tires on axle ends.[55]

A commercial vehicle tire condition study conducted by the Federal Motor Carrier Safety Administration (FMCSA) in 2003 found similar indicators of poor tire inflation pressure maintenance in commercial fleets. The FMCSA concluded that only 44 percent of all tires on commercial vehicles were inflated within 5 psi of the recommended pressure, while over 7 percent of all tires in operation on commercial vehicles were underinflated by at least 20 psi. It was also determined that the rates of tires used in dual assemblies that differed in pressure by more than 5 psi was approximately 20 percent for tractor duals and 25 percent for trailer duals. Finally, the FMCSA concluded that there were significant differences in tire inflation maintenance practices between private and for-hire fleets, smaller and larger fleets, and local bus and motor coach fleets.[56]

If drivers or fleets are not diligent about checking and attending to under-inflated tires, the trailer may have much higher rolling resistance and much higher CO_2 emissions and fuel consumption. Proper tire inflation pressure can be maintained with a rigorous tire inspection and maintenance program and EPA provides information on proper tire inflation pressure through its SmartWay program.[57] Tire pressure monitoring (TPM) and automatic tire inflation (ATI) systems are designed to address under-inflated tires. Both systems alert drivers if a tire's pressure drops below its set point. TPM systems monitor the tires and require user-interaction to reinflate to the appropriate pressure. Yet unless the vehicle experiences a catastrophic tire failure, simply alerting the driver that a tire's pressure is low may not necessarily result in action to correct the problem. A driver may continue driving to their final destination before addressing the tires, resulting in many miles of driving with improperly inflated tires. Current ATI systems take advantage of trailers' air brake systems to supply air back into the tires (continuously or on demand) until a selected pressure is achieved. In the event of a slow leak, ATI systems have the added benefit of maintaining enough pressure to allow the driver to get to a safe stopping area.[58] The agencies believe TPM systems cannot sufficiently guarantee the proper inflation of tires due to the inherent user-interaction required. Therefore, ATI systems are the only pressure systems the agencies are proposing to recognize in GEM.

Estimates of the benefits of ATI systems vary depending on the base level of maintenance already performed by the driver or fleet, as well as the number of miles the trailer travels. Vehicles that are well maintained or that travel fewer miles would experience less benefits from ATI systems compared to vehicles that log many miles or have a history of driving with poorly inflated tires. The agencies believe ATI systems can provide a CO_2 and fuel consumption benefit to most tractors and trailers. Drivers and fleets that diligently maintain their tires will spend less time and money to inspect each tire knowing that they are properly inflated. Vehicles that have lower annual VMT due to long periods between uses would be less susceptible to low tire pressures when they resume activity. Vehicles with high annual VMT would experience the fuel savings associated with consistent tire pressures.

2.4.3.4 Retreaded Tires

The tread life of a tire is a measure of durability and some tires are designed specifically for greater durability. Commercial vehicle tires are designed to be retreaded, a process in which a new tread is bonded to the tire casing. The original tread of a tire will last anywhere from 100,000 miles to over 300,000 miles, depending on vehicle operation, original tread depth, tire axle position, and proper tire maintenance. Retreading can extend the tire's useful life by 100,000 miles or more.[59] In 2005, the Tire Industry Association estimated that approximately 17.6 million retreaded truck tires were sold in North America[60].

All of the top commercial vehicle tire manufacturers are involved in tire retread manufacturing. Bridgestone Bandag Tire Solutions accounts for 42 percent of the domestic retreaded vehicle tire market with its Bandag retread products; Goodyear Tire and Rubber Company accounts for 28 percent, mostly through its Wingfoot Commercial Tire Systems; Michelin Retread Technologies Incorporated, with Megamile, Oliver, and Michelin retread products, accounts for 23 percent. Other tire companies like Continental and independent retread suppliers like Marangoni Tread North America (which also produces the Continental "ContiTread" retread product) make up the remaining 7 percent.[61] The retreading industry itself consists of hundreds of retreaders who sell and service retreaded tires, often (but not always) using machinery and practices identified with one of the major retread producers. There are about 800 retread plants in North America.[62] The top 100 retreaders in the U.S. retread 47,473 truck tires per day.

To maintain the quality of the casing and increase the likelihood of retreading, a tire should be retreaded before the tread depth is reduced to its legal limit. At any time, steer tires must have a tread depth of at least 4/32 of an inch and other tires, including drive tires and trailer tires, must have a tread depth of at least 2/32 of an inch (49 CFR § 393.75). Trucking fleets often retread tires before tire treads reach this minimum depth in order to preserve the integrity of the tire casing for retreading. If the casing remains in good condition, a truck tire can be safely retreaded multiple times. Heavy truck tires in line haul operation can be retread 2 to 3 times and medium-duty truck tires in urban use can be retread 5 or more times.[63] To accommodate this practice, many commercial vehicle tire manufacturers warranty their casings for up to five years, excluding damage from road hazards or improper maintenance.

To protect the casing, a steer tire is generally retreaded once the tread is worn down to 6/32 of an inch and a drive tire is retreaded once the tread is worn down to 8/32 of an inch.[64] Tires used on Class 8 vehicles are retreaded as many as three times.

Both the casing and the tread contribute to a tire's rolling resistance. It is estimated that 35 to 50 percent of a tire's rolling resistance is the result of the tread. Differences in drive tire rolling resistance of up to 50 percent for the same casing with various tread compounds have been demonstrated. For example, a fuel efficient tread (as defined by the manufacturer) was added to two different casings resulting in an average increase in rolling resistance of 48 percent. When a nonfuel efficient tread (also defined by the manufacturer) was added to the same casings, the rolling resistance increased by 125 percent on average. This characterizes the effect of the tread on the rolling resistance of a tire.

Because tires can be retreaded multiple times, changes in the casing due to wear, damage and material aging may impact rolling resistance to a greater degree than would occur in an original tire. Additionally, as evidenced above, if a tread compound different than the original tread is used, a retreaded tire can have higher or lower rolling resistance than the original tire. Since the agencies have no way of knowing whether the rolling resistance of retreaded tires will be higher or lower than the rolling resistance of the original tires, we similarly have no way of knowing whether low rolling resistance tire benefits will continue to accrue for a vehicle's entire lifetime.

2.4.4 **Transmissions**

Transmissions are a significant vehicle component. They are part of the drive train, which also includes axles and tires. Ways to improve transmissions include shift strategy, gear efficiency, gear ratios, etc. The relative importance of having an efficient transmission increases when vehicles operate in conditions with a higher shift density. Each shift represents an opportunity to lose speed or power that would have to be regained after the shift is completed. Further, each shift engages gears that have their own inherent inefficiencies.

Optimization of vehicle gearing to engine performance through selection of transmission gear ratios, final drive gear ratios and tire size can play a significant role in reducing fuel consumption and GHGs. Optimization of gear selection versus vehicle and engine speed accomplished through driver training or automated transmission gear selection can provide additional reductions. The 2010 NAS report found that the opportunities to reduce fuel consumption in heavy-duty vehicles due to transmission and driveline technologies in the 2015 time frame ranged between 2 and 8 percent.[65]

The design goal is for the transmission to deliver the needed power to the vehicle while maintaining engine operation within the engine's "sweet spot" for most efficient operation. Truck and chassis manufacturers today offer a wide range of tire sizes, final gear ratios and transmission choices so that owners can work with application engineers to specify an optimal combination given the intended vehicle service class and other performance needs.

2.4.4.1 Optimizing Number of Gears and Gear Ratios

Manufacturers can choose to replace 6-speed transmissions with 8-speed or more automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies for smooth shifts.

The Phase 1 rulemaking projected that 8-speed transmissions could incrementally reduce fuel consumption by 1 to 3 percent from a baseline 6-speed automatic transmission over some test cycles. The SwRI report uses 2 to 3 percent fuel consumption reduction when replacing 6-speed baseline automatic transmissions with improved 8-speed automatic transmissions.

2.4.4.2 Gear Efficiencies

As described elsewhere for axles and engines, the efficiency of gears can be improved by reducing friction and minimizing mechanical losses. This can be done by reducing the friction between the two gears in contact. This friction is reduced mainly by improving the surface finish of the gears. The other way of doing is by reducing the amount of distance the gear faces are sliding against each other.

2.4.4.3 Shift Strategies

Calibrating the transmission shift schedule to upshift earlier and quicker, and to lock up or partially lock up the torque converter under a broader range of operating conditions can reduce fuel consumption and CO_2 emissions. However, this operation can result in a perceptible degradation in noise, vibration, and harshness. The degree to which NVH can be degraded before it becomes noticeable to the driver is strongly influenced by characteristics of the vehicle, and although it is somewhat subjective, it always places a limit on how much fuel consumption can be improved by transmission control changes.

During operation, an automatic transmission's controller manages the operation of the transmission by scheduling the upshift or downshift, and locking or allowing the torque converter to slip based on a preprogrammed shift schedule. The shift schedule contains a number of lookup table functions, which define the shift points and torque converter lockup based on vehicle speed and throttle position, and other parameters such as temperature. Aggressive shift logic can be employed in such a way as to maximize fuel efficiency by modifying the shift schedule to upshift earlier and inhibit downshifts under some conditions, which reduces engine pumping losses and engine friction. The application of this technology does require a manufacturer to confirm that drivability, durability, and NVH are not significantly degraded.

A torque converter is a fluid coupling located between the engine and transmission in vehicles with automatic transmissions and continuously-variable transmissions (CVT). This fluid coupling allows for slip so the engine can run while the vehicle is idling in gear (as at a stop light), provides for smoothness of the powertrain, and also provides for torque multiplication during acceleration, and especially launch. During light acceleration and cruising, the inherent slip in a torque converter causes increased fuel consumption, so modern automatic transmissions utilize a clutch in the torque converter to lock it and prevent this slippage. Fuel consumption can be further reduced by locking up the torque converter at lower vehicle speeds, provided there is sufficient power to propel the vehicle, and noise and vibration are not excessive. If the torque converter cannot be fully locked up for maximum efficiency, a partial lockup strategy can be employed to reduce slippage. Early torque converter lockup is applicable to all vehicle types with automatic transmissions. Some torque converters would require upgraded clutch materials to withstand additional loading and the slipping conditions during partial lock-up. As with aggressive shift logic, confirmation of acceptable drivability, performance, durability and NVH characteristics would be required to successfully implement this technology.

2.4.4.4 Architectures

The manual transmission architecture has traditionally been considered the most efficient architecture since it did not experience the losses inherent in a torque converter required on a traditional automatic transmission (a traditional automatic transmission being a transmission with fully automated shifting and using a hydraulic lock-up torque converter for smooth vehicle launching from a stop). However, this traditional understanding has been called into question as advances in electronics and computer processing power allow for more efficiency from a manual transmission architecture with fully automated shifting. The two primary manual transmission architectures employing automated shifting are the automated manual transmission (AMT) and the dual-clutch transmission (DCT). When implemented well, these mechanically more efficient designs could inherently provide better fuel efficiency and lower greenhouse gas emissions than conventional torque converter automatic transmission designs and, potentially, even fully manual transmissions. These transmissions offer the inherently lower losses of a manual transmission with the efficiency and shift quality advantages of electronic controls. The lower losses stem from the elimination of the conventional lock-up torque converter, and a greatly reduced need for high pressure hydraulic circuits to hold clutches to maintain gear ratios (in automatic transmissions).

2.4.4.4.1 ***AMT***

An AMT is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by electronics. The term AMT generally refers to a single clutch design (differentiating it from a dual-clutch transmission, or dual-clutch AMT, described below) which is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, dual-clutch designs are more common in light-duty applications where driver acceptance is of primary importance. In the HD sector, shift quality remains important but is less so when compared to light-duty. As a result, the single-clutch AMT architecture can be an attractive technology for HD vehicles.

2.4.4.4.2 ***DCT***

A DCT uses separate clutches (and separate gear shafts) for the even-numbered and the odd-numbered gears. In this way, the next expected gear is pre-selected thereby allowing for faster and smoother shifting. For example, in a 6 speed DCT, if the vehicle is accelerating in third gear, the shaft with gears one, three and five has gear three engaged and is transmitting power to the wheels. The shaft with gears two, four, and six is idle but has gear four engaged. When a shift is required, the controller disengages the odd-gear clutch while simultaneously engaging the even-gear clutch, thus making a smooth shift. If, on the other hand, the driver slows the vehicle instead of continuing to accelerate, the transmission would have to change to second gear on the idling shaft to anticipate a downshift. This shift can be made quickly on the idling shaft since there is no torque being transferred on it.

There are variations of the DCT design, with some having wet clutches and some dry clutches, and more recent versions that incorporate a torque converter similar to but smaller than the torque converter of a traditional automatic transmission. The wet clutch designs offer a higher torque capacity that comes from the use of a hydraulic system that cools the clutches. Wet clutch systems are also less efficient than dry clutch systems due to the losses associated with the hydraulic pumping. They also are more costly due to the hydraulics.

2.4.4.5 Hybrid Powertrain Systems

The industry is currently developing many variations of hybrid powertrain systems. The hybrids developed to date have seen fuel consumption and CO_2 emissions reductions between 20 and 50 percent in the field. However, there are still some key issues that are restricting the penetration of hybrids, including overall system cost, battery technology, and lack of cost-effective electrified accessories.

A hybrid vehicle is a vehicle that combines two significant sources of propulsion energy, where one uses a consumable fuel (like diesel), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. light-duty market, some manufacturers have been producing heavy-duty hybrid models for many years, and others are looking to develop hybrid models in future years.

Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.

- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.

- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine were downsized to maintain the same performance as the conventional version. The non-downsizing approach is used for vehicles where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed HD pickup truck attribute, manufacturers are hesitant to offer a truck with a downsized engine that can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles.

Strong hybrid technology utilizes an axial electric motor connected to the transmission input shaft and connected to the engine crankshaft through a clutch. The axial motor is a motor/generator that can provide sufficient torque for launch assist, all electric operation, and the ability to recover significant levels of braking energy.

A hybrid drive unit is complex and consists of discrete components such as the electric traction motor, transmission, generator, inverter, controller and cooling devices. Certain types of drive units may work better than others for specific vehicle applications or performance requirements. Several types of motors and generators have been developed for hybrid-electric drive systems, many of which merit further evaluation and development on specific applications. Series HEVs typically have larger motors with higher power ratings because the motor alone propels the vehicle, which may be applicable to Class 3-5 applications. In parallel hybrids, the power plant and the motor combine to propel the vehicle. Motor and engine torque are usually blended through couplings, planetary gear sets and clutch/brake units. The same mechanical components that make parallel heavy-duty hybrid drive units possible can be designed into series hybrid drive units to decrease the size of the electric motor(s) and power electronics.

An electrical energy storage system is needed to capture energy from the generator, to store energy captured during vehicle braking events, and to return energy when the driver demands power. This technology has seen a tremendous amount of improvement over the last decade and recent years. Advanced battery technologies and other types of energy storage are emerging to give the vehicle its needed performance and efficiency gains while still providing a product with long life. The focus on the more promising energy storage technologies such as nickel metal-hydride (NiMH) and lithium technology batteries along with ultra-capacitors for the heavy-duty fleet should yield interesting results after further research and applications in the light-duty fleet.

Heavy-duty hybrid vehicles also use regenerative braking for improved fuel economy, emissions, brake heat, and wear. A conventional heavy vehicle relies on friction brakes at the wheels, sometimes combined with an optional engine retarder or driveline retarder to reduce vehicle speed. During normal braking, the vehicle’s kinetic energy is wasted when it is converted to heat by the friction brakes. The conventional brake configuration has large components, heavy brake heat sinks, and high temperatures at the wheels during braking, audible brake squeal, and consumable components requiring maintenance and replacement. Hybrid electric systems recover some of the vehicle’s kinetic energy through regenerative braking, where kinetic energy is captured and directed to the energy storage system. The remaining kinetic energy is dissipated through conventional wheel brakes or in a driveline or transmission retarder. Regenerative braking in a hybrid electric vehicle can require integration with the vehicle’s foundation (friction) braking system to maximize performance and safety.

Today’s systems function by simultaneously using the regenerative features and the friction braking system, allowing only some of the kinetic energy to be saved for later use. Optimizing the integration of the regenerative braking system with the foundation brakes would increase the benefits and is a focus for continued work. This type of hybrid regenerative braking system improves fuel economy, GHG emissions, brake heat, and wear.

In a hydraulic hybrid system, deceleration energy is taken from the drivetrain by an inline hydraulic pump/motor unit by pumping hydraulic fluid into high pressure cylinders. The fluid, while not compressible, pushes against a membrane in the cylinder that compresses an inert gas to 5,000 PSI or more when fully charged. Upon acceleration, the energy stored in the pressurized tank pushes hydraulic fluid back into the drivetrain pump/motor unit, allowing it to motor into the drivetrain and assist the vehicle's engine with the acceleration event. This heavy-duty vehicle hybrid approach has been demonstrated successfully, producing good results on a number of commercial and military trucks.

Despite the significant future potential for hybrids discussed above, there are no simple solutions applicable for each heavy-duty hybrid application due to the large vocational vehicle fleet variation. A choice must be made relative to the requirements and priorities for the application. Challenges in motor subsystems such as gear reductions and cooling systems must be considered when comparing the specific power, power density, and cost of the motor assemblies. High speed motors can significantly reduce weight and size, but they require speed reduction gear sets that can offset some of the weight savings, reduce reliability and add cost and complexity. Air-cooled motors are simpler and generally less expensive than liquid cooled motors, but they are larger and heavier, and they require access to ambient air, which can carry dirt, water, and other contaminants. Liquid-cooled motors are generally smaller and lighter for a given power rating, but they may require more complex cooling systems that can be avoided with air-cooled versions. Various coolant options, including water, water-glycol, and oil, are available for liquid-cooled motors but must be further researched for long term durability. Electric motors, power electronics, electrical safety, regenerative braking, and power-plant control optimization have been identified as the most critical technologies requiring further research to enable the development of higher efficiency hybrid electric propulsion systems.

2.4.5 **Axles**

2.4.5.1 Axle Efficiency

Axle efficiency is improved by reducing generally two categories of losses; mechanical losses and spin losses.

Mechanical losses can be reduced by reducing the friction between the two gears in contact. This friction is reduced mainly by improving the surface finish of the gears. The other way of doing is by reducing the amount of distance the gear faces are sliding against each other. Generally speaking frictional losses are proportional to the torque on the axle not a function of rotational speed of the axle.

Spin losses on the other hand are a function of speed and not torque. One of the main ways to reduce the spin losses of the axle is by using a lower viscosity lubricant. Some high-performance lower viscosity formulations have been designed to have superior performance at high operating temperatures, and may have extended change intervals.

A study conducted by researchers at Shell Global Solutions on a Mercedes Benz OM 460LA heavy-duty diesel engine run under the World Harmonized Transient Cycle (WHTC) and World Harmonized Stationary Cycle (WHSC), used a combination of a SAE 5W-30 engine oil, SAE 75W-80 gearbox oil and SAE 75W-90 axle oil. The combination yielded average fuel economy improvements of 1.8 percent over the WHTC and 1.1 percent over the WHSC, relative to a SAE 15W-40 engine oil, SAE 80W gearbox and SAE 90 axle oil [VT-27]. The baseline lubricants represent current mainstream products, and the new lubricants were top-tier formulations focusing on modified viscometric effects. Using the WHSC cycle, significant variations in the individual lubricant contribution under different speed and load conditions within the cycle were identified. Additionally, an average fuel economy improvement of 1.8 percent was observed using medium-duty trucks under a range of typical European driving conditions in a controlled field trial.[66]

Spin losses can also be reduced by lower the volume of lubricant in the sump. This reduces the surface area of the gears that is churning through the lubricant. One of the main challenges of doing this is making sure that there is still adequate coverage of lubricant on the gears and bearings as well as adequate circulation so that the lubricant temperature doesn't rise too high and accelerate the aging of the lubricant.

If a manufacturer wishes to demonstrate a benefit specific to any technology that improves axle efficiency, an axle efficiency test could be performed to support an off-cycle technology credit application. See draft RIA Chapter 3 for a description of the proposed test procedure for rear axle efficiency.

2.4.5.2 Gear Ratio

Combining with transmission ratio, selection of the axle ratio can play a significant role in vehicle performance. For an on-highway tractor, the axle ratio must be selected in such a way that the engine can constantly run inside the sweet spot, where the engine efficiency is optimal for a typical constant cruise speed like 65 mile per mile. Although many vehicles on the road already use the fast axle ratio as low as 2.64:1 with the direct drive of transmission, which moves the engine speed in the range of 1200 rpm or even lower, most vehicles still use higher or slower axle ratio, which puts the engine speed in the range of 1300-1400 rpm. In order to take advantage of optimal engine speed, which is typically in the range of 1100-1150 rpm for HHD diesel vehicles, it is expected that the faster axle ratio lower than 2.64:1 would be widely used in 2018 and beyond for tractors. Furthermore, in order to enhance vehicle performance, many axle manufacturers are developing dual speed axles, allowing vehicles to switch to the higher axle ratio during transient driving conditions, such as city traffic. On the vocational side, the ability to start a heavy vehicle, climb hills, and operate smoothly at low speed is strongly influenced by axle ratio, and therefore, one can see a large of variation of axle ratios depending on the application.

2.4.5.3 Tandem Drive Axle Improvements

Manufacturers are developing technologies to enable heavy trucks with two rear drive axles to be driven solely by the lead rear axle either permanently or on a part time basis.

2.4.5.3.1 ***6 x 2***

Most tractors and heavy heavy-duty vocational vehicles today have three axles – a steer axle and two rear drive axles, which is commonly referred to as a 6x4 configuration. Manufacturers offer 6x2 tractors that include one rear drive axle and one rear non-driving axle. The 6x2 tractors offer three distinct benefits. First, the non-driving rear axle does not have internal friction and therefore reduces the overall parasitic losses in the drivetrain. In addition, the 6x2 configuration typically weighs approximately 300 to 400 pounds less than a 6x4 configuration.[67] Finally, the 6x2 typically costs less or is cost neutral when compared to a 6x4 tractor. Sources cite the effectiveness of 6x2 axles at between 1 and 3 percent.[68] Similarly, with the increased use of double and triple trailers, which reduce the weight on the tractor axles when compared to a single trailer, manufacturers offer 4x2 axle configurations. The 4x2 axle configuration would have as good as or better fuel efficiency performance than a 6x2.

2.4.5.3.2 ***Enhanced 6x2***

One of the drawbacks of 6x2 axle is lack of traction, specifically during the winter condition and high grade road when the road is slippery. In order to overcome this deficiency, some axle manufacturers offer products that perform similar to the 6x4 configurations. SMARTandem offered by Meritor is just one of the examples.[69] In this system, the axle runs 6x2 for most time. Once the conditions that require more traction are experienced, the vehicle activates the system to add more loads into one the powered axle, thus instantly increasing traction. This system offers weight savings in the range of 300 to 400 lbs, as well as 2 percent fuel saving as compared with conventional 6x4 axle.

2.4.5.3.3 ***2.4.4.3.3 Disconnect 6x4 Axle***

Based on confidential stakeholder discussions, the agencies anticipate that the axle market may offer, in the proposed time frame of Phase 2, a Class 8 version of the type of axle disconnect that today allows 4x4 operators of HD pickup trucks to automatically disconnect or reconnect the front axle depending on needs for traction in varying driving conditions. The Class 8 version would likely function for the two tandem drive axles in a similar manner as the HD pickup trucks do for the front axle. The switching could be automated or user-commanded. In these cases, the axle actuator housing, sometimes called the axle disconnect housing, is part of the differential that houses the gears and shift fork required to lock two axles together. The axle actuator works together with the transfer case to send torque to all four wheel-ends. Recently, Dana Holding Corporation has developed an axle system that switches between the two modes based on driving conditions to maximize driveline efficiency.[70] When high traction is required, the system operates in 6x4 mode. When 6x4 tractive effort is not required, the system operates in 6x2 mode. It is reported that this type of system can offer 2.5 percent benefits.

In the 4x4 example, the transfer case connects the input from the transmission to the rear and front driveshafts. The axle actuator housing is found on the differential. In the 4x4 example, a shift fork inside the axle actuator housing slides a locking collar over two gears locking both driver and passenger side axles together. In some 4x4 vehicles, those with automatic 4WD, this process occurs automatically. In others, with selective 4WD, the driver can choose to engage 4WD or RWD with a switch. These have slightly different axle actuator housings and have actuator solenoids mounted to them.[71] These systems would not provide the weight reduction benefit of the permanent 6x2 configuration, and may offer less fuel savings, especially with operator-switchable systems.

2.4.6 Weight Reduction

Mass reduction is a technology that can be used in a manufacturer's strategy to meet the proposed Phase 2 standards. Vehicle mass reduction (also referred to as "down-weighting" or 'light-weighting"), decreases fuel consumption and GHG emissions by reducing the energy demand needed to overcome inertia forces, and rolling resistance. Reduced mass in heavy-duty vehicles can benefit fuel efficiency and CO_2 emissions in two ways. If a truck is running at its gross vehicle weight limit with high density freight, more freight can be carried on each trip, increasing the truck's ton-miles per gallon. If the vehicle is carrying lower density freight and is below the GVWR (or GCW) limit, the total vehicle mass is decreased, reducing rolling resistance and the power required to accelerate or climb grades.

Many vehicle components are typically made of heavier material, such as steel. Manufacturers have worked with mass reduction technologies for many years and a lot of these technologies have been used in production vehicles. The weight savings achieved by adopting mass reduction technologies offset weight gains due to increased vehicle size, larger powertrains, and increased feature content (sound insulation, entertainment systems, improved climate control, etc.). Generally, an empty truck makes up about one-third of the total vehicle weight. Every 10 percent drop in vehicle weight reduces fuel use about 5 percent.[72]

Although many gains have been made to reduce vehicle mass, many of the features being added to modern tractors to benefit fuel efficiency, such as additional aerodynamic features or idle reduction systems, have the effect of increasing vehicle weight, causing mass to stay relatively constant. Material and manufacturing technologies can also play a significant role in vehicle safety by reducing vehicle weight, and in the improved performance of vehicle passive and active safety systems. Hybrid powertrains, fuel cells and auxiliary power would not only present complex packaging and weight issues, they would further increase the need for reductions in the weight of the body, chassis, and powertrain components in order to maintain vehicle functionality.

Manufacturers may employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction, also referred to as primary mass reduction, plus the additional mass reduction taken from indirect ancillary systems and components, also referred to as secondary mass reduction or mass compounding.

Mass reduction can be achieved through a number of approaches, even while maintaining other vehicle functionalities. As summarized by NAS in its 2011 light duty vehicle report, there are two key strategies for primary mass reduction: 1) substituting lighter materials for heavier materials; and 2) changing the design to use less material.[73]

2.4.6.1 Material Substitution

Substitution of a material used in an assembly or a component for one with lower density and/or higher strength includes replacing a common material such as mild steel with higher-strength and advanced steels, aluminum, magnesium, and composite materials. In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and unless strength is matched, some substituted components may need to be more numerous (i.e. two brackets instead of one). Further, one choices of material may lead a manufacturer to invest more heavily in adjusting its manufacturing process to its properties, thus possibly impeding its ability to consider other materials. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and noise, vibration and harshness (NVH).

One example that combines material substitution with component-elimination is the use of wide-based single tires and aluminum rims to replace traditional dual tires and rims, eliminating eight steel rims and eight tires from a tractor. Using aluminum, metal alloys, metal matrix composites, and other lightweight components where appropriate can reduce empty vehicle weight (known as “tare weight”), improve fuel efficiency, and reduce greenhouse gas emissions. In addition, in weight-sensitive applications, lightweight components can allow more cargo and increased productivity. A report by the National Commission on Energy Policy estimates that a fuel economy gain of 5.0 percent on certain applications could be achieved by vehicle mass reduction further illustrating the fuel economy gains possible on heavy-duty applications.[74] A report for the U.S. DOT estimated potential reductions in modal GHG emissions are 4.6 percent, though it also found that current light-weight materials are costly and are application- and vehicle-specific with need for further research and development for advanced materials.[75]

The principal barriers to overcome in reducing the weight of heavy vehicles are associated with the cost of lightweight materials, the difficulties in forming and manufacturing lightweight materials and structures, the cost of tooling for use in the manufacture of relatively low-volume vehicles (when compared to automotive production volumes), and ultimately, the extreme durability requirements of heavy vehicles. While light-duty vehicles may have a life span requirement of several hundred thousand miles, typical heavy-duty commercial vehicles must last over 1 million miles with minimum maintenance, and often are used in secondary applications for many more years. This requires high strength, lightweight materials that provide resistance to fatigue, corrosion, and can be economically repaired. Additionally, because of the limited production volumes and the high levels of customization in the heavy-duty market, tooling and manufacturing technologies that are used by the light-duty automotive industry are often uneconomical for heavy vehicle manufacturers. Lightweight materials such as aluminum, titanium and carbon fiber composites provide the opportunity for significant weight reductions, but their material cost and difficult forming and manufacturing requirements make it difficult for them to compete with low-cost steels. In addition, although mass reduction is currently occurring on both vocational vehicles and line haul tractors, the addition of other systems for fuel economy, performance or comfort increases the vehicle mass offsetting the mass reduction that has already occurred, thus is not captured in the overall vehicle mass measurement (e.g. 500 lbs for WHR). Most vehicle manufacturers offer lightweight tractor models that are 1,000 or more pounds lighter than comparable models. Lighter-weight models combine different weight-saving options that may include:[76]

- Cast aluminum alloy wheels can save up to 40 pounds each for total savings of 400 pounds
- Aluminum axle hubs can save over 120 pounds compared to ductile iron or steel
- Centrifuge brake drums can save nearly 100 pounds compared to standard brake drums
- Aluminum clutch housing can save 50 pounds compared to iron clutch housing
- Composite front axle leaf springs can save 70 pounds compared to steel springs
- Aluminum cab frames can save hundreds of pounds compared to standard steel frames

2.4.6.2 Synergistic Effects - Reduced Power Demand

Manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction plus the additional mass reduction that can be taken from indirect ancillary systems and components, as a result of full vehicle optimization, effectively compounding or obtaining a secondary mass reduction from a primary mass reduction. The strategy of using less material compared to the baseline component or system can be achieved by optimizing the design and structure of vehicle components, systems and vehicle structure. Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. For example, the Future Steel Vehicle (FSV) project sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry Grade and Gauge) optimization, and subsystem optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure.[77] Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials.

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle performance. If a powertrain is downsized, a portion of the mass reduction may be attributed to the reduced torque requirement that results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission torque converter and gear ratios, and changes to final drive gear ratio. The reduced powertrain torque may enable the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (e.g., for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. However, there may trade-offs, as it is possible that use of a downsized engine may require a transmission with more gears. The combined mass reductions of the engine, drivetrain, and body would reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which would allow for further optimization and potential mass reduction.

One example of a synergistic effect is rotational inertia. Reducing the weight of rotating components provides an enhanced fuel efficiency benefit over reducing the weight of static components. In theory, as components such as brake rotors, brake drums, wheels, tires, crankshafts, camshafts, and piston assemblies become lighter, the power consumption to rotate the masses would be directly proportional to the mass decrease. Using physical properties of a rotating component such as a wheel, it is relatively straightforward to calculate an equivalent mass. However, we do not have enough information to derive industry average values for equivalent mass, nor have we evaluated the best way for GEM to account for this. Using typical values for a heavy-duty steel wheel compared to a similar-sized aluminum wheel, the agencies estimate the equivalent mass ratio is in the range of 1.2 to 1.3. That means that by reducing the mass of a wheel by 20 pounds, the vehicle could theoretically perform as if 26 pounds had been reduced.

Estimates of the synergistic effects of mass reduction and the compounding effect that occurs along with it can vary significantly from one report to another. For example, in discussing its estimate, an Auto-Steel Partnership report states that "These secondary mass changes can be considerable—estimated at an additional 0.7 to 1.8 times the initial mass change."[78] This means for each one pound reduction in a primary component, up to 1.8 pounds can be reduced from other structures in the vehicle (*i.e.*, a 180 percent factor). The report also discusses that a primary variable in the realized secondary weight reduction is whether or not the powertrain components can be included in the mass reduction effort, with the lower end estimates being applicable when powertrain elements are unavailable for mass reduction. However, another report by the Aluminum Association, which primarily focuses on the use of aluminum as an alternative material for steel, estimated a factor of 64 percent for secondary mass reduction even though some powertrain elements were considered in the analysis.[79] That report also notes that typical values for this factor vary from 50 to 100 percent. Although there is a wide variation in stated estimates, synergistic mass reductions do exist, and the effects result in tangible mass reductions. Mass reductions in a single vehicle component, for example a door side impact/intrusion system, may actually result in a significantly higher weight savings in the total vehicle, depending on how well the manufacturer integrates the modification into the overall vehicle design. Accordingly, care must be taken when reviewing reports on weight reduction methods and practices to ascertain if compounding effects have been considered or not.

2.4.7 **Vehicle Speed Limiter**

The power required to move a vehicle increases as the vehicle speed increases. Travelling at lower speeds provides additional efficiency to the vehicle performance. Most vehicles today have the ability to electronically control the maximum vehicle speed through the engine controller. This feature is used today by fleets and owners to provide increased safety and fuel economy. Currently, these features are designed to be able to be changed by the owner and/or dealer.

The impact of this feature is dependent on the difference between the governed speed and the speed that would have been travelled, which is dependent on road type, state speed limits, traffic congestion, and other factors. The agencies plan to assess the benefit of a vehicle speed limiter by reducing the maximum drive cycle speed on the 65 mph Cruise mode of the cycle. The maximum speed of the drive cycle is 65 mph, therefore any vehicle speed limit with a setting greater than this would show no benefit for purposes of these regulations, but may still show benefit in the real world in states where the interstate truck speed limit is greater than the national average of 65.5 mph.

The benefits of this simple technology are widely recognized. The American Trucking Association (ATA) developed six recommendations to reduce carbon emissions from trucks in the United States. Their first recommendation is to enact a national truck speed limit of 65 mph and require that trucks manufactured after 1992 have speed governors set at not greater than 65 mph.[80] The SmartWay program includes speed management as one of their key Clean Freight Strategies and provides information to the public regarding the benefit of lower highway speeds.[81]

Some countries have enacted regulations to reduce truck speeds. For example, the United Kingdom introduced regulations in 2005 which require new trucks used for goods movement to have a vehicle speed limiter not to exceed 90 km/hr (56 mph).[82] The Canadian Provinces of Ontario and Quebec developed regulations which took effect in January 2009 that requires on-highway commercial heavy-duty trucks to have speed limiters which limit the truck's speed to 105 km/hr (65 mph).[83]

Many truck fleets consider speed limiter application a good business practice in their operations. A Canadian assessment of heavy-duty truck speed limiters estimated that 60 percent of heavy truck fleets in North America use speed limiters.[83] Con Way Freight, Con Way Truckload, and Wal-Mart currently govern the speeds of their fleets between 62 and 65 mph.[84]

A potential disbenefit of this technology is the additional time required for goods movement, or loss of productivity. The elasticity between speed reduction and productivity loss has not been well defined in industry. The Canadian assessment of speed limiters cited above found that the fuel savings due to the lower operating speeds outweigh any productivity losses. A general consensus among the OEMs is that a one percent decrease in speed might lower productivity by approximately 0.2 percent.[84]

2.4.8 Reduced Idling Time

2.4.8.1 Engine Shutdown with Alternate Power Source during Hoteling

Class 8 heavy-duty diesel truck extended engine idling expends significant amounts of fuel in the United States. Department of Transportation regulations require a certain amount of rest for a corresponding period of driving hours, as discussed in Chapter 1. Extended idle occurs when Class 8 long haul drivers rest in the sleeper/cab compartment during rest periods as drivers find it more convenient and economical to rest in the truck cab itself. In many cases it is the only option available. During this rest period a driver will generally idle the truck in order to provide heating or cooling or run on-board appliances. During rest periods the truck's main propulsion engine is running but not engaged in gear and it remains in a stationary position. In some cases the engine can idle in excess of 10 hours. During this period of time, fuel consumption will generally average 0.8 gallons per hour.[113] Average overnight fuel usage would exceed 8 gallons in this example. When multiplied by the number of long haul trucks without idle control technology that operate on national highways on a daily basis, the number of gallons consumed by extended idling would exceed 3 million gallons per day. Fortunately, a number of alternatives (idling reduction technologies) are available to alleviate this situation.

2.4.8.1.1 *Idle Control Technologies*

Idle reduction technologies in general utilize an alternative energy source in place of operating the main engine. By using these devices the truck driver can obtain needed power for services and appliances without running the engine. A number of these devices attach to the truck providing heat, air conditioning, or electrical power for microwave ovens, televisions, etc.

The idle control technologies (along with their typical hourly fuel rate) available today include the following:[85]

- Auxiliary Power Unit (APU) powers the truck's heating, cooling, and electrical system. The fuel use of an APU is typically 0.2 gallons per hour
- Fuel Operated Heater (FOH) provides heating services to the truck through small diesel fired heaters. The fuel use is typically 0.04 gallons per hour
- Battery Air Conditioning Systems (BAC) provides cooling to the truck
- Thermal Storage Systems provide cooling to trucks

Another alternative involves electrified parking spaces, with or without modification to the truck. An electrified parking space system operates independently of the truck's engine and allows the truck engine to be turned off while it supplies heating, cooling, and electrical power. These systems provide off-board electrical power to operate either:

1. A single system electrification which requires no on-board equipment by providing an independent heating, cooling, and electrical power system, or
2. A dual system which allows driver to plug in on-board equipment

In the first case, power is provided to stationary equipment that is temporarily attached to the truck. In the second, the truck is modified to accept power from the electrical grid to operate on-board truck equipment. The retail price of idle reduction systems varies depending on the level of sophistication. For example, on-board technologies such as APUs can retail for over $7,000 while options such as electrified parking spaces require negligible up-front costs for equipment for the tractor itself, but will accrue fees with usage.[86]

CO_2 emissions and fuel consumption during extended idling are significant contributors to emissions and fuel consumption from Class 8 sleeper cabs. The federal test procedure does evaluate idle emissions and fuel consumption as part of the drive cycle and related emissions measurement. However, long duration extended idle emissions and fuel consumption are not fully represented during the prescribed test cycle. To address the fact that real-world fuel and emissions savings can occur with idle reduction technologies that cannot be reflected on the test cycle, the agencies adopted in Phase 1 a credit mechanism for manufacturers who provide for idle control using an automatic engine shutdown (AES) system on the tractor. This credit recognizes the CO_2 reductions and fuel consumption savings attributed to idle control systems and allows vehicle manufacturers flexibility in product design and performance capabilities, compared to an alternative where the agencies would allow credits for specific idle control technologies.

2.4.8.2 Stop Start

For heavy-duty vehicles to apply engine stop-start technology without a reduction in vehicle function, some additional vehicle technologies are needed. To some extent this could be considered similar to a mild hybrid system, but it is not the same as the mild hybrid system described for HD pickups and vans described below in Chapter 2.5. The agencies are projecting the presence of a battery sufficient to offer electrified power steering, and some other electrified accessories. Some systems may replace the conventional alternator with a belt or crank driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack.

The NACFE Idle Reduction Confidence report was written with long haul tractors in mind; however the section on vehicle electrification discusses inverters and on-vehicle solar energy capture, and offers some insights relevant to vocational vehicle electrification as it pertains to stop-start systems.[87] Inverters and beltless alternators can use DC power stored in batteries to power on-board electrical devices and re-start engines. One example of a company that supplies battery-inverter idle reduction systems for vocational vehicles is Vanner.[88] There are also systems available today that are designed to capture solar energy and store this energy for distribution to electrified accessories and engine re-starting. One example of a company that supplies on-vehicle solar energy capture for vocational vehicles is eNow.[89]

2.4.8.3 Neutral Idle

Automatic transmissions historically apply torque to an engine when in gear at zero speed, such as when stopped at a traffic light. These transmissions can be programmed to place a smaller load on the engine, resulting in lower rpm and lower fuel consumption, essentially shifting the transmission to neutral at zero speed.

2.4.9 **Air Conditioning**

2.4.9.1 Refrigerant Leakage

Hydrofluorocarbon (HFC) refrigerants, which are powerful GHG pollutants, can be emitted to the atmosphere through component and system leaks during operation, during maintenance and servicing, and with disposal at the end of the vehicle's life. The current widely-used refrigerant – R134a, has a much higher global warming potential (GWP) than CO_2, therefore a small leakage of this refrigerant has a much greater global warming impact than a similar amount of emissions of CO_2 or other mobile source GHGs.

Direct emissions of HFC from air conditioning systems can be reduced by minimizing system leaks. Based on measurements from 300 European light-duty vehicles (collected in 2002 and 2003), Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was estimated to be 53 g/yr.[90] This corresponds to a leakage rate of 6.9 percent per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, therefore it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S. at 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the A/C usage patterns also vary between the two continents, which may influence leakage rates.

Vincent et al., from the California Air Resources Board estimated the in-use refrigerant leakage rate to be 80 g/yr.[91] This is based on consumption of refrigerant in commercial fleets, surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52 percent empty and the fraction recovered at end-of-life was 8.5 percent.

Manufacturers today are complying with the HD Phase 1 program requirements to reduce A/C leakage emissions by utilizing high-quality, low-leakage air conditioning system components in the production of new tractors, and HD pickup trucks and vans. Some of the components available to manufacturers are low-permeation flexible hoses, multiple o-ring or seal washer connections, and multiple-lip compressor shaft seals. The availability of low leakage components in the market is being driven by the air conditioning credit program in the light-duty GHG rulemaking. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50 percent by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system.[92]

2.4.9.2 System Efficiency

A program could be developed that includes efficiency improvements. CO_2- equivalent emissions and fuel consumption are also associated with air conditioner efficiency, since air conditioners create load on the engine. See 74 FR at 49529. However, as in Phase 1, the agencies are not proposing air conditioning efficiency standards for heavy-duty vehicles, as the fuel consumption and CO_2 emissions due to air conditioning systems in heavy-duty trucks are minimal (compared to their overall fuel consumption and emissions of CO_2). For example, EPA conducted modeling of a Class 8 sleeper cab using GEM to evaluate the impact of air conditioning and found that it leads to approximately 1 gram of CO_2/ton- mile. Therefore, a projected 24 percent improvement of the air conditioning system (the level projected in the light-duty GHG rulemaking), would only reduce CO_2 emissions by less than 0.3 g CO_2/ton-mile, or approximately 0.3 percent of the baseline Class 8 sleeper cab CO_2 emissions.

2.4.9.3 Solar Control

Solar reflective paint and solar control glazing can reduce the temperature inside a vehicle, and therefore reduce the air conditioning requirements. The reduction in air conditioning load can lead to reductions in fuel consumption and GHG emissions. CARB's Low Emission Vehicle III Regulations (LEVIII) include a GHG credit for this technology.[93] Solar reflective paints reflect approximately a half of the solar energy by reflecting the infrared portion of the solar spectrum. A study conducted by National Renewable Energy Laboratory found benefits to sleeper cab tractors using reflective paint.[94] Solar control glazing reflects some of the solar energy from the glass. CARB found that most heavy-duty trucks today use solar absorbing glass.

There are many factors that influence the level of emissions and fuel consumption reductions due to solar control glazing and solar reflective paint. The fraction of time spent idling during the daytime hours, the fraction of hours of the day that are sunny, the ambient temperatures, the wind conditions and/or vehicle speed, the fraction of the vehicles that are painted colors other than white, and other factors influence the potential impact of these technologies. Because of the difficulty in assessing the potential emission reductions from solar control paint and glazing, the agencies are not proposing this technology as part of HD Phase 2, but these types of technologies could be considered under the innovative technology program.

2.4.10 **Other Accessory Improvements**

Electric power steering (EPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles such as Class 2b and 3 may require a higher voltage system which may add cost and complexity.

The 2017 light-duty final rule estimated a one to two percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. The SwRI report estimated 0.8 percent to 1 percent effectiveness. The agencies reviewed these SwRI effectiveness estimates and found them to be accurate, thus they have been retained for this proposal.

In addition to the purely hybrid technologies, which decreases the proportion of propulsion energy coming from the fuel by increasing the proportion of that energy coming from electricity, there are other steps that can be taken to improve the efficiency of auxiliary functions (*e.g.*, power-assisted steering or air-conditioning) which also reduce CO_2 emissions and fuel consumption. Optimization of the auxiliary functions is collectively referred to as vehicle or accessory load electrification because they generally use electricity instead of engine power. These improvements are considered enablers for hybrid systems.

2.4.11 **Predictive Cruise Control**

Cruise control is commonly used in light-duty and heavy-duty applications to maintain a vehicle at a set speed. However, cruise control systems with additional intelligence and predictive control in are much more complex but offer opportunities to reduce fuel consumption and GHG emissions. Many of the heavy-duty manufacturers are developing intelligent cruise control systems and though they resemble each other in overall function, each manufacturer is doing it differently.

As an example, an intelligent cruise control system partnered with a source of elevation information could detect when the vehicle is on a hill and know when it is close to cresting the hill. During this time, the vehicle may be allowed to temporarily travel at a lower speed to prevent the need for a transmission downshift, which consumes more fuel because it requires the engine to increase the rpm and run in a less efficient part of the fuel map. Similarly, predictive cruise control allows a vehicle to exceed the speed set point by a specified amount so that the vehicle will start the next hill at a higher speed and reduce the likelihood of needing to downshift on the next hill.

The amount of reduction in fuel consumption and CO_2 emissions depends significantly on the terrain. Sources estimate that the overall savings is approximately two percent.[95]

2.5 Technology Application and Estimated Costs – HD Pickups and Vans

2.5.1 Gasoline Engines

Spark ignited (gasoline) engines used in complete Class 2b and 3 pickups and vans include engines offered in a manufacturer’s light-duty truck counterparts, as well as engines specific to the Class 2b and 3 segment. Based on 2014 MY specifications, these engines typically range in displacement between 5 and 7 liters, though smaller and larger engines have also been used in this market. The majority of these engines are a V8 configuration, although the V10 configuration is also marketed.

The engine technologies are based on the technologies described in the Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document and Sections 2.2 and 2.3 above.[96] Some of the references come from the 2010 NAS Report, Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy-Duty Vehicles. These technologies include engine friction reduction, cam phasing, cylinder deactivation and stoichiometric gas direct injection. Included with each technology description is an estimate of the improvement in fuel consumption and GHGs that is achievable through the use of the technology in heavy-duty pickup trucks and vans.

2.5.1.1 Low Friction Lubricants

One of the most basic methods of reducing fuel consumption in both gasoline and diesel engines is the use of lower viscosity engine lubricants. More advanced multi-viscosity engine oils are available today with improved performance in a wider temperature band and with better lubricating properties. This can be accomplished by changes to the oil base stock (*e.g.*, switching engine lubricants from a Group I base oils to lower-friction, lower viscosity Group III synthetic) and through changes to lubricant additive packages (*e.g.*, friction modifiers and viscosity improvers). The use of 5W-30 motor oil is now widespread and auto manufacturers are introducing the use of even lower viscosity oils, such as 5W-20 and 0W-20, to improve cold-flow properties and reduce cold start friction. However, in some cases, changes to the crankshaft, rod and main bearings and changes to the mechanical tolerances of engine components may be required. In all cases, durability testing would be required to ensure that durability is not compromised. The shift to lower viscosity and lower friction lubricants would also improve the effectiveness of valvetrain technologies such as cylinder deactivation, which rely on a minimum oil temperature (viscosity) for operation.

Based on light-duty 2017-2025 MY vehicle rulemaking, and previously-received confidential manufacturer data, the agencies have estimated the effectiveness of low friction lubricants to be between 0 to 1 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.2 Engine Friction Reduction

Manufacturers can reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Approximately 10 percent of the energy consumed by a vehicle is lost to friction, and just over half is due to frictional losses within the engine. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available.

Estimations of fuel consumption improvements due to reduced engine friction from the 2015 NHTSA Technology Study range from 1 percent to 2 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.3 Engine Parasitic Demand Reduction

Manufacturers can reduce mechanical engine loads and improve fuel consumption by implementing variable-displacement oil pumps, higher-efficiency direct injection fuel pumps, and variable speed/displacement coolant pumps.

Estimations of fuel consumption improvements due to reduced engine parasitic demand from the 2015 NHTSA Technology Study range from 1 percent to 2 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.4 Variable Valve Timing

Variable valve timing (VVT) classifies a family of valve-train designs that alter the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control the level of residual gases in the cylinder. VVT reduces pumping losses when the engine is lightly loaded by controlling valve timing closer to the optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used to alter (and optimize) the effective compression ratio where it is advantageous for certain engine operating modes (*e.g.*, in the Atkinson Cycle).

VVT has now become a widely adopted technology in the light duty fleet: in MY 2014, most of all new cars and light trucks had engines with some method of variable valve timing.[97] Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. Therefore, the degree of further improvement across the fleet is limited by the level of valvetrain technology already implemented on the vehicles. The three major types of VVT are listed below.

Each of the implementations of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as "camshaft phasing." The phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

2.5.1.4.1 *Coupled Cam Phasing for Overhead Valve (OHV) and Single Overhead Camshaft (SOHC) Engines*

Valvetrains with coupled (or coordinated) cam phasing (CCP) can modify the timing of both the inlet valves and the exhaust valves an equal amount by varying the phasing of the camshaft across an engine's range of operating speeds; also known as VVT. For engines configured as an overhead valve (OHV) or as a single overhead camshaft (SOHC) only one cam phaser is required per camshaft to achieve CCP.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.4.2 *Intake Cam Phasing (ICP) for Dual Overhead Camshaft Engines (DOHC)*

Valvetrains with ICP, which is the simplest of the cam phasing technologies, can modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed. This requires the addition of a cam phaser on each bank of intake valves on the engine. An in-line 4-cylinder engine has one bank of intake valves, while V-configured engines have two banks of intake valves.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the heavy-duty 2014-2018 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 2 percent reduction in fuel consumption for this technology.

2.5.1.4.3 *Dual Cam Phasing (DCP) for Dual Overhead Camshaft Engines (DOHC)*

The most flexible VVT design is dual (independent) cam phasing, where the intake and exhaust valve opening and closing events are controlled independently. This option allows the option of controlling valve overlap, which can be used as an internal EGR strategy. At low engine loads, DCP creates a reduction in pumping losses, resulting in improved fuel consumption. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved depends on the residual tolerance of the combustion system. Additional improvements are observed at idle, where low valve overlap could result in improved combustion stability, potentially reducing idle fuel consumption. DCP requires two cam phasers on each bank of the engine.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the light-duty 2012-2016 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 3 percent reduction in fuel consumption for this technology.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.5 Variable Valve Lift (VVL)

Controlling the lift of the valves provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVL into their fleets (Toyota, Honda, and BMW). There are two major classifications of variable valve lift, described below:

2.5.1.5.1 ***Discrete Variable Valve Lift (DVVL)***

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. By optimizing the cam profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. This increases the efficiency of the engine. These cam profiles consist of a low and a high-lift lobe, and may include an inert or blank lobe to incorporate cylinder deactivation (in the case of a 3-step DVVL system). DVVL is normally applied together with VVT control. DVVL is also known as Cam Profile Switching (CPS). DVVL is a mature technology with low technical risk.

Based on the light-duty MY 2017-2025 final rule, previously-received confidential manufacturer data, 2015 NHTSA Technology Study, and report from the Northeast States Center for a Clean Air Future (NESCCAF), the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.6 Cylinder Deactivation

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part-cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque within which it can deactivate the cylinders. Noise and vibration issues reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellations systems to address Noise Vibration and Harshness (NVH) concerns and to allow a greater operating range of activation.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently.

Based on the 2015 NHTSA Technology Study and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 2.5 and 3.5 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.7 Stoichiometric Gasoline Direct Injection

Stoichiometric gasoline direct injection (SGDI) engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures, and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers have recently introduced vehicles with SGDI engines, including GM and Ford, who have announced their plans to increase dramatically the number of SGDI engines in their light-duty portfolios.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of SGDI to be between 1 and 2 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.1.8 Turbocharging and Downsizing (TRBDS)

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

Almost every major manufacturer currently markets a vehicle with some form of boosting. While boosting has been a common practice for increasing performance for several decades, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common “turbo lag”) while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios for example a very small displacement engine in a vehicle with significant curb weight, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of GDI systems with turbocharged engines and charge air cooling also reduces the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios. Ford's "EcoBoost" downsized, turbocharged GDI engines introduced on MY 2010 vehicles allow the replacement of V8 engines with V6 engines with improved in 0-60 mph acceleration and with fuel economy improvements of up to 12 percent.[98]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines.[14,15,16,17,18] Confidential manufacturer data suggests an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system;[99] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[100] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[101] These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

The agencies reviewed estimates from the LD 2017-2025 final rule, the TSD, and existing public literature. The previous estimate from the MYs 2017-2025 suggested a 12 to 14 percent effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over baseline fixed-valve engines, similar to the estimate for Ford's EcoBoost engine, which is already in production. Additionally, the agencies analyzed Ricardo vehicle simulation data and the 2015 NHTSA Technology Study for various turbocharged engine packages. Based on these data, and considering the widespread nature of the public estimates, the agencies assume that turbocharging and downsizing, would provide a 16.4 percent effectiveness improvement over naturally aspirated engines as applied to Class 2b and 3 vehicles.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

Note that for this analysis we determined that this technology path is only applicable to heavy duty applications that have operating conditions more closely associated with light duty vehicles. This includes vans designed mainly for cargo volume or modest payloads having similar GCWR to light duty applications. These vans cannot tow trailers heavier than similar light duty vehicles and are largely already sharing engines of significantly smaller displacement and cylinder count compared to heavy duty vehicles designed mainly for trailer towing.

2.5.1.9 Cooled Exhaust-Gas Recirculation

Cooled exhaust gas recirculation or Boosted EGR is a combustion concept that involves utilizing EGR as a charge diluent for controlling combustion temperatures and cooling the EGR prior to its introduction to the combustion system. Higher exhaust gas residual levels at part load conditions reduce pumping losses for increased fuel economy. The additional charge dilution enabled by cooled EGR reduces the incidence of knocking combustion and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this proposal would use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. The engines would also use single-stage, variable geometry turbocharging with higher intake boost pressure available across a broader range of engine operation than conventional turbocharged SI engines. Such a system is estimated to be capable of an additional 3 to 5 percent effectiveness relative to a turbocharged, downsized GDI engine without cooled-EGR. The agencies have also considered a more advanced version of such a cooled EGR system that employs very high combustion pressures by using dual stage turbocharging.

2.5.2 **Diesel Engines**

Diesel engines in this class of vehicle have emissions characteristics that present challenges to meeting federal NO_X emissions standards. It is a significant systems-engineering challenge to maintain the fuel consumption advantage of the diesel engine while meeting U.S. emissions regulations. Fuel consumption can be negatively impacted by emissions reduction strategies depending on the combination of strategies employed. Emission compliance strategies for diesel vehicles sold in the U.S. are expected to include a combination of improvements of combustion, air handling system, aftertreatment, and advanced system control optimization. These emission control strategies are being introduced on Tier 2 light-duty diesel vehicles today.

Some of the engine technologies are described in the Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document.[102] Others are from the 2010 NAS Report, Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, and the 2015 NHTSA Technology Study. Several key advances in diesel technology have made it possible to reduce emissions coming from the engine prior to aftertreatment. These technologies include engine friction and parasitic loss reduction, improved fuel systems (higher injection pressure and multiple-injection capability), advanced controls and sensors to optimize combustion and emissions performance, higher EGR levels and EGR cooling to reduce NO_X, and advanced turbocharging systems.

2.5.2.1 Low Friction Lubricants

Consistent with the discussion above for gasoline engines (see Section 2.5.1.1), the agencies are expecting some engine changes to accommodate low friction lubricants. Based on the light-duty 2014-2018 MY HD vehicle rulemaking, and previously-received confidential manufacturer data, the agencies estimated the effectiveness of low friction lubricants to be between 0 to 1 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

Based on a survey of the current powertrains being applied to the Class 2b and 3 segment and the level of powertrain sharing with the light duty vehicle market for these vehicles, the majority of light heavy duty gasoline engines in the 2014 Class 2b and 3 vehicle models are utilizing some form of low friction lubricants to achieve power and emission goals, and so this technology is considered to be in the baseline.

2.5.2.2 Engine Friction Reduction

Reduced friction in bearings, valve trains, and the piston-to-liner interface will improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. In virtually all production engines, the piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offer opportunities for friction reduction. Use of more advanced oil lubricant that could be available for production in the future may also eventually play a key role in reducing friction. Mechanical loads can also be reduced by converting the water, oil, and fuel pumps in the engine from fixed displacement to variable displacement.

Estimations of fuel consumption improvements due to reduced engine friction from the 2015 NHTSA Technology Study range from 1 percent to 2 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.2.3 Turbocharger Technology

Compact two stage turbochargers can increase the boost level with wider operation range, thus improving engine thermal efficiency. Ford's new developed 6.7L Scorpion engine features a twin-compressor turbocharger[103]. Cummins has also developed its own two stage turbochargers.[104] It is expected that this type of technology will continue to be improved by better system matching and development of higher compressor and turbine efficiency.

Based on the 2015 NHTSA Technology Study and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 2 and 3 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.2.4 Reduction of Parasitic Loads

Accessories that are traditionally gear- or belt-driven by a vehicle's engine can be optimized and/or converted to electric power. Examples include the engine water pump, oil pump, fuel injection pump, air compressor, power-steering pump, cooling fans, and the vehicle's air-conditioning system which can be converted to full electrically driven loads or an electromechanical arrangement that retains some mechanically connected aspects. Optimization and improved pressure regulation may significantly reduce the parasitic load of the water, air and fuel pumps. Electrification may result in a reduction in power demand, because electrically-powered accessories (such as the air compressor or power steering) operate only when needed if they are electrically powered, but they impose a parasitic demand all the time if they are engine-driven. In other cases, such as cooling fans or an engine's water pump, electric power allows the accessory to run at speeds independent of engine speed, which can reduce power consumption. The 2015 NHTSA Technology Study used a 1 to 2 percent fuel consumption reduction for diesel engine parasitic improvements.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.2.5 Aftertreatment Improvements

The HD diesel pickup and van segment has largely adopted the SCR type of aftertreatment system to comply with criteria pollutant emission standards. As the experience base for SCR expands over the next few years, many improvements in this aftertreatment system such as construction of the catalyst, thermal management, and reductant optimization may result in a reduction in the amount of fuel used in the process. However, due to uncertainties with these improvements regarding the extent of current optimization and future criteria emissions obligations, the agencies are not considering aftertreatment improvements as a fuel-saving technology in the rulemaking analysis for HD pickups and vans.

2.5.3 **Drivetrain**

The agencies have also reviewed the transmission technology estimates used in the light-duty 2012-2016 MY vehicle rulemaking. In doing so, the agencies have considered or reconsidered all available sources and updated the estimates as appropriate. The section below describes each of the transmission technologies considered for this rulemaking.

2.5.3.1 Automatic 8-Speed Transmissions

Manufacturers can also choose to replace 6-speed transmissions with transmissions capable of 8-speeds or more. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers continue to develop strategies for smooth operation.

As discussed in the heavy-duty 2014-2018 MY vehicle rulemaking along with confidential manufacturer data projected that 8-speed transmissions could incrementally reduce fuel consumption by 1 to 3 percent from a baseline 6-speed automatic transmission. The SwRI report uses 2 to 3 percent fuel consumption reduction when replacing 6-speed baseline automatic transmissions with improved 8-speed automatic transmissions.

The agencies reviewed and revised these effectiveness estimates based on usage and testing methods for Class 2b and 3 vehicles. The agencies estimate the effectiveness for a conversion from a 6 to 8-speed transmission to be 2.7 percent.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.3.2 High Efficiency Transmission

For this proposal, a high efficiency transmission refers to some or all of a suite of incremental transmission improvement technologies that should be available within the 2019 to 2025 timeframe. The majority of these improvements address mechanical friction within the transmission. These improvements include but are not limited to: shifting clutch technology improvements, improved kinematic design, dry sump lubrication systems, more efficient seals, bearings and clutches (reducing drag), component superfinishing and improved transmission lubricants.

2.5.3.3 Electric Power Steering (EPS)

Electric power steering (EPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles such as Class 2b and 3 may require a higher voltage system which may add cost and complexity.

The 2017 light-duty final rule estimated a one to two percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. The SwRI report estimated 0.8 percent to 1 percent effectiveness. The agencies reviewed these SwRI effectiveness estimates and found them to be accurate, thus they have been retained for this proposal.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.3.4 Improved Accessories

The accessories on an engine, including the alternator, coolant and oil pumps are traditionally mechanically-driven. A reduction in CO_2 emissions and fuel consumption can be realized by driving them electrically, and only when needed (“on-demand”).

Electric water pumps and electric fans can provide better control of engine cooling. For example, coolant flow from an electric water pump can be reduced and the radiator fan can be shut off during engine warm-up or cold ambient temperature conditions which would reduce warm-up time, reduce warm-up fuel enrichment, and reduce parasitic losses.

Indirect benefit may be obtained by reducing the flow from the water pump electrically during the engine warm-up period, allowing the engine to heat more rapidly and thereby reducing the fuel enrichment needed during cold operation and warm-up of the engine. Faster oil warm-up may also result from better management of the coolant warm-up period. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator used to supply power to the electrified accessories.

Intelligent cooling can more easily be applied to vehicles that do not typically carry heavy payloads, so larger vehicles with towing capacity present a challenge, as these vehicles have high cooling fan loads.[A] However, towing vehicles tend to have large cooling system capacity and flow scaled to required heat rejection levels when under full load situations such as towing at GCWR in extreme ambient conditions. During almost all other situations, this design characteristic may result in unnecessary energy usage for coolant pumping and heat rejection to the radiator.

The agencies considered whether to include electric oil pump technology for the rulemaking. Because it is necessary to operate the oil pump any time the engine is running, electric oil pump technology has insignificant effect on efficiency. Therefore, the agencies decided to not include electric oil pump technology.

2.5.3.5 Mild Hybrid (MHEV)

Mild hybrid systems offer idle-stop functionality and a limited level of regenerative braking and power assist. These systems replace the conventional alternator with a belt or crank driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack.

For the MHEV technology the agencies sized the system using a 7 kW starter/generator and 8 kWh Li-ion battery pack. The estimates were developed by Argonne National Laboratory as a supplement to the 2015 NHTSA Technology Study, resulting in an effectiveness range of 4 to 5 percent depending on the vehicle's engine. We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.3.6 Strong Hybrid (SHEV)

A hybrid vehicle is a vehicle that combines two significant sources of propulsion energy, where one uses a consumable fuel (like gasoline), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient

[A] In the CAFE model, improved accessories refers solely to improved engine cooling. However, EPA has included a high efficiency alternator in this category, as well as improvements to the cooling system.

point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.

- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.
- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine was downsized to maintain the same performance as the conventional version. The non-downsizing approach is used for vehicles like trucks where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed truck attribute, manufacturers are hesitant to offer a truck with downsized engine which can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles.

Strong Hybrid technology utilizes an axial electric motor connected to the transmission input shaft and connected to the engine crankshaft through a clutch. The axial motor is a motor/generator that can provide sufficient torque for launch assist, all electric operation, and the ability to recover significant levels of braking energy.

For SHEV, the agencies also relied on the study by Argonne National Laboratory to supplement the 2015 NHTSA Technology Study to determine that the effectiveness of these systems in terms of CO_2 reduction. For the SHEV technology the agencies sized the system using a 50 kW starter/generator and a70 kWh Li-ion battery pack. The estimates resulted in an effectiveness range of 18 to 22 percent depending on the engine. The estimates assume no engine downsizing in order to maintain vehicle performance and/or maintain towing and hauling performance.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.4 **Aerodynamics**

Aerodynamic drag is an important aspect of the power requirements for Class 2b and 3 trucks. Because aerodynamic drag is a function of the cube of vehicle speed, small changes in the aerodynamics of a Class 2b and 3 can reduce drag, fuel consumption, and GHG emissions. Some of the opportunities to reduce aerodynamic drag in Class 2b and 3 vehicles are similar to those in Class 1 and 2 (*i.e.*, light-duty) vehicles. In general, these transferable features make the cab shape more aerodynamic by streamlining the airflow over the bumper, grill, windshield, sides, and roof. Class 2b and 3 vehicles may also borrow from light-duty vehicles certain drag reducing accessories (*e.g.*, streamlined mirrors, operator steps, and sun visors). The great variety of applications for Class 2b and 3 trucks result in a wide range of operational speed profiles (*i.e.*, in-use drive cycles) and functional requirements (*e.g.*, shuttle buses that must be tall enough for standing passengers, trucks that must have racks for ladders). This variety makes it challenging to develop aerodynamic solutions that consider the entire vehicle.

Many factors affect a vehicle's aerodynamic drag and the resulting power required to move it through the air. While these factors change with air density and the square and cube of vehicle speed, respectively, the overall drag effect is determined by the product of its frontal area and drag coefficient. Reductions in these quantities can therefore reduce fuel consumption and CO_2 emissions. Although frontal areas tend to be relatively similar within a vehicle class (mostly due to market-competitive size requirements), significant variations in drag coefficient can be observed. Significant changes to a vehicle's aerodynamic performance may need to be implemented during a redesign (*e.g.*, changes in vehicle shape). However, shorter-term aerodynamic reductions, with a somewhat lower effectiveness, may be achieved through the use of revised exterior components (typically at a model refresh in mid-cycle) and add-on devices that are currently being applied. The latter list would include revised front and rear fascias, modified front air dams and rear valances, addition of rear deck lips and underbody panels, and lower aerodynamic drag exterior mirrors.

For this proposal, the agencies considered two levels of aero improvements. The first level includes such body features as air dams, tire spats, and perhaps one underbody panel resulting in a 5 percent aerodynamic drag reduction. The agencies estimated the CO_2 and fuel consumption effectiveness of this first level of aerodynamic drag at 0.75 percent.

The second level which includes the features of level 1 plus additional body features such as active grille shutters[B], rear visors, larger under body panels or low-profile roof racks resulting in a 10 percent aerodynamic drag reduction. The agencies estimated the CO_2 and fuel consumption effectiveness of this second level of aerodynamic drag at 1.5 percent. We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.5 **Tires**

Typically, tires used on Class 2b/3 vehicles are not designed specifically for the vehicle. These tires are designed for broader use and no single parameter is optimized. Similar to vocational vehicles, the market has not demanded tires with improved rolling resistance thus far; therefore, manufacturers have not traditionally designed tires with low rolling resistance for Class 2b/3 vehicles. The agencies believe that a regulatory program that incentivizes the optimization of tire rolling resistance, traction and durability can bring about GHG emission and fuel consumption reductions of 1.1 percent from this segment based on a 10 percent reduction in rolling resistance.

[B] For details on how active aerodynamics are considered for off-cycle credits, see TSD Chapter 5.2.2.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.5.6 Mass Reduction

Mass reduction is a technology that can be used in a manufacturer's strategy to meet the Heavy Duty Greenhouse Gas Phase 2 standards. Vehicle mass reduction (also referred to as "down-weighting" or 'light-weighting"), decreases fuel consumption and GHG emissions by reducing the energy demand needed to overcome inertia forces, and rolling resistance. Automotive companies have worked with mass reduction technologies for many years and a lot of these technologies have been used in production vehicles. The weight savings achieved by adopting mass reduction technologies offset weight gains due to increased vehicle size, larger powertrains, and increased feature content (sound insulation, entertainment systems, improved climate control, panoramic roof, etc.). Sometimes mass reduction has been used to increase vehicle towing and payload capabilities.

Manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction, also referred to as primary mass reduction, plus the additional mass reduction taken from indirect ancillary systems and components, also referred to as secondary mass reduction or mass compounding. There are more secondary mass reductions achievable for light-duty vehicles compared to heavy-duty vehicles, which are limited due to the higher towing and payload requirements for these vehicles.

Mass reduction can be achieved through a number of approaches, even while maintaining other vehicle functionalities. As summarized by NAS in its 2011 light duty vehicle report, there are two key strategies for primary mass reduction: 1) changing the design to use less material; 2) substituting lighter materials for heavier materials.[105]

The first key strategy of using less material compared to the baseline component can be achieved by optimizing the design and structure of vehicle components, systems and vehicle structure. Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. For example, the Future Steel Vehicle (FSV) project sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry Grade and Gauge) optimization, and subsystem optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure.[106] Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials.

The second key strategy to reduce mass of an assembly or component involves the substitution of lower density and/or higher strength materials. Material substitution includes replacing materials, such as mild steel, with higher-strength and advanced steels, aluminum, magnesium, and composite materials. In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and a manufacturer may invest more heavily in adjusting to a particular type of advanced material, thus complicating its ability to consider others. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and noise, vibration and harshness (NVH).

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle acceleration performance. If a powertrain is downsized, a portion of the mass reduction may be attributed to the reduced torque requirement which results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission torque converter and gear ratios, and changes to final drive gear ratio. The reduced powertrain torque enables the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (e.g., for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. Likewise, the combined mass reductions of the engine, drivetrain, and body in turn reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which allows for further optimization and potential mass reduction. However, pickup trucks have towing and hauling requirements which must be taken into account when determining the amount of secondary mass reduction that is possible and so it is less than that of passenger cars.

Ford's MY 2015 F-150 is one example of a light duty manufacturer who has begun producing high volume vehicles with a significant amount of mass reduction identified, specifically 250 to 750 lb per vehicle.[107] The vehicle is an aluminum intensive design and includes an aluminum cab structure, body panels, and suspension components, as well as a high strength steel frame and a smaller, lighter and more efficient engine. The Executive Summary to Ducker Worldwide's 2014 report states that state that the MY 2015 F-150 contains 1080 pounds of aluminum with at least half of this being aluminum sheet and extrusions for body and closures.[108] Ford engine range for its light duty truck fleet includes a 2.7L EcoBoost V-6. It is possible that the strategy of aluminum body panels would be applied to the heavy duty F-250 and F-350 versions when they are redesigned.[109]

The US EPA recently completed a multi-year study with FEV North America, Inc. on the lightweighting of a light-duty pickup truck, a 2011 GMC Silverado, titled "Mass Reduction and Cost Analysis –Light-Duty Pickup Trucks Model Years 2020-2025".[110] Results contain a cost curve for various mass reduction percentages with the main solution being evaluated for a 21.4 percent (511 kg/1124 lb) mass reduction resulting in an increased direct incremental manufacturing cost of $2228. In addition, the report outlines the compounding effect that occurs in a vehicle with performance requirements including hauling and towing. Secondary mass evaluation was performed on a component level based on an overall 20 percent vehicle mass reduction. Results revealed 84 kg of the 511 kg, or 20 percent, were from secondary mass reduction. Information on this study is summarized in SAE paper 2015-01-0559. The US DOT has also sponsored an on-going pickup truck lightweighting project. This project uses a more recent baseline vehicle, a MY 2014 GMC Silverado, and the project will be finished by early

2016. Both projects will be utilized for the light-duty GHG Phase 2 Midterm Evaluation mass reduction baseline characterization and may be used to update assumptions of mass reduction for HD pickups and vans for the final Phase 2 rulemaking.

In order to determine if technologies identified on light duty trucks are applicable to heavy-duty pickups, the U.S. EPA also contracted with FEV North America, Inc. to perform a scaling study in order to evaluate the technologies identified for the light-duty truck would be applicable for a heavy-duty pickup truck, in this study a Silverado 2500, a Mercedes Sprinter and a Renault Master. This report is currently being drafted and will be peer reviewed and finalized between the NPRM and FRM. In general, the heavy-duty pickup truck scaling study reveals results similar to the light-duty truck study; however, the mass reduction and cost for the Sprinter and Master were less in percent mass reduction and with much higher costs than the heavy-duty pickup truck. The specific results will be included in the final rulemaking.

We present cost estimates for this technology in Chapter 2.12 of this draft RIA.

2.6 Technology Application– SI Engines

This section summarizes the technologies the agencies project as a feasible path to meeting the proposed engine standards for spark-ignition engines used in vocational vehicles – that is engines that are engine-certified and intended for vocational vehicles that will be GEM-certified. These standards apply with respect to emissions measured over the FTP test cycle. This cycle is described in Chapter 3.1. See Chapter 2.5 for spark-ignited engine technologies projected for the proposed Phase 2 HD pickup and van vehicle standards.

Heavy-duty spark-ignited (SI) engines are used in almost 30 percent of vocational vehicles. Operators that choose gasoline engines do so for reasons similar to those for HD complete pickups and vans. Gasoline engines have the advantage of being less expensive and lower weight than diesels, but tend to also be less durable and have higher fuel consumption. Thus, gasoline engines are most likely to be purchased for applications with lower annual VMT, where fuel costs are less important than upfront costs.

Today some SI-powered vocational vehicles are sold as incomplete vehicles by a vertically integrated chassis manufacturer, where the Phase 1 rules allow manufacturers to choose to certify incomplete vehicles with weight ratings between 8,501 and 14,000 lbs GVWR as vocational vehicles under the GEM certification procedures including separate engine GHG certification, if the engine is also engine-certified for criteria pollutants.[C] In this case, vertically integrated means both the engine and chassis are manufactured by the same entity.

In Phase 1 we generally required that vehicles that are chassis-certified for criteria pollutants be chassis-certified for GHGs and fuel consumption, and likewise that vehicles with engines certified for criteria pollutants (which in this case would be engines installed in vocational vehicles exclusively) be certified to the vocational vehicle standards for GHGs and fuel consumption, with minor exceptions. We believe that this approach involving consistent

[C] See 76 FR 57106 (September 15, 2011) and 40 CFR 1037.104(f) chassis- and engine-certification for criteria pollutants and GHG's is the most sensible way to structure a program to minimize both the testing burden and the potential for gaming.

There is a Phase 1 optional provision that allows manufacturers to certify Class 4 or 5 (14,001 to 19,500 lb GVWR) complete or incomplete vehicles to be chassis certified and thereby included within the Class 2b/3 fleet average.[D] In Section XIV of the preamble to this rulemaking, EPA is requesting comment on some specific issues related to chassis certification of vehicles over 14,000 lbs GVWR for criteria pollutants. As adopted in Phase 1, the engines in these vehicles must be engine-certified for criteria pollutants, but the manufacturers may include the vehicles in their fleet average standard and annual compliance GHG calculations, using the same certification and compliance provisions as for the lighter vehicles. Such vehicles are not required to meet the vocational vehicle standards. Because sales volumes of Class 4 and 5 trucks are relatively small, and because we expect these Class 4 and 5 and Class 2b and 3 trucks to generally use the same technologies and face roughly the same technology challenge in meeting their standards targets, we do not believe that this provision dilutes the stringency of the fleet average standards.

Another, less common way that SI-powered vocational vehicles are built is by a non-integrated chassis manufacturer purchasing an engine from a company that also produces complete and/or incomplete HD pickup trucks and vans. The Phase 1 program allows SI engine manufacturers to sell these so-called "loose" SI engines to other chassis manufacturers for use in vocational vehicles. The primary certification path designed in the Phase 1 program in this scenario is for the "loose" engine to be engine certified and the vehicle to be GEM certified under the GHG rules. This is common practice for CI engines, and in Phase 2 the agencies propose to continue this as the primary certification path for SI engines intended for vocational vehicles.

In Phase 1 we adopted a special provision aimed at simplifying compliance for manufacturers of complete HD pickups and vans that also sell a relatively small number of loose engines. This flexibility provision enables these manufacturers to avoid meeting the separate SI engine standard, instead averaging them into the applicable HD pickup and van fleet-wide average.[E] Loose engine sales account for the vast majority of CI-powered vocational vehicles, but represent a very small fraction of the SI-powered vocational vehicle market.

The SI engines certified and sold as loose engines into the heavy-duty vocational vehicle market are typically large V8 and V10 engines produced by General Motors and Ford. The number of engine families certified in the past for this segment of vehicles is very limited and has ranged between three and five engine models.[F] Unlike the heavy-duty diesel engines typical of this segment that are built for vocational vehicles, these SI engines are primarily developed for chassis-certified heavy-duty pickup trucks and vans, but are also installed in incomplete vocational vehicles.

[D] See 76 FR 57259-57260, September 15, 2011 and 78 FR 36374, June 17, 2013
[E] See 40 CFR 1037.150(m) and 49 CFR 535.5(a)(7).
[F] See EPA's heavy-duty engine certification database at http://www.epa.gov/otaq/certdata.htm#largeng.

Under this special Phase 1 provision, these loose engines need not be certified to engine-based GHG and fuel consumption standards, but instead may be treated under the regulations as though they are additional sales of the manufacturer's complete pickup and van products, on a one-for-one basis. The pickup/van vehicle so chosen must be the vehicle with the highest emission test weight that uses the engine (as this vehicle is likely to have the highest GHG emissions and fuel consumption).[G] However, if this vehicle is a credit-generator under the HD pickup and van fleet averaging program, no credits would be generated by these engine-as-vehicle contributors to the fleet average; they would be treated as just achieving the target standard. If, on the other hand, the vehicle is a credit-user, the appropriate number of additional credits would be needed to offset the engine-as-vehicle contributors. The purchaser of the engine would treat it as any other certified engine, and would still need to meet applicable vocational vehicle standards for the vehicles in which the engine is installed.

2.6.1 **Defining the Baseline Engines**

In deriving the stringency of the proposed Phase 2 SI engine standard, the agencies first reviewed the technology that was presumed in the MY 2010 Phase 1 baseline and the technology that was projected would be adopted to meet the MY 2016 SI engine standard, finalized as part of the Phase 1 program. Engines certified to this standard would represent a logical level at which to set a Phase 2 baseline performance level.

The agencies finalized MY 2016 standards that require manufacturers to achieve a five percent reduction in CO_2 compared to the Phase 1 MY 2010 baseline. That MY 2010 baseline engine was described in the Phase 1 preamble at Section III.B.2.a.iii, as a naturally aspirated, overhead valve V8 engine.[H]

In deriving the stringency of the MY 2016 gasoline engine standards, the agencies projected 100 percent adoption of engine friction reduction, coupled cam phasing, and stoichiometric gasoline direct injection (SGDI) to produce an overall five percent reduction from the reference engine, over the engine FTP test cycle. Table 2-4 presents the technologies projected to be present on an engine following this technology path.

Table 2-4 MY 2016 Technology Projection for SI Engines

TECHNOLOGY	ADOPTION RATE
Coupled Cam Phasing	100%
Engine friction reduction	100%
Gasoline direct injection	100%

In deciding whether to consider the above package as representing the Phase 2 baseline performance of SI engines, the agencies reviewed available certification information and

[G] Equivalent test weight is defined at 40 CFR 1037.104(d)(11) and is determined based on a vehicle's adjusted loaded vehicle weight as specified in 40 CFR 86.129, except that for vehicles over 14,000 pounds, this may be rounded to the nearest 500 pound increment.
[H] See 76 FR 57231

consulted with stakeholders to determine the degree to which these projections match with engines being produced today and engine product plans during the Phase 1 time frame. The agencies have learned that no SI engine manufacturer has applied SGDI to this type of engine to date, though cam phasing and engine friction reduction are widely being employed. Furthermore, no SI engine manufacturer has yet certified an engine to the future MY 2016 SI engine standard, and the agencies do not have specific information about what alternate technology paths the manufacturers may take.

Another possible method to establish a Phase 2 SI engine baseline performance level would be to assess the engines that are currently being produced for complete HD SI pickup trucks. These vehicles are powered by engines that closely resemble engines intended for vocational vehicles. Further, cab-complete and box-delete vehicles sold into vocational applications are often derived from HD pickup truck chassis. The SI engine technologies assessed for the reference fleet for the HD pickup and van program are described in the preamble Section VI and in the draft RIA Chapter 10. As described in the draft RIA Chapter 10, vehicle manufacturers typically offer few models (i.e. only a pickup truck and/or a cargo van) and while there are a large number of variants of each model, the degree of component sharing across the variants can make diversified technology application either economically impractical or impossible. Similarly, these manufacturers produce a limited number of engines and tune them for slight variants in output for a variety of car and truck applications. Manufacturers limit complexity in their engine portfolio for much the same reason as they limit complexity in vehicle variants: they face engineering manpower limitations, and supplier, production and service costs that scale with the number of parts produced.

The SI engine technologies that were considered in developing the proposed Phase 2 HD pickup truck standards and their projected adoption rates are shown in Table 2-5, as taken from Table VI-10 of the preamble. The vehicle-level technologies considered for the gasoline HD pickup truck standards and shown in Table VI-10 are not presented here. Considering the above-described constraints on engine technology adoption, it's not surprising the projections for technology packages for the Phase 2 HD pickup and van program include a limited set of SI engine technologies for HD pickup trucks.

Table 2-5 CAFE Model Technology Adoption Rates for HD Gasoline Pickup Trucks

TECHNOLOGY	REFERENCE CASE[a]	PROPOSAL (2.5% PER YEAR)[b]	
	2018	With strong hybrids	Without strong hybrids
Level 1 Low friction lubricants and Engine friction reduction	100%	100%	100%
Level 2 Low friction lubricants and Engine friction reduction[c]	35 to 40%	100%	100%
Cylinder deactivation (overhead valve)	8 to 9%	56%	56%
Variable valve timing	0%	56%	56%
Gasoline direct injection	0%	0%	56%

Notes:
[a] These values are taken from a spreadsheet file with CAFE model output, representing technology adoption rates projected in the no-action scenario.
[b] These values are taken from Section VI.C.8, Table VI-10 of the preamble, and represent technology adoption rates projected in the flat baseline scenario.

[c] Level 2 friction reduction as shown here is incremental to Level 1 friction reduction.

In comparing the technologies and projected adoption rates in Table 2-4 and Table 2-5, there are notable differences between what is projected for complete vehicles in MY 2018 and what was projected for engine-certified engines in MY 2016. The CAFE model used by the agencies treats different types of variable valve timing technologies as a group, so that coupled cam phasing would be included under the heading variable valve timing. The only type of variable valve timing that is feasible on an overhead valve engine is coupled cam phasing.[I] In light of the differences in projected adoption rates of SGDI and variable valve timing, there is uncertainty about the technology pathways that may be taken by SI engine manufacturers in the Phase 1 time frame. Thus, the agencies have concluded that it would be more appropriate to set the Phase 2 baseline performance level equal to the Phase 1 MY 2016 engine standard, rather than a performance level representing more or less technology than is represented by that standard.

2.6.2 Phase 2 Technology Feasibility and Effectiveness

A detailed description of many technologies potentially available to improve the fuel efficiency of SI engines can be found above in draft RIA Chapter 2.2. In deriving the stringency of the proposed Phase 2 SI engine standard, the agencies excluded the technologies already presumed in the baseline engine (see Table 2-4), and rejected technologies not considered as part of the proposed HD pickup truck standards (see Table 2-5). The agencies have not identified a single SI engine technology that we believe belongs on engine-certified vocational engines that we do not also project to be used on complete heavy-duty pickups and vans.

It is also important to consider how these engines will be used. Engines in pickup trucks are likely to be driven very differently than engines in vocational vehicles. For example, a complete pickup truck may do an extensive amount of towing while vocational vehicles rarely tow trailers. Further, the most popular applications for SI engines in vocational vehicles are motor homes and school buses, which each have very different driving patterns, which also differ from those of pickup trucks. The agencies believe these differences in application and intended use may lead manufacturers to offer engines that may have small differences, and that such differences would be captured by the vehicle test procedures applicable to those applications. Specifically, complete HD pickups are certified using a chassis test procedure that is described in 40 CFR part 86, while vocational vehicles are certified using the GEM vehicle simulation tool described in 40 CFR part 1037.

In light of the market structure described above in Chapter 2.6, when the agencies considered the feasibility of more stringent Phase 2 standards for SI vocational engines, we identified the following key questions:

1. Will there be technologies available that could reduce in-use emissions from vocational SI engines?

[I] See Preamble at Section VI.C.5(a)(iv)

2. Would these technologies be applied to complete vehicles and carried-over to engine certified engines without a new standard?
3. Would these technologies be applied to meet the vocational vehicle standards?
4. What are the drawbacks associated with setting a technology-forcing Phase 2 standard for SI engines?

With respect to the first question, the agencies have identified Level 2 lubricants, Level 2 engine friction reduction, and cylinder deactivation as technologies available to be considered for a Phase 2 SI engine standard. With respect to the second question, based on Table 2-5, we project that these may be applied to complete vehicles. The agencies have further determined that to the extent these technologies would be viable for complete vehicles, they would also be applied to engine-certified engines, to the extent they would not detract from performance required by vocational vehicle owners.

With respect to the third question, we believe that to the extent these engine technologies are viable and effective, they would be applied to meet the GEM-based standards for vocational vehicles. As described elsewhere in this proposal, the Phase 2 GEM would recognize engine technologies through interpolation of engine data generated by engine manufacturers and submitted to EPA and NHTSA for vehicle certification. Thus, it would be possible for cylinder deactivation to be recognized over the vocational vehicle GEM test cycles, if it were present on a vocational SI engine.

Nevertheless, significant uncertainty remains about how much benefit would be provided by the identified Phase 2 candidate SI engine technologies. It is possible that the combined improvement of these technologies would be one percent or less. The degree of improvement for friction reduction is generally not cycle-dependent, but the effectiveness of cylinder deactivation is highly cycle-dependent.

It appears the fourth question regarding drawbacks is the most important. The agencies could propose a technology forcing standard for engine-certified SI engines based on a projection of each of these identified candidate technologies being effective for all engines. However, the agencies see value in setting the standard at a level that would not require every projected technology to work as expected. Effectively requiring technologies to match our current projections would create the risk that the standard would not be feasible if even a single one of the technologies failed to match our projections. This risk is amplified for SI engines because of the very limited product offerings, which provide far fewer opportunities for averaging than exist for CI engines.

Given the relatively small improvement projected, and the likelihood that most or all of this improvement would result anyway from the complete HD pickup and van standards and the vocational vehicle standards, we do not believe such risk is justified at the engine level.

Because one of the guiding principles of the Phase 2 program is maintaining customer choice, we have a strong interest in structuring a program that would enable SI engine manufacturers to continue supplying loose engines to the vocational vehicle market. For the reasons discussed above, rather than proposing a more stringent engine standard, the agencies are proposing to maintain the MY 2016 fuel consumption and CO_2 emission standards for SI engines for use in vocational vehicles: 7.06 gallon/100 bhp-hr and 627 g CO_2/bhp-hr, as measured over the Heavy-duty FTP engine test cycle.

In the preamble Section V and the draft RIA Chapter 2.9, the agencies describe the vocational vehicle standards, including details about ways we considered SI engine technologies such as advanced friction reduction over the GEM vehicle test cycles, as part of the proposed Phase 2 vocational vehicle standards.

2.7 Technology Application and Estimated Costs – CI Engines

2.7.1 Phase 1 Engines

For analytical purposes, the agencies are projecting the technologies that may be used to meet the 2017 diesel engine standard. This technology package serves as a baseline for costs for this proposal. The agencies project that such engines will be equipped with an aftertreatment system which meets EPA's 0.20 grams of NO_X/bhp-hr standard with a selective catalytic reduction (SCR) system along with EGR and meets the PM emissions standard with a diesel particulate filter (DPF) with active regeneration. The following discussion of technologies describes improvements over the 2017 model year engine performance, unless otherwise noted.

The CO_2 performance over the FTP as well as SET for the baseline engines were developed through manufacturer reporting of CO_2 in their non-GHG certification applications for 2014 model year. This data was carefully considered to ensure that the baseline represented an engine meeting the 0.20 g/bhp-hr NO_X standard. For those engines that were not at this NO_X level or higher, the agencies derived a CO_2 correction factor to bring them to a 0.20 g/bhp-hr NO_X emissions rate. The CO_2 correction factor is derived based on available experimental data obtained from manufacturers and public literature. The agencies then sales-weighted the CO_2 performance to derive a baseline CO_2 performance for each engine subcategory.

In order to establish baseline SET performance for the tractor engine and FTP performance for the vocational, several sources were considered. Some engine manufacturers provided the agencies with SET modal and FTP results or fuel consumption maps to represent their engine ranging from 2011 to 2013 model year engine fuel consumption performance. As a supplement to this, complete engine map CO_2 data (including SET modes) acquired in EPA test cells as well as those obtained from Southwest Research Institute under the agency contract were also considered. Those maps are subsequently adjusted to represent 2021 and 2024 model year engine maps by using predefined technologies that are being used in current 2014 production.

In summary, the baseline CO_2 performance for each diesel engine category is included in Table 2-6.

Table 2-6 Baseline CO_2 Performance (g/bhp-hr)

LHDD - FTP	MHDD - FTP	HHDD - FTP	HHDD - SET	HHDD - SET
576	576	555	487	460

2.7.2 Individual Technology Feasibility and Cost

The cost for combustion system optimization includes costs associated with several individual technologies, specifically, improved cylinder head, turbo efficiency improvements, EGR cooler improvements, higher pressure fuel rail, improved fuel injectors and improved pistons. The cost estimates for each of these technologies are presented in Section 2.12 of this draft RIA for heavy HD, medium HD and light HD engines, respectively.

The agencies have included the costs of model-based control development in the research and development costs applied separately to each engine manufacturer.

2.7.3 Test Cycle Weighting

The current SET modes used for tractor engine certification in Phase 1 has relative large weighting in C speed as shown in the middle column of the following table:

Table 2-7 SET Modes Weighting Factors

SPEED/% LOAD	WEIGHTING FACTOR IN PHASE 1 (%)	PROPOSED WEIGHTING FACTOR IN PHASE 2 (%)
Idle	15	12
A, 100	8	9
B, 50	10	10
B, 75	10	10
A, 50	5	12
A, 75	5	12
A, 25	5	12
B, 100	9	9
B, 25	10	9
C, 100	8	2
C, 25	5	1
C, 75	5	1
C, 50	5	1
Total	100	100
A:	23	45
B:	39	38
C:	23	5

It can be seen from the above table that 23 percent weighting is in C speed, which is typically in the range of 1800 rpm for HHD engines. However, many of today's HHD engines do not commonly operate in such a high speed in real world driving conditions, specifically during cruise vehicle speed between 55 and 65 mph. The agencies received confidential business information from a few vehicle manufacturers that support this observation. Furthermore, one of the key technology trends is to down speed, moving the predominant engine speed from the range of 1300-1400 rpm to the range of 1150-1200 rpm at vehicle speed of 65mph. This trend would make the predominant engine speed even further away from C speed. Therefore, it can be argued that, if the current SET weighting factors were retained in Phase 2, the test would even more poorly reflect real-world driving operations. Further, some technologies developed the standard may not be as effective over real world driving conditions, while technologies that would be more likely to deliver real world reductions could be under-represented on the test. Accordingly, the agencies are proposing to adjust the weighting of the various modes in the SET cycle as presented in the third column of Table 2-7.

As shown, the new proposed SET mode weighting basically would move most of the C weighting to A speed. It also would slightly reduce the weighting factor on the idle speed. These proposed values are based on the confidential business information obtained from vehicle manufacturers.

2.7.4 **Technology Packages**

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement for a tractor engine. The agencies considered improvements in parasitic and friction losses through piston designs to reduce friction, improved lubrication, and improved water pump and oil pump designs to reduce parasitic losses. The aftertreatment improvements are available through additional improvements to lower backpressure of the systems, further optimization of the engine-out NO_X levels, and further reduction on ammonia slop out of SCR. Improvements to the EGR system and air flow through the intake and exhaust systems, along with turbochargers, can also produce engine efficiency improvements. Improvement of combustion and controls can reduce fuel consumption of the engine. Engine downsizing is part of consideration for improving efficiency, specifically when this technology is used together with down speeding. Although one of the most effective technologies to improve engine efficiency is the use of waste heat recovery (WHR) with Rankine cycle concept, the agencies do not project that this technology will have noticeable market penetration until MY 2024. The reason is that this type of WHR system involves many components that require extensive field testing to assure reliability. See Chapter 2.3.9 above. The high technology cost, longer pay back period (if the cost and benefit of using WHR is considered in isolation), concern about commercial acceptance (given the technology complexity, cost, concern about demurrage costs and warranty claims in early model years) again point to longer necessary lead time for introducing this technology. During the stringency development based on various technologies, the agencies received strong supports from various stakeholders, provided as many confidential business information (CBI). Table 2-8 lists those potential technologies together with the agencies' estimated market penetration for tractor engine. However, as can be seen from this table, the agencies would not be able to release the more detailed numbers along each mode of 13 SET modes to justify our stringency proposal due to nature of CBI. It should be pointed out that the stringency developed in Table 2-8 is based on the new proposed reweighting SET factors.

With respect to market penetration, the agencies use the current market information and literature values to project what would be in the time frame beyond 2021. For example, only Daimler uses turbo-compound in their DD15 and DD16 engines currently. However, they are phasing out turbo-compound with the replacement of asymmetric turbo technology for most applications. In the meantime, Volvo just announced that they would put their new developed turbo-compound technology into the market. Combining both manufacturers' market shares, the agencies estimate 5 percent market share in 2021. With the assumption that this technology could prove to be cost effective and be accepted by market well, more production from existing manufacturers or even some of other manufacturers could adopt this technology in some of their trucks, and therefore the market share could pick up 10 percent after 2024. The agencies assume that the WHR with Rankine cycle will pick up momentum with more lead time because of the nature of high performance. However, as pointed out in Chapter 2.3.9, it would be hard to see massive production in the 2021 because of many potential issues. The agencies expect a small market penetration with one percent in 2021. Based on the industrial trend for typical complicated system like WHR, it would take time to have a sizeable market penetration, and therefore, it is estimated that 5 percent in 2024, and 15 percent in 2027. Except downsizing, all other technologies, such as parasitic/friction loss, aftertreatment, air breathing system, and combustion use the same assumption on the market penetration, such as 45 percent in 2021, 95 percent in 2024, and 100 percent in 2027. With respect to engine downsizing, the agencies don't expect high market penetration as others, because downsizing always has the trade-off with reliability and resale values. However, we do see the potential that this type of technology can be effective when combining with down speeding, specifically when power demand drops due to more efficient engine and vehicle. It is a matter of choices. We assume 10 percent, 20 percent, and 30 percent market penetration in 2021, 2024, and 2027 respectively.

It should be pointed out that the technology road maps shown in Table 2-8 including both reduction and market penetration would be only one of many paths manufacturers might adopt in order to achieve 1.5 percent, 3.7, and 4.2 percent reduction goals in 2021, 2024 and 2027 respectively. In addition, use of 1 percent, 5 percent, and 15 percent market penetration on WHR in 2021, 2024, and 2027 is one of many potential paths. Considering relatively small assumed market penetration, this only translates into very small percent improvements due to WHR. The manufacturers should be able to make up the difference or achieve the same reduction goals for 2021, 2024 and 2027 by either increasing individual technology improvement factors or increasing market penetration or combination of both.

Table 2-8 Projected Tractor Engine Technologies and Reduction, Percent Improvements Beyond Phase 1, 2017 Engine as Baseline

SET MODE	SET WEIGHTED REDUCTION (%) 2020-2027	MARKET PENETRATION (2021)	MARKET PENETRATION (2024)	MARKET PENETRATION (2027)
Turbo compound with clutch	1.8%	5%	10%	10%
WHR (Rankine cycle)	3.6%	1%	5%	15%
Parasitic/Friction (Cyl Kits, pumps, FIE), lubrication	1.4%	45%	95%	100%
Aftertreatment (lower dP)	0.6%	45%	95%	100%
EGR/Intake & exhaust manifolds/Turbo /VVT/Ports	1.1%	45%	95%	100%
Combustion/FI/Control	1.1%	45%	95%	100%
Downsizing	0.3%	10%	20%	30%
Weighted reduction (%)		1.5%	3.7%	4.2%

For the vocational engines, the agencies considered the same technology package developed for the HHD diesel engines as for the LHD diesel and MHD diesel engines. Similar to tractor engines, the package includes parasitic and friction reduction, improved lubrication, aftertreatment improvements, EGR system and air flow improvements, and combustion improvement. However, WHR technology is not part of the package. The reason is that WHR is not as efficient in transient mode, and since this is the principal operating mode for vocational vehicles, we project limited benefit for using WHR for vocational applications. Table 2-9 below lists those potential technologies together with the agencies' estimated market penetration for vocational engines, which is developed by combining the various CBI data with the agencies' engineering judgment.

The market penetration estimate shown in this table uses the same principle as the one discussed in the tractor engine. In terms of effectiveness, the model based control would be one of the most effective technologies. However, it would take significant efforts to develop it and put into production, such as neural network approach developed by Daimler[19,20], because one of the issues is that it is still not clear how this type of technology interact with on-board diagnostics (OBD). Therefore, we expect 25 percent market penetration in 2021, 30 percent in 2024, and finally 40 percent in 2027. In contrast, all other technologies, such as parasitic/friction, air breathing system, aftertreatment, and combustion are relatively more mature than the model based control, and therefore, higher market penetration is assumed.

Table 2-9 Projected Vocational Engine Technologies and Reduction, Percent Improvements Beyond Phase 1, 2017 Engine as Baseline

TECHNOLOGY	GHG EMISSIONS REDUCTION 2020-2027	MARKET PENETRATION 2021	MARKET PENETRATION 2024	MARKET PENETRATION 2027
Model based control	2.0%	25%	30%	40%
Parasitic /Friction	1.5%	60%	90%	100%
EGR/Air/VVT /Turbo	1.0%	50%	90%	100%
Improved AT	0.5%	50%	90%	100%
Combustion Optimization	1.0%	50%	90%	100%
Weighted reduction (%)- L/M/HHD		2.0%	3.5%	4.0%

2.7.5 2021 Model Year HHD Diesel Engine Package for Tractor

As can be seen from Table 2-8 the weighted reduction for a MY2021 tractor engine is 1.5 percent. With this reduction, the numerical stringency values for 2021 can be derived from the Phase 1 rules. These proposed standards are shown in Table 2-10.

Table 2-10 2021 Model Year Proposed Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	479	453
Fuel Consumption (gal/100 bhp-hr)	4.71	4.45

The cost estimates for the complete HHD diesel engine packages can be developed accordingly as shown in Table 2-11.

Table 2-11 Technology Costs as Applied in Expected Packages for MY2021 Tractor Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$7	$7
Valve Actuation	$82	$82
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$3	$3
Turbocharger (improved efficiency)	$9	$9
Turbo Compounding	$50	$50
EGR Cooler (improved efficiency)	$2	$2
Water Pump (optimized, variable vane, variable speed)	$43	$43
Oil Pump (optimized)	$2	$2
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$2	$2
Fuel Rail (higher working pressure)	$5	$5
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$5	$5
Piston (reduced friction skirt, ring and pin)	$1	$1
Valve Train (reduced friction, roller tappet)	$39	$39
Waste Heat Recovery	$105	$105
“Right sized” engine	-$40	-$40
Total	$314	$314

Note:
[a] Costs presented here include application rates.

2.7.6 2021 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

From Table 2-9, the proposed weighted reduction for 2021 model years of all LHD/MHD/HHD vocational diesel engines is 2.0 percent. Table 2-12 lists the numerical stringency values in 2021 model year.

Table 2-12 2021 Model Year Proposed Standards -- Vocational

	LHDD - FTP	MHDD - FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	565	565	544
Fuel Consumption (gal/100 bhp-hr)	5.55	5.55	5.34

The cost estimates for the MY2021 vocational diesel engines are shown in Table 2-13. We present technology cost estimates along with adoption rates in Chapter 2.12 of this draft RIA. We present package cost estimates in greater detail in Chapter 2.13 of this draft RIA.

Table 2-13 Technology Costs as Applied in Expected Packages for MY2021 Vocational Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$8	$8	$8
Valve Actuation	$91	$91	$91
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$3	$3
Turbocharger (improved efficiency)	$10	$10	$10
EGR Cooler (improved efficiency)	$2	$2	$2
Water Pump (optimized, variable vane, variable speed)	$57	$57	$57
Oil Pump (optimized)	$3	$3	$3
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$3	$3	$3
Fuel Rail (higher working pressure)	$7	$6	$6
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$8	$6	$6
Piston (reduced friction skirt, ring and pin)	$1	$1	$1
Valve Train (reduced friction, roller tappet)	$69	$52	$52
Model Based Controls	$28	$28	$28
Total	$293	$270	$270

Note:
[a] Costs presented here include application rates.

2.7.7 2024 Model Year HHDD Engine Package for Tractor

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement in the 2024 model year. The agencies considered additional improvements in the technologies included in the 2021 model year package. Compared to 2021 technology package, the technology package in 2024 considers higher market adoption as shown in Table 2-8, thus deriving the stringency at 3.7 percent. Table 2-14 below shows the proposed 2024 model year tractor engine standards.

Table 2-14 2024 Model Year Proposed Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	469	443
Fuel Consumption (gal/100 bhp-hr)	4.61	4.35

The costs for the MY2024 tractor diesel engines are shown in Table 2-15. We present technology cost estimates along with adoption rates in Chapter 2.12 of this draft RIA. We present package cost estimates in greater detail in Chapter 2.13 of this draft RIA.

Table 2-15 Technology Costs as Applied in Expected Packages for MY2024 Tractor Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$14	$14
Valve Actuation	$166	$166
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$6
Turbocharger (improved efficiency)	$17	$17
Turbo Compounding	$92	$92
EGR Cooler (improved efficiency)	$3	$3
Water Pump (optimized, variable vane, variable speed)	$84	$84
Oil Pump (optimized)	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4
Fuel Rail (higher working pressure)	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3
Valve Train (reduced friction, roller tappet)	$75	$75
Waste Heat Recovery	$502	$502
"Right sized" engine	-$85	-$85
Total	$904	$904

Note:
[a] Costs presented here include application rates.

2.7.8 2024 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

The agencies developed the 2024 model year LHD/MHD/HHD diesel engine package based on additional improvements in the technologies included in the 2021 model year package as shown in Table 2-9. The projected impact of these technologies provides an overall reduction of 3.5 percent over the 2017 model year baseline. Table 2-16 below shows the proposed 2024 model year standards in numerical values.

Table 2-16 2024 Model Year Proposed Standards – Vocational

	LHDD - FTP	MHDD - FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	556	556	536
Fuel Consumption (gal/100 bhp-hr)	5.46	5.46	5.26

Costs for MY 2024 vocational diesel engines are shown in Table 2-17. We present technology cost estimates along with adoption rates in Chapter 2.12 of this draft RIA. We present package cost estimates in greater detail in Chapter 2.13 of this draft RIA.

Table 2-17 Technology Costs as Applied in Expected Packages for MY2024 Vocational Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$13	$13	$13
Valve Actuation	$157	$157	$157
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$10	$6	$6
Turbocharger (improved efficiency)	$16	$16	$16
EGR Cooler (improved efficiency)	$3	$3	$3
Water Pump (optimized, variable vane, variable speed)	$79	$79	$79
Oil Pump (optimized)	$4	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4	$4
Fuel Rail (higher working pressure)	$10	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$13	$10	$10
Piston (reduced friction skirt, ring and pin)	$2	$2	$2
Valve Train (reduced friction, roller tappet)	$95	$71	$71
Model Based Controls	$31	$31	$31
Total	$437	$405	$405

Note:
[a] Costs presented here include application rates.

2.7.9 2027 Model Year HHDD Engine Package for Tractor

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement in the 2027 model year. The agencies considered additional improvements in the technologies included in the 2021 model year package. Compared to 2021 technology package, the technology package in 2027 considers higher market adoption as shown in Table 2-8, thus deriving the stringency at 4.2 percent. Table 2-18 below shows the proposed 2027 model year tractor engine standards.

Table 2-18 2027 Model Year Proposed Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	466	441
Fuel Consumption (gal/100 bhp-hr)	4.58	4.33

The costs for the MY2027 tractor diesel engines are shown in Table 2-19. We present technology cost estimates along with adoption rates in Chapter 2.12 of this draft RIA. We present package cost estimates in greater detail in Chapter 2.13 of this draft RIA.

Table 2-19 Technology Costs as Applied in Expected Packages for MY2027 Tractor Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$14	$14
Valve Actuation	$169	$169
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$6
Turbocharger (improved efficiency)	$17	$17
Turbo Compounding	$87	$87
EGR Cooler (improved efficiency)	$3	$3
Water Pump (optimized, variable vane, variable speed)	$84	$84
Oil Pump (optimized)	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4
Fuel Rail (higher working pressure)	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3
Valve Train (reduced friction, roller tappet)	$75	$75
Waste Heat Recovery	$1,340	$1,340
"Right sized" engine	-$127	-$127
Total	$1,698	$1,698

Note:
[a] Costs presented here include application rates.

2.7.10 2027 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

The agencies developed the 2027 model year LHD/MHD/HHD diesel engine package based on additional improvements in the technologies included in the 2021 model year package as shown in Table 2-9. The projected impact of these technologies provides an overall reduction of 4.0 percent over the 2017 model year baseline. Table 2-20 below shows the proposed 2027 model year standards in numerical values.

Table 2-20 2027 Model Year Proposed Standards – Vocational

	LHDD - FTP	MHDD- FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	553	553	533
Fuel Consumption (gal/100 bhp-hr)	5.43	5.43	5.23

Costs for MY 2027 vocational diesel engines are shown in Table 2-21. We present technology cost estimates along with adoption rates in Chapter 2.12 of this draft RIA. We present package cost estimates in greater detail in Chapter 2.13 of this draft RIA.

Table 2-21 Technology Costs as Applied in Expected Packages for MY2027 Vocational Diesel Engines under the Preferred Alternative relative to the Less Dynamic Baseline (2012$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$14	$14	$14
Valve Actuation	$169	$169	$169
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$10	$6	$6
Turbocharger (improved efficiency)	$17	$17	$17
EGR Cooler (improved efficiency)	$3	$3	$3
Water Pump (optimized, variable vane, variable speed)	$84	$84	$84
Oil Pump (optimized)	$4	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4	$4
Fuel Rail (higher working pressure)	$11	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$13	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3	$3
Valve Train (reduced friction, roller tappet)	$100	$75	$75
Model Based Controls	$39	$39	$39
Total	$471	$437	$437

Note:
[a] Costs presented here include application rates.

2.7.11 HD Diesel Engine Packages under the More Stringent Alternative 4

The more stringent alternative 4 would impose new standards in MYs 2021 and 2024, with the MY2024 standards essentially equivalent to the MY2027 standards under the preferred alternative. The resultant HDD engine costs for both tractors and vocational engines in MYs 2021 and 2024 are shown in Table 2-22. Note that, while the technology application rates in MY2024 under alternative 4 are essentially identical to those for MY2027 under alternative 3, the costs are higher under alternative 4 due to learning effects and markup changes that are estimated to have occurred by MY2027 under alternative 3.

Table 2-22 Technology Costs as Applied in Expected Packages for HD Diesel Engines under the More Stringent Alternative 4 relative to the Less Dynamic Baseline (2012$)[a]

MODEL YEAR	MHDD TRACTOR	HHDD TRACTOR	LHDD VOCATIONAL	MHDD VOCATIONAL	HHDD VOCATIONAL
2021	$656	$656	$372	$345	$345
2024	$1,885	$1,885	$493	$457	$457

Note:
[a] Costs presented here include application rates.

2.8 Technology Application and Estimated Costs – Tractors

2.8.1 Defining the Baseline Tractors

The fuel efficiency and CO_2 emissions of combination tractors vary depending on the configuration of the tractor. Many aspects of the tractor impact its performance, including the engine, transmission, drive axle, aerodynamics, and rolling resistance. For each tractor subcategory, the agencies selected a theoretical tractor to represent the average 2017 model year tractor that meets the Phase 1 standards (see 76 FR 57212, September 15, 2011). These tractors are used as baselines from which to evaluate costs and effectiveness of additional technologies and standards. The specific attributes of each tractor subcategory are listed below in Table 2-23. Using these values, the agencies assessed the CO_2 emissions and fuel consumption performance of the proposed baseline tractors using the proposed version of Phase 2 GEM. The results of these simulations are shown below in Table 2-24.

The Phase 1 2017 model year tractor standards and the baseline 2017 model year tractor results are not directly comparable. The same set of aerodynamic and tire rolling resistance technologies were used in both setting the Phase 1 standards and determining the baseline of the Phase 2 tractors. However, there are several aspects that differ. First, a new version of GEM was developed and validated to provide additional capabilities, including more refined modeling of transmissions and engines. Second, the determination of the proposed HD Phase 2 CdA value takes into account a revised test procedure, a new standard reference trailer, and wind averaged drag. In addition, the proposed HD Phase 2 version of GEM includes road grade in the 55 mph and 65 mph highway cycles, as discussed in preamble Section III.E. Finally, the agencies assessed the current level of automatic engine shutdown and idle reduction technologies used by the tractor manufacturers to comply with the 2014 model year CO_2 and fuel consumption standards. To date, the manufacturers are meeting the 2014 model year standards without the use of this technology. Therefore, the agencies are revising the baseline APU adoption rate back to 30 percent, the value used in the Phase 1 baseline.

Table 2-23 GEM Inputs for the Baseline Class 7 and 8 Tractor

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2017 MY 11L Engine 350 HP	2017 MY 11L Engine 350 HP	2017 MY 11L Engine 350 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP
Aerodynamics (CdA in m^2)								
5.00	6.40	6.42	5.00	6.40	6.42	4.95	6.35	6.22
Steer Tires (CRR in kg/metric ton)								
6.99	6.99	6.87	6.99	6.99	6.87	6.87	6.87	6.54
Drive Tires (CRR in kg/metric ton)								
7.38	7.38	7.26	7.38	7.38	7.26	7.26	7.26	6.92
Extended Idle Reduction Adoption Rate								
N/A	N/A	N/A	N/A	N/A	N/A	30%	30%	30%
Transmission = 10 Speed Manual Transmission **Gear Ratios =** 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Ratio = 3.70								

Table 2-24 Class 7 and 8 Tractor Baseline CO_2 Emissions and Fuel Consumption

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
CO_2 (grams CO_2/ton-mile)	107	118	121	86	93	95	79	87	88
Fuel Consumption (gal/1,000 ton-mile)	10.5	11.6	11.9	8.4	9.1	9.3	7.8	8.5	8.6

The 2017 model year baseline fuel maps in the HD Phase 2 version of GEM are different than those used in 2017 year fuel maps in the HD Phase 1 version. The baseline map in the HD Phase 2 version takes two major factors into consideration. The first is the likelihood of engine down speeding beyond the 2020 model year and the second is to make the gradient of brake specific fuel consumption rate (BSFC) around the fuel consumption sweet spot less radical when compared to the HD Phase 1 version's engine fuel map.

Figure 2-11 gives an example of an engine fuel map for a 455hp rated engine.

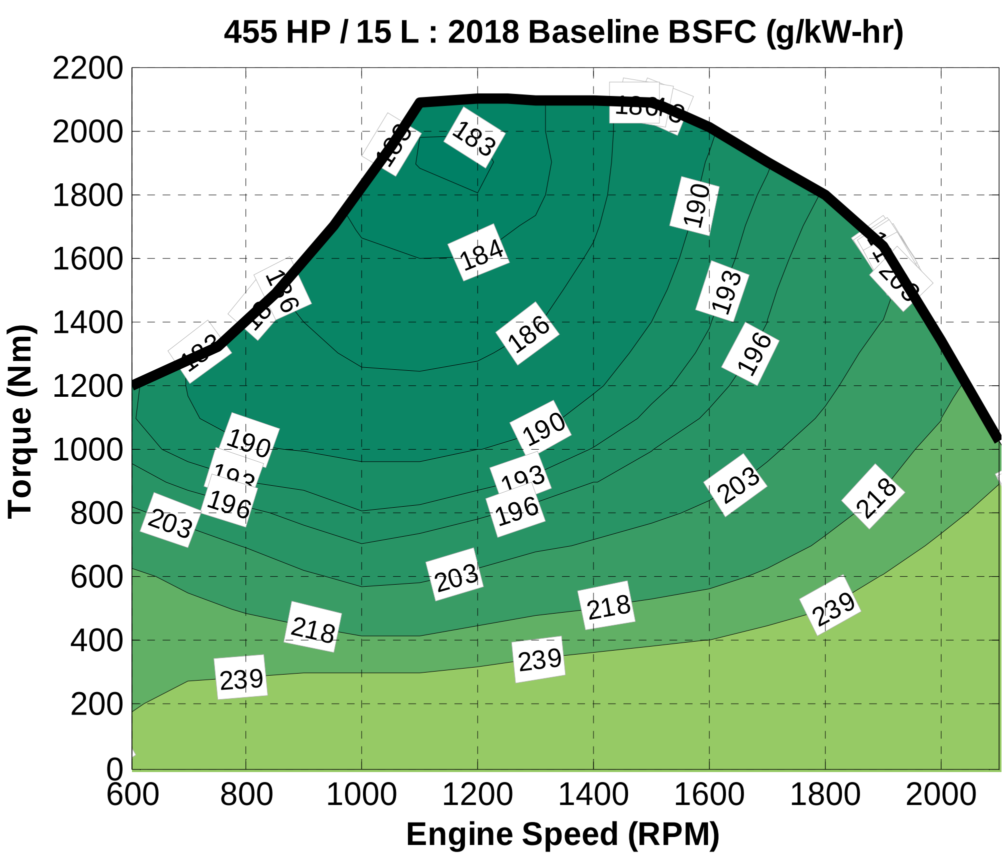


Figure 2-11 2018MY 15L Engine Fuel Map

2.8.2 **Defining the Proposed Tractor Technology Packages**

The agencies' assessment of the proposed technology effectiveness was developed through the use of GEM in coordination with modeling conducted by Southwest Research Institute. The agencies developed the proposed standards through a three-step process, similar to the approach used in Phase 1. First, the agencies developed technology performance characteristics for each technology, as described below. Each technology is associated with an input parameter which in turn would be used as an input to the Phase 2 GEM simulation tool and its effectiveness thereby modeled. Second, the agencies combined the technology performance levels with a projected technology adoption rate to determine the GEM inputs used to set the stringency of the proposed standards. Third, the agencies input these parameters into Phase 2 GEM and used the output to determine the proposed CO_2 emissions and fuel consumption levels. All percentage improvements noted below are over the 2017 baseline tractor.

2.8.2.1 Aerodynamics

The aerodynamic packages are categorized as Bin I, Bin II, Bin III, Bin IV, Bin V, Bin VI, or Bin VII based on the wind averaged drag aerodynamic performance determined through testing conducted by the manufacturer. In general, the proposed CdA values for each package and tractor subcategory were developed through EPA's coastdown testing of tractor-trailer combinations, the 2010 NAS report, and SAE papers.

2.8.2.2 Tire Rolling Resistance

The proposed rolling resistance coefficient target for Phase 2 was developed from SmartWay's tire testing to develop the SmartWay verification, testing a selection of tractor tires as part of the Phase 1 and Phase 2 programs, and from 2014 MY certification data. Even though the coefficient of tire rolling resistance comes in a range of values, to analyze this range, the tire performance was evaluated at four levels determined by the agencies. The four levels are the baseline (average) from 2010, Level I and Level 2 from Phase 1, and Level 3 that achieves an additional 25 percent improvement over Level 2. The Level 1 rolling resistance performance represents the threshold used to develop SmartWay designated tires for long haul tractors. The Level 2 threshold represents an incremental step for improvements beyond today's SmartWay level and represents the best in class rolling resistance of the tires we tested. The Level 3 values represent the long-term rolling resistance value that Michelin predicts could be achieved in the 2025 timeframe.[111] The tire rolling resistance level assumed to meet the 2017 MY Phase 1 standard high roof sleeper cab is considered to be a weighted average of 10 percent baseline rolling resistance, 70 percent Level 1, and 20 percent Level 2. The tire rolling resistance to meet the 2017MY Phase 1 standards for the high roof day cab, low roof sleeper cab, and mid roof sleeper cab includes 30 percent baseline, 60 percent Level 1 and 10 percent Level 2. Finally, the low roof day cab 2017MY standard can be met with a weighted average rolling resistance consisting of 40 percent baseline, 50 percent Level 1, and 10 percent Level 2.

2.8.2.3 Idle Reduction

The benefits for the extended idle reductions were developed from literature, SmartWay work, and the 2010 NAS report. Additional details regarding the comments and calculations are included in RIA Section 2.4.

2.8.2.4 Transmission

The benefits for automated manual, automatic, and dual clutch transmissions were developed from literature and from simulation modeling conducted by Southwest Research Institute. The benefit of these transmissions is proposed to be set to a two percent improvement over a manual transmission due to the automation of the gear shifting.

2.8.2.5 Drivetrain

The reduction in friction due to low viscosity axle lubricants is set to 0.5 percent. 6x4 and 4x2 axle configurations lead to a 2.5 percent improvement in vehicle efficiency. Downspeeding would be as demonstrated through the Phase 2 GEM inputs of transmission gear ratio, drive axle ratio, and tire diameter. Downspeeding is projected to improve the fuel consumption by 1.8 percent.

2.8.2.6 Accessories and Other Technologies

Compared to 2017MY air conditioners, air conditioners with improved efficiency compressors could reduce CO_2 emissions by 0.5 percent. Improvements in accessories, such as power steering, can lead to an efficiency improvement of 1 percent over the 2017MY baseline. Based on literature information, intelligent controls such as predictive cruise control could reduce CO_2 emissions by two percent while automatic tire inflation systems improve fuel consumption by one percent by keeping tire rolling resistance to its optimum based on inflation pressure.

2.8.2.7 Weight Reduction

The weight reductions were developed from tire manufacturer information, the Aluminum Association, the Department of Energy, SABIC and TIAX.

2.8.2.8 Vehicle Speed Limiter

The agencies did not include vehicle speed limiters in setting the Phase 1 stringency levels. The agencies are not including vehicle speed limiters in the technology package for setting the proposed standards for Class 7 and 8 tractors.

2.8.2.9 Summary of Technology Performance

Table 2-25 describes the performance levels for the range of Class 7 and 8 tractor vehicle technologies.

Table 2-25 Proposed Phase 2 Technology Inputs

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine									
	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP
Aerodynamics (CdA in m2)									
Bin I	5.3	6.7	7.6	5.3	6.7	7.6	5.3	6.7	7.4
Bin II	4.8	6.2	7.1	4.8	6.2	7.1	4.8	6.2	6.9
Bin III	4.3	5.7	6.5	4.3	5.7	6.5	4.3	5.7	6.3
Bin IV	4.0	5.4	5.8	4.0	5.4	5.8	4.0	5.4	5.6
Bin V			5.3			5.3			5.1
Bin VI			4.9			4.9			4.7
Bin VII			4.5			4.5			4.3
Steer Tires (CRR in kg/metric ton)									
Base	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Level 1	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Level 2	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Level 3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Drive Tires (CRR in kg/metric ton)									
Base	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Level 1	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Level 2	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Level 3	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Idle Reduction (% reduction)									
APU	N/A	N/A	N/A	N/A	N/A	N/A	5%	5%	5%
Other	N/A	N/A	N/A	N/A	N/A	N/A	7%	7%	7%
Transmission Type (% reduction)									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	2%	2%	2%	2%	2%	2%	2%	2%	2%
Auto	2%	2%	2%	2%	2%	2%	2%	2%	2%
Dual Clutch	2%	2%	2%	2%	2%	2%	2%	2%	2%
Driveline (% reduction)									
Axle Lubricant	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
6x2 or 4x2 Axle	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Downspeed	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
Accessory Improvements (% reduction)									
A/C	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Electric or Mech. Access.	1%	1%	1%	1%	1%	1%	1%	1%	1%

Off-Cycle Technologies (% reduction)									
Predictive Cruise Control	2%	2%	2%	2%	2%	2%	2%	2%	2%
Automated Tire Inflation System	1%	1%	1%	1%	1%	1%	1%	1%	1%

2.8.3 **Tractor Technology Adoption Rates**

As explained above, tractor manufacturers often introduce major product changes together, as a package. In this manner the manufacturers can optimize their available resources, including engineering, development, manufacturing and marketing activities to create a product with multiple new features. In addition, manufacturers recognize that a vehicle design will need to remain competitive over the intended life of the design and meet future regulatory requirements. In some limited cases, manufacturers may implement an individual technology outside of a vehicle's redesign cycle.

With respect to the levels of technology adoption used to develop the proposed HD Phase 2 standards, NHTSA and EPA established technology adoption constraints. The first type of constraint was established based on the application of fuel consumption and CO_2 emission reduction technologies into the different types of tractors. For example, extended idle reduction technologies are limited to Class 8 sleeper cabs using the assumption that day cabs are not used for overnight hoteling. A second type of constraint was applied to most other technologies and limited their adoption based on factors reflecting the real world operating conditions that some combination tractors encounter. This second type of constraint was applied to the aerodynamic, tire, powertrain, and vehicle speed limiter technologies. Table 2-26, Table 2-27 and Table 2-28 specify the adoption rates that EPA and NHTSA used to develop the proposed standards.

NHTSA and EPA believe that within each of these individual vehicle categories there are particular applications where the use of the identified technologies would be either ineffective or not technically feasible. The addition of ineffective technologies provides no environmental or fuel efficiency benefit, increases costs and is not a basis upon which to set a maximum feasible improvement under 49 USC Section 32902 (k), or appropriate under 42 U.S.C. Section 7521 (a)(2). For example, the agencies are not predicating the proposed standards on the use of full aerodynamic vehicle treatments on 100 percent of tractors, because we know that in many applications (for example gravel truck engaged in local aggregate delivery) the added weight of the aerodynamic technologies would increase fuel consumption and hence CO_2 emissions to a greater degree than the reduction that would be accomplished from the more aerodynamic nature of the tractor.

2.8.3.1 Aerodynamics Adoption Rate

The impact of aerodynamics on a tractor-trailer's efficiency increases with vehicle speed. Therefore, the usage pattern of the vehicle will determine the benefit of various aerodynamic technologies. Sleeper cabs are often used in line haul applications and drive the majority of their miles on the highway travelling at speeds greater than 55 mph. The industry has focused aerodynamic technology development, including SmartWay tractors, on these types of trucks. Therefore the agencies are proposing the most aggressive aerodynamic technology application to this regulatory subcategory. All of the major manufacturers today offer at least one SmartWay sleeper cab tractor model, which is represented as Bin III aerodynamic performance. The proposed aerodynamic adoption rate for Class 8 high roof sleeper cabs in 2024 (i.e., the degree of technology adoption on which the stringency of the proposed standard is premised) consists of 30 percent of Bin IV, 25 percent Bin V, 13 percent Bin VI, and 2 percent Bin VII reflecting our assessment of the fraction of tractors in this segment that could successfully apply these aerodynamic packages. We believe that there is sufficient lead time to develop aerodynamic tractors that can move the entire high roof sleeper cab aerodynamic performance to be as good as or better than today's SmartWay designated tractors. The changes required for Bin IV and better performance reflect the kinds of improvements projected in the Department of Energy's SuperTruck program. That program assumes that such systems can be demonstrated on vehicles by 2017. In this case, the agencies are projecting that truck OEMs would be able to begin implementing these aerodynamic technologies as early as 2021 MY on a limited scale. Importantly, our averaging, banking and trading provisions provide manufacturers with the flexibility to implement these technologies over time even though the standard changes in a single step.

The aerodynamic adoption rates used to develop the proposed standards for the other tractor regulatory categories are less aggressive than for the Class 8 sleeper cab high roof. Aerodynamic improvements through new tractor designs and the development of new aerodynamic components is an inherently slow and iterative process. The agencies recognize that there are tractor applications which require on/off-road capability and other truck functions which restrict the type of aerodynamic equipment applicable. We also recognize that these types of trucks spend less time at highway speeds where aerodynamic technologies have the greatest benefit. The 2002 VIUS data ranks trucks by major use.[112] The heavy trucks usage indicates that up to 35 percent of the trucks may be used in on/off-road applications or heavier applications. The uses include construction (16 percent), agriculture (12 percent), waste management (5 percent), and mining (2 percent). Therefore, the agencies analyzed the technologies to evaluate the potential restrictions that would prevent 100 percent adoption of more advanced aerodynamic technologies for all of the tractor regulatory subcategories.

2.8.3.2 Low Rolling Resistance Tire Adoption Rate

For the tire manufacturers to further reduce tire rolling resistance, the manufacturers must consider several performance criteria that affect tire selection. The characteristics of a tire also influence durability, traction control, vehicle handling, comfort, and retreadability. A single performance parameter can easily be enhanced, but an optimal balance of all the criteria would require improvements in materials and tread design at a higher cost, as estimated by the agencies. Tire design requires balancing performance, since changes in design may change different performance characteristics in opposing directions. Similar to the discussion regarding lesser aerodynamic technology application in tractor segments other than sleeper cab high roof, the agencies believe that the proposed standards should not be premised on 100 percent application of Level IV tires in all tractor segments given the potential interference with vehicle utility that could result.

2.8.3.3 Weight Reduction Technology Adoption Rate

The agencies propose setting the 2021 through 2027 model year tractor standards without using weight reduction as a technology to demonstrate the feasibility. The agencies view weight reduction as a technology with a high cost that offers a small benefit in the tractor sector. For example, our estimate of a 400 pound weight reduction would cost $2,050 (2012$) in MY2021, but offer a 0.3 percent reduction in fuel consumption and CO_2 emissions.

2.8.3.4 Idle Reduction Technology Adoption Rate

Idle reduction technologies provide significant reductions in fuel consumption and CO_2 emissions for Class 8 sleeper cabs and are available on the market today. There are several different technologies available to reduce idling. These include APUs, diesel fired heaters, and battery powered units. Our discussions with manufacturers indicate that idle technologies are sometimes installed in the factory, but it is also a common practice to have the units installed after the sale of the truck. We would like to continue to incentivize this practice and to do so in a manner that the emission reductions associated with idle reduction technology occur in use. Therefore, as adopted in Phase 1, we are allowing only idle emission reduction technologies which include an automatic engine shutdown (AES) with some override provisions. In the preamble in Section III, we request comment on other approaches that would appropriately quantify the reductions that would be experienced in the real world.

We propose a 90 percent adoption rate for this technology for Class 8 sleeper cabs. The agencies are unaware of reasons why AES with extended idle reduction technologies could not be applied to this high fraction of tractors with a sleeper cab, except those deemed a vocational tractor, in the available lead time.

The agencies are interested in extending the idle reduction benefits beyond Class 8 sleepers, including day cabs. The agencies reviewed literature to quantify the amount of idling which is conducted outside of hoteling operations. One study, conducted by Argonne National Laboratory, identified several different types of trucks which might idle for extended amounts of time during the work day.[113] Idling may occur during the delivery process, queuing at loading docks or border crossings, during power take off operations, or to provide comfort during the work day. However, the study provided only “rough estimates” of the idle time and energy use for these vehicles. The agencies are not able to appropriately develop a baseline of workday idling for day cabs and identify the percent of this idling which could be reduced through the use of AES.

2.8.3.5 Vehicle Speed Limiter Adoption Rate

As adopted in Phase 1, we propose to continue the approach where vehicle speed limiters may be used as a technology to meet the proposed standard. In setting the proposed standard, however, we assumed a zero percent adoption rate of vehicle speed limiters. Although we believe vehicle speed limiters are a simple, easy to implement, and inexpensive technology, we want to leave the use of vehicles speed limiters to the truck purchaser. Since truck fleets purchase tractors today with owner-set vehicle speed limiters, we considered not including VSLs in our compliance model. However, we have concluded that we should allow the use of VSLs that cannot be overridden by the operator as a means of compliance for vehicle manufacturers that wish to offer it and truck purchasers that wish to purchase the technology. In doing so, we are providing another means of meeting that standard that can lower compliance cost and provide a more optimal vehicle solution for some truck fleets. For example, a local beverage distributor may operate trucks in a distribution network of primarily local roads. Under those conditions, aerodynamic fairings used to reduce aerodynamic drag provide little benefit due to the low vehicle speed while adding additional mass to the vehicle. A vehicle manufacturer could choose to install a VSL set at 55 mph for this customer. The resulting tractor would be optimized for its intended application and would be fully compliant with our program all at a lower cost to the ultimate tractor purchaser.[J]

As in Phase 1, we have chosen not to base the proposed standards on performance of VSLs because of concerns about how to set a realistic adoption rate that avoids unintended adverse impacts. Although we expect there will be some use of VSL, currently it is used when the fleet involved decides it is feasible and practicable and increases the overall efficiency of the freight system for that fleet operator. To date, the compliance data provided by manufacturers indicate that none of the tractor configurations include a tamper-proof VSL setting less than 65 mph. At this point the agencies are not in a position to determine in how many additional situations use of a VSL would result in similar benefits to overall efficiency or how many customers would be willing to accept a tamper-proof VSL setting. We are not able at this time to quantify the potential loss in utility due to the use of VSLs. Absent this information, we cannot make a determination regarding the reasonableness of setting a standard based on a particular VSL level. Therefore, the agencies are not premising the proposed standards on use of VSL, and instead would continue to rely on the industry to select VSL when circumstances are appropriate for its use. The agencies have not included either the cost or benefit due to VSLs in analysis of the proposed program's costs and benefits.

2.8.3.6 Summary of the Adoption Rates used to Determine the Proposed Standards

Table 2-26, Table 2-27, and Table 2-28 provide the adoption rates of each technology broken down by weight class, cab configuration, and roof height.

Table 2-26 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the Proposed 2021 MY Standards

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
2021 MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%

[J] The agencies note that because a VSL value can be input into GEM, its benefits can be directly assessed with the model and off cycle credit applications therefore are not necessary even though the proposed standard is not based on performance of VSLs (i.e. VSL is an on-cycle technology).

Bin II	75%	75%	0%	75%	75%	0%	75%	75%	0%
Bin III	25%	25%	40%	25%	25%	40%	25%	25%	40%
Bin IV	0%	0%	35%	0%	0%	35%	0%	0%	35%
Bin V			20%			20%			20%
Bin VI			5%			5%			5%
Bin VII			0%			0%			0%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	60%	60%	60%	60%	60%	60%	60%	60%	60%
Level 2	25%	25%	25%	25%	25%	25%	25%	25%	25%
Level 3	10%	10%	10%	10%	10%	10%	10%	10%	10%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	60%	60%	60%	60%	60%	60%	60%	60%	60%
Level 2	25%	25%	25%	25%	25%	25%	25%	25%	25%
Level 3	10%	10%	10%	10%	10%	10%	10%	10%	10%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	80%	80%	80%
Transmission Type									
Manual	45%	45%	45%	45%	45%	45%	45%	45%	45%
AMT	40%	40%	40%	40%	40%	40%	40%	40%	40%
Auto	10%	10%	10%	10%	10%	10%	10%	10%	10%
Dual Clutch	5%	5%	5%	5%	5%	5%	5%	5%	5%
Driveline									
Axle Lubricant	20%	20%	20%	20%	20%	20%	20%	20%	20%
6x2 or 4x2 Axle				10%	10%	20%	10%	10%	20%
Downspeed	20%	20%	20%	20%	20%	20%	20%	20%	20%
Accessory Improvements									
A/C	10%	10%	10%	10%	10%	10%	10%	10%	10%
Electric Access.	10%	10%	10%	10%	10%	10%	10%	10%	10%
Off-Cycle Technologies									
Predictive Cruise Control	20%	20%	20%	20%	20%	20%	20%	20%	20%
Automated Tire Inflation System	20%	20%	20%	20%	20%	20%	20%	20%	20%

Table 2-27 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the Proposed 2024 MY Standards

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
2024MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	60%	60%	0%	60%	60%	0%	60%	60%	0%
Bin III	38%	38%	30%	38%	38%	30%	38%	38%	30%
Bin IV	2%	2%	30%	2%	2%	30%	2%	2%	30%
Bin V			25%			25%			25%
Bin VI			13%			13%			13%
Bin VII			2%			2%			2%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 2	30%	30%	30%	30%	30%	30%	30%	30%	30%
Level 3	15%	15%	15%	15%	15%	15%	15%	15%	15%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 2	30%	30%	30%	30%	30%	30%	30%	30%	30%
Level 3	15%	15%	15%	15%	15%	15%	15%	15%	15%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	90%	90%	90%
Transmission Type									
Manual	20%	20%	20%	20%	20%	20%	20%	20%	20%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	20%	20%	20%	20%	20%	20%	20%	20%	20%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 or 4x2 Axle				20%	20%	60%	20%	20%	60%
Downspeed	40%	40%	40%	40%	40%	40%	40%	40%	40%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	20%	20%	20%	20%	20%	20%	20%	20%	20%
Electric Access.	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other Technologies									
Predictive Cruise	40%	40%	40%	40%	40%	40%	40%	40%	40%

Control									
Automated Tire Inflation System	40%	40%	40%	40%	40%	40%	40%	40%	40%

Table 2-28 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the Proposed 2027 MY Standards

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
2027 MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	50%	50%	0%	50%	50%	0%	50%	50%	0%
Bin III	40%	40%	20%	40%	40%	20%	40%	40%	20%
Bin IV	10%	10%	20%	10%	10%	20%	10%	10%	20%
Bin V			35%			35%			35%
Bin VI			20%			20%			20%
Bin VII			5%			5%			5%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	25%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	25%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	90%	90%	90%
Transmission Type									
Manual	10%	10%	10%	10%	10%	10%	10%	10%	10%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	30%	30%	30%	30%	30%	30%	30%	30%	30%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 Axle				20%	20%	60%	20%	20%	60%
Downspeed	60%	60%	60%	60%	60%	60%	60%	60%	60%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	30%	30%	30%	30%	30%	30%	30%	30%	30%
Electric Access.	30%	30%	30%	30%	30%	30%	30%	30%	30%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated	40%	40%	40%	40%	40%	40%	40%	40%	40%

Tire Inflation System									

2.8.4 **Derivation of the Proposed Tractor Standards**

The agencies used the technology effectiveness inputs and technology adoption rates to develop GEM inputs to derive the proposed HD Phase 2 fuel consumption and CO_2 emissions standards for each subcategory of Class 7 and 8 combination tractors. Note that we have analyzed one technology pathway for each proposed level of stringency as required by the Clean Air Act, but manufacturers would be free to use any combination of technology to meet the standards on average. As such, the agencies derived a scenario tractor for each subcategory by weighting the individual GEM input parameters included in Table 2-25 with the adoption rates in Table 2-26, Table 2-27, and Table 2-28. For example, the proposed CdA value for a 2021MY Class 8 Sleeper Cab High Roof scenario case was derived as 40 percent times 6.3 plus 35 percent times 5.6 plus 20 percent times 5.1 plus 5 percent times 4.7, which is equal to a CdA of 5.74 m^2. Similar calculations were made for tire rolling resistance, transmission types, idle reduction, and other technologies. To account for the proposed engine standards and engine technologies, the agencies assumed a compliant engine fuel map in GEM, as described in the section below.[K] The agencies then ran GEM with a single set of vehicle inputs, as shown in Table 2-30, to derive the proposed standards for each subcategory.

2.8.4.1 2021 through 2027 MY Engine Fuel Maps

One of the most significant changes in the HD Phase 2 version of GEM is the allowance for manufacturers to enter their own engine fuel maps by following the test procedure described in the Chapter 3 Test Procedure section of this draft RIA. The GEM engine fuel map input file consists of three types of information in csv format. The first set of information contains the engine fueling map and includes three columns: engine speed in rpm, engine torque in Nm, and engine fueling rate in g/s. In the second set of information contains the engine full torque or lug curve in two columns: engine speed in rpm and torque in NM. The third set of information contains the motoring torque and uses the same format and units as the full load torque curve.

The agencies developed default engine fuel maps for all subcategories, utilizing the same format that the manufacturers would be required to provide. Fuel maps were developed for the 2021, 2024, and 2027 model years by applying the technologies assumed in deriving the proposed engine standards to the 2018 baseline engine fuel maps. Those default maps are derived from multiple sources of confidential business information from different stakeholders together with engineering judgment. These maps cover a total of 18 vehicles subcategories including nine tractor subcategories. We would like to point out that some of the subcategories share the same engine fuel maps. A list of all of the engine fuel maps used in setting the

[K] See draft RIA Chapter 2.7 explaining the derivation of the proposed engine standards.

standards for each subcategory is given in Table 2-29. The model years covered by the maps are 2021, 2024, and 2027 and are shown in Figure 2-12, Figure 2-13, and Figure 2-14.

Table 2-29 GEM Default CI Engine Fuel Maps for Tractor Vehicles

REGULATORY SUBCATEGORY		ENGINE FUEL MAP
Class 8 Combination	Sleeper Cab - High Roof	15L - 455 HP
Class 8 Combination	Sleeper Cab - Mid Roof	15L - 455 HP
Class 8 Combination	Sleeper Cab - Low Roof	15L - 455 HP
Class 8 Combination	Day Cab - High Roof	15L - 455 HP
Class 8 Combination	Day Cab - Mid Roof	15L - 455 HP
Class 8 Combination	Day Cab - Low Roof	15L - 455 HP
Class 7 Combination	Day Cab - High Roof	11L - 350 HP
Class 7 Combination	Day Cab - Mid Roof	11L - 350 HP
Class 7 Combination	Day Cab - Low Roof	11L - 350 HP

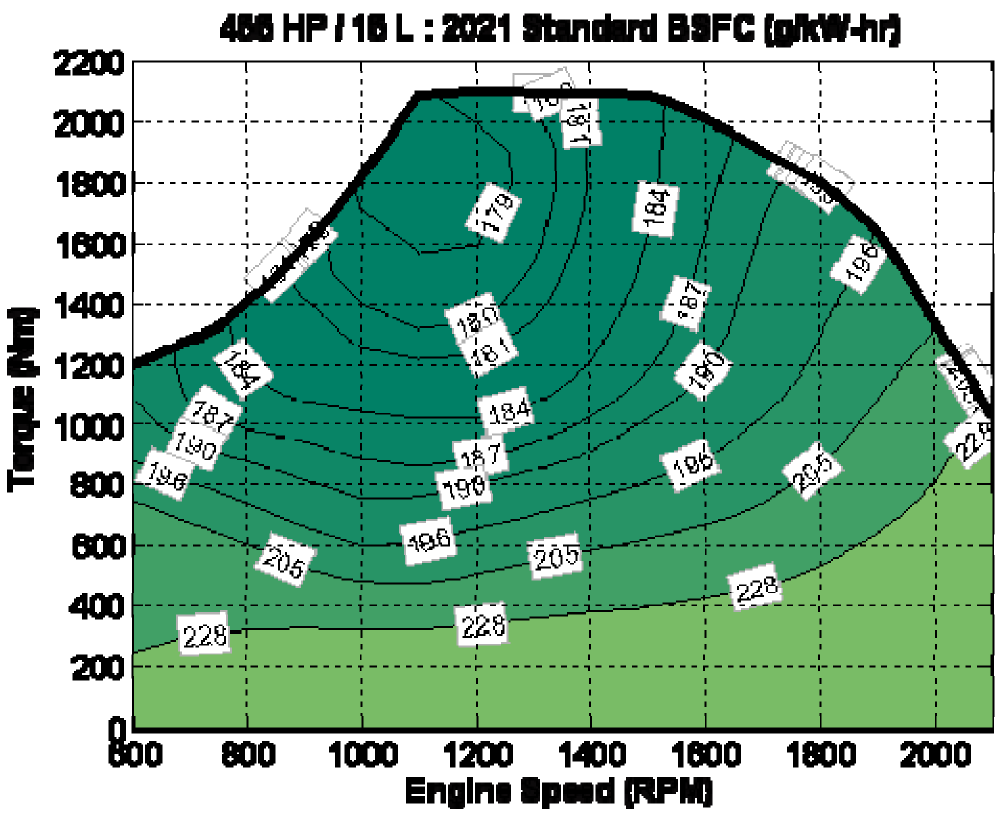


Figure 2-12 455 HP Engine fuel map used in HD Phase 2 version of GEM to Set 2021MY Standards

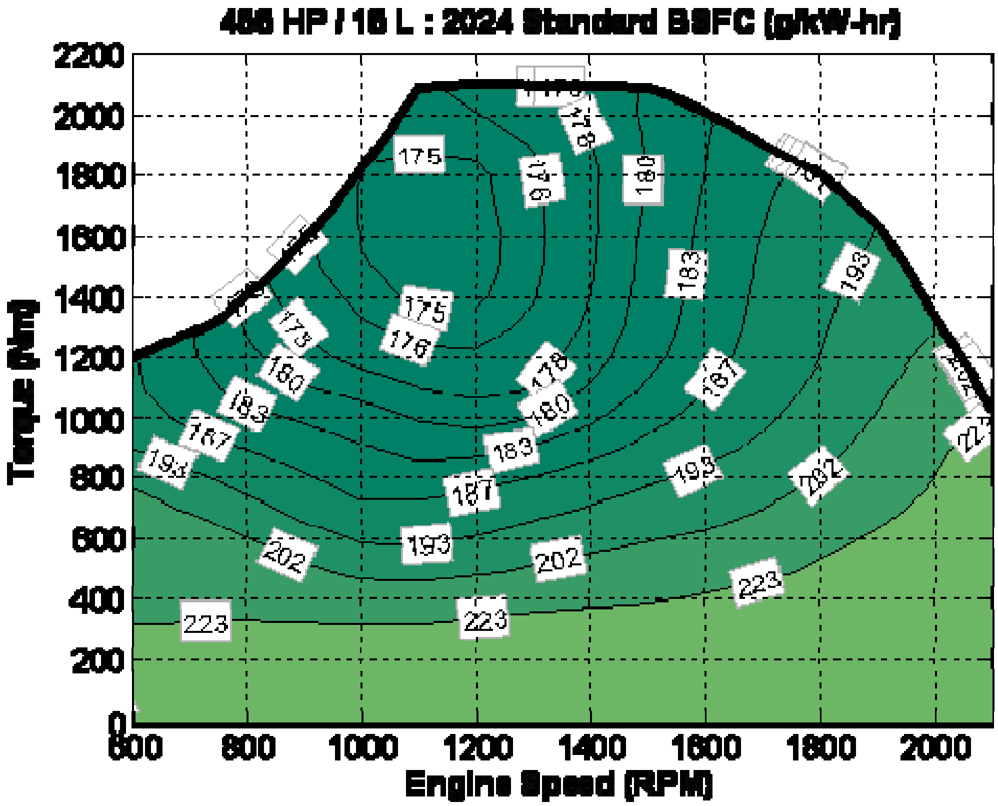


Figure 2-13 455 HP Engine fuel map used in HD Phase 2 version of GEM to Set 2024MY Standards

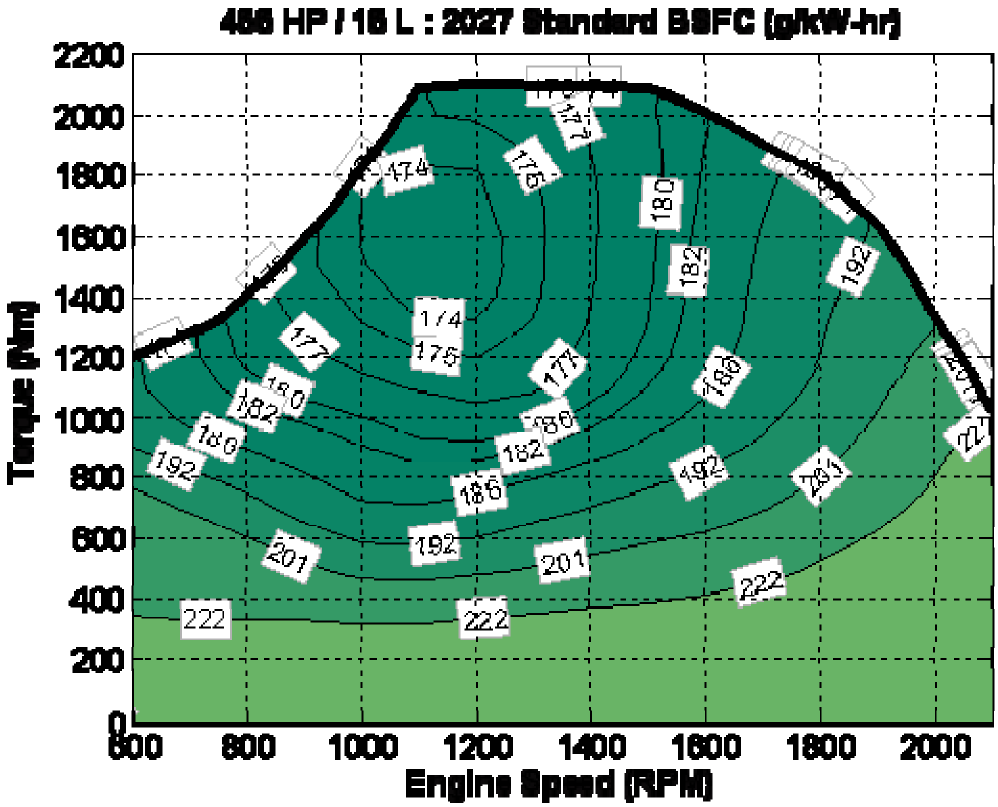


Figure 2-14 455 HP Engine fuel map used in HD Phase 2 version of GEM to Set 2027MY Standard

Table 2-30 GEM Inputs for the Proposed 2021MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP
Aerodynamics (CdA in m2)								
4.68	6.08	5.94	4.68	6.08	5.94	4.68	6.08	5.74
Steer Tires (CRR in kg/metric ton)								
6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Drive Tires (CRR in kg/metric ton)								
6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	2.5%	2.5%	2.5%
Transmission = 10 speed Automated Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive axle Ratio = 3.55								
6x2 Axle Disconnect Weighted Effectiveness								
N/A	N/A	N/A	0.3%	0.3%	0.5%	0.3%	0.3%	0.5%
Low Friction Axle Lubrication = 0.1%								
Transmission benefit = 1.1%								
Predictive Cruise Control =0.4%								
Accessory Improvements = 0.1%								
Air Conditioner Efficiency Improvements = 0.1%								
Automatic Tire Inflation Systems = 0.2%								
Weight Reduction = 0 pounds								

Table 2-31 GEM Inputs for the Proposed 2024MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP
Aerodynamics (CdA in m2)								
4.59	5.99	5.74	4.59	5.99	5.74	4.59	5.99	5.54
Steer Tires (CRR in kg/metric ton)								
5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Drive Tires (CRR in kg/metric ton)								
6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Extended Idle Reduction Adoption Rate								
N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Transmission = 10 speed Automated Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive axle Ratio = 3.36								
6x2 Axle Disconnect Weighted Effectiveness								
N/A	N/A	N/A	0.5%	0.5%	1.5%	0.5%	0.5%	1.5%
Low Friction Axle Lubrication = 0.2%								
Transmission benefit = 1.8%								
Predictive Cruise Control =0.8%								
Accessory Improvements = 0.2%								
Air Conditioner Efficiency Improvements = 0.1%								
Automatic Tire Inflation Systems = 0.4%								
Weight Reduction = 0 pounds								
Direct Drive Weighted Efficiency = 1% for sleeper cabs; 0.8% for day cabs								

Table 2-32 GEM Inputs for the Proposed 2027MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP
Aerodynamics (CdA in m^2)								
4.52	5.92	5.52	4.52	5.92	5.52	4.52	5.92	5.32
Steer Tires (CRR in kg/metric ton)								
5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Drive Tires (CRR in kg/metric ton)								
5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Transmission = 10 speed Automated Manual Transmission **Gear Ratios =** 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive axle Ratio = 3.2								
6x2 Axle Disconnect Weighted Effectiveness								
N/A	N/A	N/A	0.5%	0.5%	1.5%	0.5%	0.5%	1.5%
Low Friction Axle Lubrication = 0.2%								
Transmission benefit = 1.8%								
Predictive Cruise Control =0.8%								
Accessory Improvements = 0.3%								
Air Conditioner Efficiency Improvements = 0.2%								
Automatic Tire Inflation Systems = 0.4%								
Weight Reduction = 0 pounds								
Direct Drive Weighted Efficiency = 1% for sleeper cabs; 0.8% for day cabs								

The level of the 2021, 2024, and 2027 model year proposed standards for each subcategory are included in Table 2-33.

Table 2-33 Proposed 2021, 2024, and 2027 Model Year Tractor Standards

2021 MODEL YEAR CO_2 GRAMS PER TON-MILE			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	97	78	70
Mid Roof	107	84	78
High Roof	109	86	77
2021 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	9.5285	7.5639	6.8762
Mid Roof	10.5108	8.2515	7.6621
High Roof	10.7073	8.4479	7.5639
2024 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	90	72	64
Mid Roof	100	78	71
High Roof	101	79	70
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.8409	7.0727	6.2868
Mid Roof	9.8232	7.5639	6.9745
High Roof	9.9214	7.7603	6.8762
2027 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	87	70	62
Mid Roof	96	76	69
High Roof	96	76	67
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.5462	6.8762	6.0904
Mid Roof	9.4303	7.4656	6.7780
High Roof	9.4303	7.4656	6.5815

2.8.4.2 Heavy-Haul Tractor Standards

For Phase 2, the agencies propose to add a tenth subcategory to the tractor category for heavy-haul tractors. The agencies recognize the need for manufacturers to build these types of vehicles for specific applications and believe the appropriate way to prevent penalizing these vehicles is to set separate standards recognizing a heavy-haul vehicle's unique needs, such as requiring a higher horsepower engine or different transmissions. The agencies are proposing this change in Phase 2 because unlike in Phase 1 the engine, transmission, and drivetrain technologies are included in the technology packages used to determine the stringency of the proposed tractor standards and are included as manufacturer inputs in GEM.

The agencies recognize that certain technologies used to determine the stringency of the proposed Phase 2 tractor standards are less applicable to heavy-haul tractors. Heavy-haul tractors are not typically used in the same manner as long-haul tractors with extended highway driving, therefore would experience less benefit from aerodynamics. Aerodynamic technologies are very effective at reducing the fuel consumption and GHG emissions of tractors, but only when traveling at highway speeds. At lower speeds, the aerodynamic technologies may have a detrimental impact due to the potential of added weight. The agencies therefore are not considering the use of aerodynamic technologies in the development of the proposed Phase 2 heavy-haul tractor standards. Moreover, because aerodynamics would not play a role in the heavy-haul standards, the agencies propose to combine all of the heavy-haul tractor cab configurations (day and sleeper) and roof heights (low, mid, and high) into a single heavy-haul tractor subcategory.[L]

Certain powertrain and drivetrain components are also impacted during the design of a heavy-haul tractor, including the transmission, axles, and the engine. Heavy-haul tractors typically require transmissions with 13 or 18 speeds to provide the ratio spread to ensure that the tractor is able to start pulling the load from a stop. Downsped powertrains are typically not an option for heavy-haul operations because these vehicles require more torque to move the vehicle because of the heavier load. Finally, due to the loading requirements of the vehicle, it is not likely that a 6x2 axle configuration can be used in heavy-haul applications.

The agencies used the following heavy-haul tractor inputs for developing the proposed 2021, 2024, and 2027 MY standards, as shown in Table 2-34.

[L] Since aerodynamic improvements are not part of the technology package, the agencies likewise are not proposing any bin structure for the heavy-haul tractor subcategory.

Table 2-34 GEM Inputs for Proposed 2021, 2024 and 2027 MY Heavy-Haul Tractor Standards

HEAVY-HAUL TRACTOR			
Baseline	**2021MY**	**2024MY**	**2027MY**
Engine = 2017 MY 15L Engine with 600 HP	Engine = 2021 MY 15L Engine with 600 HP	Engine = 2024 MY 15L Engine with 600 HP	Engine = 2027 MY 15L Engine with 600 HP
Aerodynamics (CdA in m^2) = 5.00			
Steer Tires (CRR in kg/metric ton) = 7.0	Steer Tires (CRR in kg/metric ton) = 6.2	Steer Tires (CRR in kg/metric ton) = 6.0	Steer Tires (CRR in kg/metric ton) = 5.8
Drive Tires (CRR in kg/metric ton) = 7.4	Drive Tires (CRR in kg/metric ton) = 6.6	Drive Tires (CRR in kg/metric ton) = 6.4	Drive Tires (CRR in kg/metric ton) = 6.2
Transmission = 13 speed Manual Transmission Gear Ratios = 12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73	Transmission = 13 speed Automated Manual Transmission Gear Ratios = 12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73	Transmission = 13 speed Automated Manual Transmission Gear Ratios = 12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73	Transmission = 13 speed Automated Manual Transmission Gear Ratios = 12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73
Drive axle Ratio = 3.55	Drive axle Ratio = 3.55	Drive axle Ratio = 3.55	Drive axle Ratio = 3.55
	6x2 Axle Disconnect Weighted Effectiveness = 0%	6x2 Axle Disconnect Weighted Effectiveness = 0%	6x2 Axle Disconnect Weighted Effectiveness = 0%
	Low Friction Axle Lubrication = 0.1%	Low Friction Axle Lubrication = 0.2%	Low Friction Axle Lubrication = 0.2%
	AMT benefit = 1.1%	AMT benefit = 1.8%	AMT benefit = 1.8%
	Predictive Cruise Control =0.4%	Predictive Cruise Control =0.8%	Predictive Cruise Control =0.8%
	Accessory Improvements = 0.1%	Accessory Improvements = 0.2%	Accessory Improvements = 0.3%
	Air Conditioner Efficiency Improvements = 0.1%	Air Conditioner Efficiency Improvements = 0.1%	Air Conditioner Efficiency Improvements = 0.2%
	Automatic Tire Inflation Systems = 0.2%	Automatic Tire Inflation Systems = 0.4%	Automatic Tire Inflation Systems = 0.4%
	Weight Reduction = 0 pounds	Weight Reduction = 0 pounds	Weight Reduction = 0 pounds

The baseline 2017 MY heavy-haul tractor would emit 57 grams of CO_2 per ton-mile and consume 5.6 gallons of fuel per 1,000 ton-mile. The agencies propose the heavy-haul standards shown in Table 2-35.

Table 2-35 Proposed Heavy-Haul Tractor Standards

HEAVY-HAUL TRACTOR			
	2021 MY	**2024 MY**	**2027 MY**
Grams of CO_2 per Ton-Mile Standard	54	52	51
Gallons of Fuel per 1,000 Ton-Mile	5.3045	5.1081	5.010

2.8.4.3 Tractor Package Costs under the Preferred and Alternative Standards

A summary of the draft technology package costs under the preferred alternative and relative to the less dynamic baseline is included in Table 2-36 through Table 2-39 for MYs 2021, 2024, and 2027, respectively. A summary of the draft technology package costs under alternative 4 and relative to the less dynamic baseline is included in Table 2-40 and Table 2-41 for MYs 2021 and 2024, respectively.

Table 2-36 Class 7 and 8 Tractor Technology Incremental Costs in the 2021 Model Year[a,b] Preferred Alternative vs. the Less Dynamic Baseline (2012$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$314	$314	$314	$314	$314	$314	$314
Aerodynamics	$687	$511	$687	$511	$656	$656	$535
Tires	$49	$9	$81	$15	$59	$59	$15
Tire inflation system	$180	$180	$180	$180	$180	$180	$180
Transmission	$3,969	$3,969	$3,969	$3,969	$3,969	$3,969	$3,969
Axle & axle lubes	$50	$50	$70	$90	$70	$70	$90
Idle reduction with APU	$0	$0	$0	$0	$2,449	$2,449	$2,449
Air conditioning	$45	$45	$45	$45	$45	$45	$45
Other vehicle technologies	$174	$174	$174	$174	$174	$174	$174
Total	$5,468	$5,252	$5,520	$5,298	$7,916	$7,916	$7,771

Notes:
[a] Costs shown are for the 2021 model year and are incremental to the costs of a tractor meeting the phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12 in particular).
[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

Table 2-37 Class 7 and 8 Tractor Technology Incremental Costs in the 2024 Model Year[a,b] Preferred Alternative vs. the Less Dynamic Baseline (2012$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$904	$904	$904	$904	$904	$904	$904
Aerodynamics	$744	$684	$744	$684	$712	$712	$723
Tires	$47	$11	$78	$18	$58	$58	$18
Tire inflation system	$330	$330	$330	$330	$330	$330	$330
Transmission	$5,883	$5,883	$5,883	$5,883	$5,883	$5,883	$5,883
Axle & axle lubes	$92	$92	$128	$200	$128	$128	$200
Idle reduction with APU	$0	$0	$0	$0	$2,687	$2,687	$2,687
Air conditioning	$82	$82	$82	$82	$82	$82	$82
Other vehicle technologies	$318	$318	$318	$318	$318	$318	$318
Total	$8,400	$8,304	$8,467	$8,419	$11,102	$11,102	$11,145

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a tractor meeting the phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).

[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).

[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

Table 2-38 Class 7 and 8 Tractor Technology Incremental Costs in the 2027 Model Year[a,b] Preferred Alternative vs. the Less Dynamic Baseline (2012$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$1,698	$1,698	$1,698	$1,698	$1,698	$1,698	$1,698
Aerodynamics	$771	$765	$771	$765	$733	$733	$802
Tires	$45	$10	$75	$17	$56	$56	$17
Tire inflation system	$314	$314	$314	$314	$314	$314	$314
Transmission	$6,797	$6,797	$6,797	$6,797	$6,797	$6,797	$6,797
Axle & axle lubes	$97	$97	$131	$200	$131	$131	$200
Idle reduction with APU	$0	$0	$0	$0	$2,596	$2,596	$2,596
Air conditioning	$117	$117	$117	$117	$117	$117	$117
Other vehicle technologies	$302	$302	$302	$302	$302	$302	$302
Total	$10,140	$10,099	$10,204	$10,209	$12,744	$12,744	$12,842

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a tractor meeting the phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).

[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12 in particular).

[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

Table 2-39 Heavy-Haul Tractor Technology Incremental Costs in the 2021, 2024, and 2027 Model Year[a,b] Preferred Alternative vs. the Less Dynamic Baseline (2012$ per vehicle)

	2021 MY	2024 MY	2027 MY
Engine[c]	$314	$904	$1,698
Tires	$81	$78	$75
Tire inflation system	$180	$330	$314
Transmission	$3,969	$5,883	$6,797
Axle & axle lubes	$70	$128	$200
Air conditioning	$45	$82	$117
Other vehicle technologies	$174	$318	$302
Total	$4,833	$7,723	$9,503

Notes:
[a] Costs shown are for the specified model year and are incremental to the costs of a tractor meeting the phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12 in particular).
[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

Table 2-40 Class 7 and 8 Tractor Technology Incremental Costs in the 2021 Model Year[a,b] Alternative 4 vs. the Less Dynamic Baseline (2012$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$656	$656	$656	$656	$656	$656	$656
Aerodynamics	$769	$632	$769	$632	$740	$740	$665
Tires	$50	$11	$83	$18	$61	$61	$18
Tire inflation system	$271	$271	$271	$271	$271	$271	$271
Transmission	$6,794	$6,794	$6,794	$6,794	$6,794	$6,794	$6,794
Axle & axle lubes	$56	$56	$75	$95	$75	$75	$115
Idle reduction with APU	$0	$0	$0	$0	$2,449	$2,449	$2,449
Air conditioning	$90	$90	$90	$90	$90	$90	$90
Other vehicle technologies	$261	$261	$261	$261	$261	$261	$261
Total	$8,946	$8,769	$8,999	$8,816	$11,397	$11,397	$11,318

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a tractor meeting the phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).

[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12 in particular).

[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

Table 2-41 Class 7 and 8 Tractor Technology Incremental Costs in the 2024 Model Year[a,b] Alternative 4 vs. the Less Dynamic Baseline (2012$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$1,885	$1,885	$1,885	$1,885	$1,885	$1,885	$1,885
Aerodynamics	$805	$935	$805	$935	$773	$773	$997
Tires	$50	$14	$83	$23	$63	$63	$23
Tire inflation system	$330	$330	$330	$330	$330	$330	$330
Transmission	$7,143	$7,143	$7,143	$7,143	$7,143	$7,143	$7,143
Axle & axle lubes	$102	$102	$138	$210	$138	$138	$210
Idle reduction with APU	$0	$0	$0	$0	$2,687	$2,687	$2,687
Air conditioning	$123	$123	$123	$123	$123	$123	$123
Other vehicle technologies	$318	$318	$318	$318	$318	$318	$318
Total	$10,757	$10,851	$10,826	$10,968	$13,461	$13,461	$13,717

Notes:
[a] Costs shown are for the 2024 model year and are incremental to the costs of a tractor meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the draft RIA (see draft RIA 2.12).
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the draft RIA (see draft RIA 2.12 in particular).
[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

2.9 Technology Application and Estimated Costs – Vocational Vehicles

The agencies are analyzing nine baseline vocational vehicle configurations: one for each of the nine proposed subcategories obtained with three weight class groups and the three proposed composite duty cycles. For each configuration, some of the attributes and parameters are proposed to be fixed by the agencies and would not be available as manufacturer inputs, while some are proposed to be available to manufacturers when identifying configurations to certify in the model years of the proposed HD Phase 2 program.

2.9.1 Vocational Engines

This section describes the engines the agencies selected to incorporate into the baseline vehicle configurations for the nine proposed subcategories of vocational vehicles, and how we used the GEM tool to establish performance levels of these baseline vehicles. The agencies have developed models for engines that represent performance of the technologies we expect would be installed in vocational vehicles in the baseline year of 2017. A description of the technologies applied to our 2017 diesel engine models can be found above in Chapter 2.7 of this draft RIA. A description of the GEM engine simulation can be found in draft RIA Chapter 4.

2.9.1.1 Baseline Vocational Engines

One of the most significant changes in the HD Phase 2 version of GEM is the provision for manufacturers to enter their own engine fuel maps by following the test procedure described in the draft RIA Chapter 3. The GEM engine fuel map input file consists of three types of input. The first is the engine fueling map and includes: engine speed in rpm, engine torque in Nm, and engine fueling rate in g/s. Second is the engine full torque or lug curve by engine speed in rpm and torque in NM. The third is the motoring torque curve.

The agencies have developed the proposed vehicle standards using engine fuel maps derived as discussed above in Chapter 2.7for all sub-categories, utilizing the same format that the OEMs would be required to provide. Four sets of diesel engine maps cover all nine vocational vehicle regulatory categories, as listed in Table 2-42. This means that some of the subcategories share the same engine fuel map. For example, all MHD vehicles use the same 7L engine with 270 hp rating.

The 15L engine was selected for the Regional HHD subcategory because these vocational vehicles often require a similar level of power as a day cab tractor. This is the same power and displacement of the engine simulated for HHD vocational vehicles in Phase 1, and is the engine powering the Kenworth T700 reference vehicle, as described in RIA Chapter 4 and summarized in Table 4-2. An 11L-345 hp engine was selected for the HHD Multi-purpose and Urban subcategories, and is the engine powering the New Flyer refuse truck as the applicable reference vehicle, as described in RIA Chapter 4. For these two subcategories, the agencies selected this engine because this is a more typical power rating for vehicles that are not long haul. For example, Volvo manufactures many vehicles that would likely be certified in these subcategories, and one product brochure describes an 11L engine as being fitted in all their TerraPro refuse trucks and other weight-sensitive applications.[114] Although the displacement and horsepower rating of this engine are similar to those of the MHD engine described above in Chapter 2.8 for Class 7 tractors, the HHD vocational engine described here is very different from that MHD tractor engine, both in terms of technology and its engine certification cycle. The engine displacements and power ratings for the MHD and LHD vocational subcategories are the same as those simulated in GEM for Phase 1. The specifications for the Kenworth T270 truck and F650 tow truck that serve as reference vehicles for all MHD and LHD are shown in Table 4-2 of draft RIA Chapter 4.

Table 2-42 GEM CI Engines for Vocational Vehicles

REGULATORY SUBCATEGORY AND DUTY CYCLE		ENGINE FUEL MAP
Heavy Heavy-Duty (Class 8)	Regional Duty Cycle	15L - 455 HP
Heavy Heavy-Duty (Class 8)	Multi-Purpose and Urban Duty Cycles	11L - 345 HP
Medium Heavy-Duty (Class 6-7)	Regional, Multi-Purpose, and Urban Duty Cycles	7L - 270 HP
Light Heavy-Duty (Class 2b-5)	Regional, Multi-Purpose, and Urban Duty Cycles	7L - 200 HP

The 2017 baseline maps in the HD Phase 2 version of GEM are different than those used for simulating engines that would meet the MY2017 vehicle standards in the HD Phase 1 rulemaking. The baseline map in the HD Phase 2 version takes two major factors into consideration. The first is the likelihood of engine down speeding beyond the 2020 model year and the second is to make the gradient of brake specific fuel consumption rate (BSFC) around the fuel consumption sweet spot less radical when compared to the HD Phase 1 version's engine fuel map. Figure 2-15 gives an example of an engine fuel map for a 455 hp rated CI engine, for the baseline year.

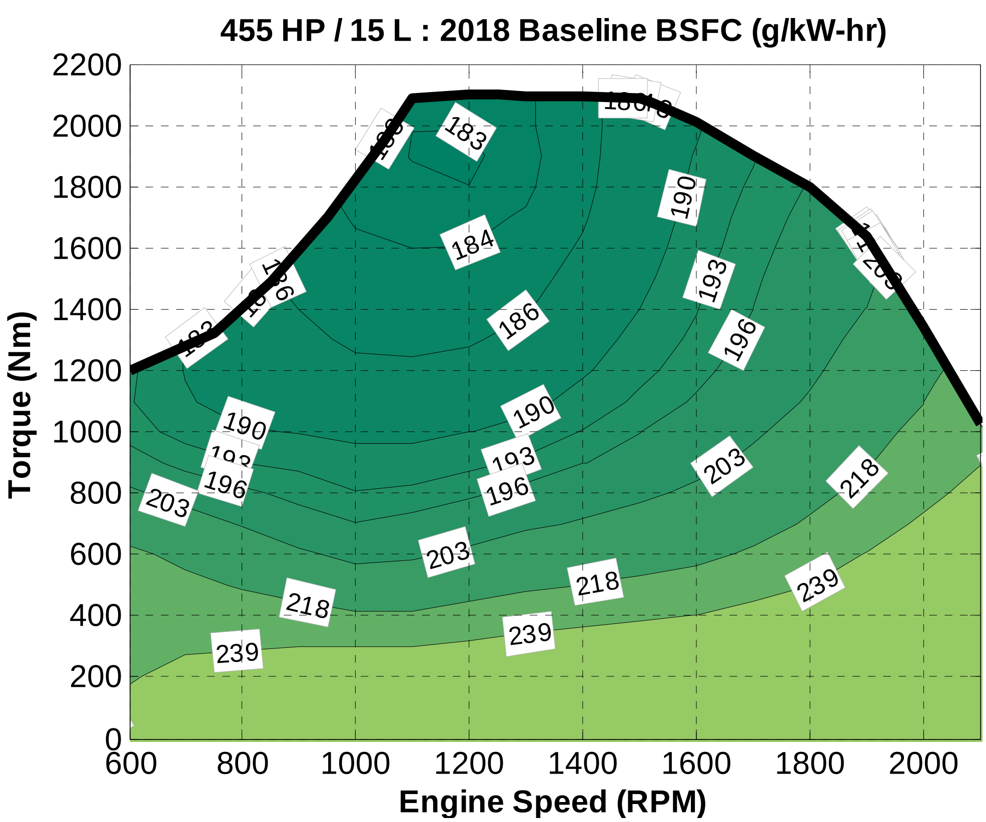


Figure 2-15 Engine fuel map for 455hp rated CI engine used in HHD Phase 2 Baseline

The agencies do not have baseline fuel maps for SI engines intended for vocational vehicles. We have not obtained sufficient manufacturer data to construct a valid set of inputs that would reasonably represent a gasoline engine that will comply with the applicable MY 2016 engine standard. In lieu of a SI engine map, we have approximated the performance of a baseline gasoline engine over the vocational vehicle GEM duty cycles by applying a correction factor to the results of simulating identical vocational vehicles fitted with CI engines. This correction factor is derived using coefficients from the MY 2018 HD pickup and van Phase 1 standards for HD gasoline pickup trucks. It is appropriate to do this, because the difference in performance of chassis-certified SI complete vehicles and similarly-sized CI complete vehicles would likely be proportional to the difference between SI-powered and CI-powered GEM-certified vocational vehicles. Using the HD pickup and van stringency curves and coefficients for the MY 2018 targets from Phase 1, the ratio of CO_2 performance of gasoline powered vehicles to diesel powered vehicles calculates to 1.058. This was derived using the equations and coefficients found at 40 CFR 1037.104(a)(2), where a work factor of 9,000 was assumed, and the resulting calculated target value for SI vehicles was divided by the similarly calculated target value for CI vehicles. The correction factor approach is not the agencies' preferred approach to establishing SI vocational vehicle baseline performance, as it has many drawbacks. One key drawback with this approach is that it does not account for the fact that SI engines operate very differently than CI engines at idle. Our current model includes information on CI engine idle performance, and assumes transmissions and torque converters appropriate for CI engines. We expect these driveline parameters would be very different for SI powered vehicles, which would affect performance over all the GEM duty cycles.

2.9.1.2 Improved Vocational Engines for Phase 2 Standard-Setting

Four model year versions of these engine maps have been developed for each of these four diesel engines: one set for MY 2017 as the baseline, a set of maps for MY2021, a set for MY2024, and a set for MY 2027, as improved over the 2017 baseline engine maps.

Because the agencies are proposing to retain the Phase 1 SI separate engine standard for all implementation years of Phase 2, we developed the proposed Phase 2 standards for vocational vehicles powered by SI engines using the same analysis described above for development of the SI baseline engine, without further improvement. When developing improvement levels for the stringency of the MY 2027 proposed vehicle standards (and the MY 2024 Alternative 4 standards), the agencies analyzed adoption rates, effectiveness, and cost of SI engine technologies that reduce friction. Consistent with our projection of adoption rates of advanced engine friction reduction on HD gasoline pickup trucks, the agencies projected that about 40 percent of SI engines intended for vocational vehicles would already have technologies applied that achieve performance equivalent to Level 2 engine friction reduction, making the available population that could upgrade to Level 2 about 60 percent for MY 2027. In terms of effectiveness, the agencies relied on the data presented in the Joint Technical Support Document (TSD) published in support of the LD GHG final rulemaking.[115] In Chapter 3 of that document, the agencies present effectiveness values for upgrading from baseline levels of engine friction reduction to Level 2 (EFR2) as ranging from 3.4 percent to 4.8 percent, for a range of LD vehicle types, and with large trucks falling in the middle of this range. The TSD describes example technologies as including low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. For this Phase 2 HD rulemaking, the agencies derived incremental EFR2 effectiveness values from the combined EFR1+EFR2 values that were relative to baseline-level friction reduction. We were able to do this because the TSD also presented incremental improvements for upgrading from EFR1 to

EFR2 as ranging from 0.83 to 1.37. The agencies then calculated a mid-range effectiveness value representing large trucks of about one percent. In terms of costs, the agencies have presented the costs of upgrading from EFR1 to EFR2, as shown in Chapter 2.12 below. Specifically, the tables in Chapter 2.12.2.17 present the incremental and total costs over the model years of the proposed Phase 2 standards for low friction lubricants and engine friction reduction. By applying our market adoption rate of approximately 60 percent to the incremental costs of upgrading to EFR2 from EFR1, we estimate a vocational vehicle package cost of approximately $70 for this technology.

2.9.2 Defining the Baseline Vocational Vehicles

Nine baseline vocational vehicle configurations have been developed. Vocational vehicle attributes that would be set by the agencies not only in the baseline but also in the executable version of the GEM include: transmission gear efficiencies, transmission inertia, engine inertia, axle efficiency, number of axles, axle inertia, axle efficiency, electrical and mechanical accessory power demand, vehicle mass and payload, and aerodynamic cross-section and drag coefficient. Other vehicle attributes that would be available as user inputs for compliance purposes and for which we have established baseline values include: engine power and displacement (and multi-point fuel map), axle ratio, transmission type and gear ratios, and tire loaded radius.

In each of these proposed baseline configurations, the agencies have not applied any vehicle-level fuel saving or emission reduction technology beyond what is required to meet the Phase 1 standards. NHTSA and EPA reviewed available information regarding the likelihood that manufacturers of vocational vehicles would apply technology beyond what is required for Phase 1, and we concluded that the best approach was to analyze a reference case that maintains technology performance at the Phase 1 level. Thus, the nine GEM-simulated baseline vocational vehicle configurations as well as the programmatic vocational vehicle reference case analyzed in this proposal represent what is referred to as a nominally flat baseline.

Tables 4-8, 4-9, and 4-10 in the draft RIA Chapter 4 present the non-user-adjustable modeling parameters for HHD, MHD and LHD vocational vehicles, respectively. In addition to those parameters, to completely define the proposed baseline vehicles, the agencies also selected parameters shown in Table 2-43, Table 2-44, and Table 2-45.

These attributes and parameters were selected to represent a range of performance across this diverse segment, and are intended to represent a reasonable range of vocational chassis configurations likely to be manufactured in the implementation years of the Phase 2 program. The tire radii and axle ratios were selected based on market research of publically available manufacturer product specifications, as well as some confidential manufacturer information about configurations sold in prior model years. The transmission gear ratios were selected based on the transmissions for which models have been validated in GEM. Using the reference vehicles noted above, the agencies were able to better determine an appropriate type of transmission and its gear ratios, for all vocational vehicles. Tire radii and axle ratios were selected using good engineering judgment and stakeholder input, to reflect reasonable final drive ratios to match with our modeled transmissions. In general, the trend is that vehicles with higher final drive ratios have been selected for the subcategories with less weighting of the highway test cycles.

The proposed Phase 2 weighting of steer tire CRR and drive tire CRR is different than in Phase 1. In Phase 1, the agencies weighted drive and steer tire CRR values as if 50 percent of the vehicle load was on the front axle and 50 percent on the rear axle(s). The agencies reviewed the Vehicle Valuation Services quick reference guide to obtain typical axle load ratings for a variety of vocational vehicle types.[116] According to that guide, the examples of vocational vehicles with two axles had a rear axle designed to carry between 1.8 and three times the weight of the front axle. Examples of vehicles with three axles had combined weights of the rear axles designed to carry loads ranging from 2.4 to 3.7 times the weight rating of the front axle. Based on this, the agencies propose a Phase 2 weighting of 0.3 times the steer tire CRR and 0.7 times the drive tire CRR, representing a weight distribution of the rear axle(s) carrying 2.3 times the weight of the front axle.

The proposed allocation of 50 percent of reduced weight back to payload is described below in Section 2.9.3.5.

Table 2-43 Heavy Heavy-Duty User-Enterable Modeling Parameters for Vocational Baseline

GEM INPUT	HHD (CLASS 8) Regional Duty Cycle	HHD (CLASS 8) Multi-Purpose Duty Cycle	HHD (CLASS 8) Urban Duty Cycle
Transmission			
Number of Forward Gears	10	5	5
Gear Ratio for Each Gear	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1, 0.73	4.6957, 2.213, 1.5291, 1, 0.7643	4.6957, 2.213, 1.5291, 1, 0.7643
Architecture Type	Manual	Automatic	Automatic
Axle			
Axle Ratio	3.76	4.33	5.29
Advanced Axle Lubrication	No	No	No
6 x 2 Axle	No	No	No
Idle Reduction			
Neutral Idle	No	No	No
Stop-Start	No	No	No
Tires			
Steer Tire CRR	7.7	7.7	7.7
Drive Tire CRR	7.7	7.7	7.7
Tire Loaded Radius	0.483	0.483	0.483
Weight Reduction (lbs)	No	No	No

Table 2-44 Medium Heavy-Duty User-Enterable Modeling Parameters for Vocational Baseline

GEM INPUT	MHD (CLASS 6-7)	MHD (CLASS 6-7)	MHD (CLASS 6-7)
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Transmission			
Number of Forward Gears	5	5	5
Gear Ratio for Each Gear	3.102, 1.8107, 1.4063, 1, 0.7117	3.102, 1.8107, 1.4063, 1, 0.7117	3.102, 1.8107, 1.4063, 1, 0.7117
Architecture Type	Automatic	Automatic	Automatic
Axle			
Axle Ratio	4.33	4.88	4.88
Advanced Axle Lubrication	No	No	No
6 x 2 Axle	No	No	No
Idle Reduction			
Neutral Idle	No	No	No
Stop-Start	No	No	No
Tires			
Steer Tire CRR	7.7	7.7	7.7
Drive Tire CRR	7.7	7.7	7.7
Tire Loaded Radius	0.462	0.462	0.426
Weight Reduction (lbs)	No	No	No

Table 2-45 Light Heavy-Duty User-Enterable Modeling Parameters for Vocational Baseline

GEM INPUT	LHD (CLASS 2B-5)	LHD (CLASS 2B-5)	LHD (CLASS 2B-5)
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Transmission			
Number of Forward Gears	5	5	5
Gear Ratio for Each Gear	3.102, 1.8107, 1.4063, 1, 0.7117	3.102, 1.8107, 1.4063, 1, 0.7117	3.102, 1.8107, 1.4063, 1, 0.7117
Architecture Type	Automatic	Automatic	Automatic
Axle			
Axle Ratio	4.1	4.56	4.56
Advanced Axle Lubrication	No	No	No
6 x 2 Axle	No	No	No
Idle Reduction			
Neutral Idle	No	No	No
Stop-Start	No	No	No
Tires			
Steer Tire CRR	7.7	7.7	7.7
Drive Tire CRR	7.7	7.7	7.7
Tire Loaded Radius	0.378	0.378	0.378
Weight Reduction (lbs)	No	No	No

2.9.2.1 Setting Normalized Vocational Vehicle Baselines

The agencies developed adjusted, normalized vocational vehicle GEM numerical baselines, from which the improvements due to the technology packages would be set. This process began with simulating the performance of each of the nine baseline vehicles defined above. In this simulation, the emissions for curb idle transmission torque were calculated for each vehicle over the idle cycle.

Next, the best performing vehicle in each weight class was identified. For the HHD weight class, this was the Regional vehicle. For the MHD and LHD weight classes, these were the Urban vehicles. Next, we calculated a normalization factor for each of the nine subcategories by dividing each GEM result of the best vehicle by the fleet weighted average result per weight class of the best vehicle. For each weight class, we assumed that 25 percent of the vehicles would use the Regional cycle, 50 percent would use the Multipurpose cycle, and 25 percent would use the Urban cycle. Then, we calculated a population-weighted result of the actual baseline GEM results in each weight class group using a presumed population distribution (25-50-25). Finally, we calculated the normalized baseline values for each of nine subcategories by multiplying the weighted baseline GEM result in each weight class by each respective normalization factor for that subcategory. This process is summarized in Table 2-46.

Table 2-46 Vocational Baseline Normalizing

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Rural, Regional	Urban	Multi-Purpose	Rural, Regional	Urban	Multi-Purpose	Rural, Regional
Straight GEM Baseline Performance								
318	328	331	200	204	199	223	216	187
Normalization Factor								
0.97	1.00	1.04	1.00	1.01	0.99	1.01	1.02	0.96
Population Weighted Best Vehicle Result								
328.8			202.4			193.9		
Population Weighted Baseline Result								
326.3			201.8			210.5		
Normalized Baseline								
316	325	339	201	203	199	212	214	203

2.9.2.2 Assigning Vocational Vehicles to Subcategories

To determine appropriate engine speed cut-points for subcategory assignments, the agencies conducted GEM simulations for each of the nine defined baseline vocational vehicles using a sweep of axle ratios ranging from 2.47:1 to 12:1. We then compared the CO_2 emission rates of the composite cycle to assess the sensitivity of the results to axle ratio, and identified the axle ratio for which the emission rate was lowest, and thus most optimized for that vehicle and duty cycle. Next the agencies compared the engine speeds attained during the 55 mph and 65 mph cruise cycles for the optimized axle ratio simulation to the maximum engine test speed of the engine in each simulated vehicle.   The diesel engines in each simulated vehicle are described above in Chapter 2.9.1. The agencies used two gasoline engine models for this analysis, which were not used for derivation of the proposed standards.

We noted considerable variability in the ratio of attained engine speed at 55 mph vs. maximum test speed, but we reasoned that if an engine was rotating close to the engine's rated speed (represented by a high percent of maximum test speed) while the vehicle is at 55 mph then it would logically be best certified using the Urban Duty Cycle. Based on our observations and good engineering judgment, we selected a cutpoint for the Urban Duty Cycle where a vehicle at 55 mph would have an engine working above 90 percent of maximum engine test speed for vocational vehicles powered by diesel engines and above 50 percent for vocational vehicles powered by gasoline engines. We similarly noted considerable variability in the ratio of attained engine speed at 65 mph vs. maximum test speed, but we reasoned that if an engine was rotating slowly (represented by a low percent of maximum test speed) while the vehicle is at 65 mph then it would logically be best certified using the Regional Duty Cycle. Based on our observations and good engineering judgment, we selected a cutpoint for the Regional Duty Cycle where a vehicle at 65 mph would have an engine working below 75 percent of maximum engine test speed for vocational vehicles powered by diesel engines and below 45 percent for vocational vehicles powered by gasoline engines. The proposed regulations describe this subcategory assignment process at 40 CFR 1037.510.

2.9.3 **Costs and Effectiveness of Vocational Vehicle Technologies**

The following paragraphs describe the vehicle-level technologies on which the proposed vocational vehicle standards are predicated, and their projected effectiveness over the proposed test cycles. The methodology for estimating costs, including indirect cost estimates and learning effects, is described in draft RIA Chapter 2.12.1. Certain elements of the cost estimating methodology are the same as for the Phase 1 program, but as described in that section, certain elements are different, including how the agencies apply the markups, how the markups change with time, and which cost elements are influenced by learning effects. As a result of different technology complexities, learning effects, and different short-term and long-term warranty and non-warranty-related indirect costs, some technology costs identified below may appear higher in MY 2021 than in MY 2027. These differences are not due to changes in adoption rates, since the costs in Chapter 2.12 and below in Chapter 2.9.3 to 2.9.4 are for applying a given technology to a single vehicle. Throughout this Chapter, where a dollar cost is given for a technology, note that these are adjusted to be valued as year 2012 dollars. Average costs for vocational vehicle technology packages, including adoption rates, are presented below in Chapter 2.9.5. Detailed descriptions of technology packages for SI engines can be found in the draft RIA Chapter 2.6. Detailed descriptions of technology packages and costs for CI engines can be found in the draft RIA Chapter 2.7.

2.9.3.1 Transmissions

Transmission improvements present a significant opportunity for reducing fuel consumption and CO_2 emissions from vocational vehicles. Transmission efficiency is important for many vocational vehicles as their duty cycles involve high percentages of driving under transient operation. The three categories of transmission improvements the agencies considered for Phase 2 are driveline optimization, architectural improvements, and hybrid powertrain systems.

Of the technologies described above in Chapter 2.4, the agencies are predicating the proposed vocational vehicle standards on performance improvements achieved by use of advanced transmissions as described in Table 2-47, below. The projected market adoption rates that inform the technology packages are described in Chapter 2.9.5.

Table 2-47 Projected Vocational Transmission Improvements over GEM Baseline

TRANSMISSION TECHNOLOGY	PROJECTED IMPROVEMENT OVER TEST CYCLE[A]		REGIONAL COMPOSITE CYCLE	MULTI-PURPOSE COMPOSITE CYCLE	URBAN COMPOSITE CYCLE
Two More Gears (over 5-speed)	ARB Transient	2%	1.1	1.7	1.9
	55 mph Cruise	0%			
	65 mph Cruise	0%			
DCT or AMT (over automatic)	ARB Transient	4%	2.1	3.4	3.8
	55 mph Cruise	0%			
	65 mph Cruise	0%			
HHD DCT or AMT (over manual)[b]	ARB Transient	4%	2.3 (2.95)	N/A	N/A
	55 mph Cruise	1.5%			
	65 mph Cruise	1.5%			
Strong Hybrid	ARB Transient	27%	14.7	22.9	25.6
	55 mph Cruise	0%			
	65 mph Cruise	0%			
Deep Driveline Integration	ARB Transient	7%	4.7	6.2	6.7
	55 mph Cruise	2%			
	65 mph Cruise	2%			

Notes:
[a] Improvement is relative to a 5-speed automatic transmission in GEM, except where noted. Technology improvements would either be modeled in GEM or would be measured over the powertrain test, except as noted.
[b] Fixed improvement for HHD AMT or DCT vs. manual transmission in GEM would be 2.3 percent as shown, in addition to the GEM-modeled improvement of one percent over the ARB Transient and zero over the cruise cycles. Combined these would be 2.95 percent.

2.9.3.1.1 *Deep Integration - Conventional*

The agencies believe an effective way to derive efficiency improvements from a transmission is by optimizing it with the engine and other driveline components to balance both performance needs and fuel savings. However, many vocational vehicles today are not operating with such optimized systems. Due to the fact that customers are able to specify their preferred components in a highly customized build process, many vocational vehicles are assembled with components that were designed more for compatibility than for optimization. To some extent, vertically integrated manufacturers are able to optimize their drivelines. However, this is not widespread in the vocational vehicle sector, resulting, primarily, from the multi-stage manufacture process. The agencies thus project that transmission and driveline optimization would yield a substantial proportion of vocational vehicle fuel efficiency improvements for Phase 2. On average, we anticipate that efficiency improvements of about five percent can be achieved from optimization, sometimes called deep integration, of drivelines. However, we are not assigning a fixed level of improvement; rather we have developed a test procedure, the powertrain test, for manufacturers to use to obtain improvement factors representative of their systems. See the draft RIA Chapter 3 for a discussion of this test procedure. Depending on the test cycle and level of integration, the agencies believe improvement factors greater than ten percent above the baseline vehicle performance could be achieved. To obtain such benefits across more of the vocational vehicle fleet, the agencies believe there is opportunity for manufacturers to form strategic partnerships and explore commercial pathways to deploy deeper driveline integration. For example, one partnership of an engine manufacturer and a transmission manufacturer has led to development of driveline components that deliver improved fuel efficiency based on optimization that could not be realized without sharing of critical data.[117]

The agencies project other related transmission technologies would be recognized over the powertrain test along with driveline optimization. These include improved mechanical gear efficiency, more sophisticated shift strategies, more aggressive torque converter lockups, transmission friction reduction, and reduced parasitic losses.[118] Each of these attributes would be simulated in GEM using default values, unless the powertrain test were employed. The expected benefits of improved gear efficiency, shift logic, and torque converter lockup are included in the total projected effectiveness of optimized conventional transmissions using the powertrain test. For conventional powertrains, the agencies are projecting effectiveness of deep integration from 3.5 to 4.8 percent, as shown in Table 2-47 above.

The agencies estimate the total cost to apply a high efficiency gearbox, aggressive shift logic, and early torque converter lockup to a vocational vehicle at $372 in MY 2021 and $315 in MY 2027, as described in draft RIA 2.12.3.5. The agencies describe the capital and operational expenses of conducting powertrain testing in the draft RIA Chapter 7.1.

2.9.3.1.2 *Architectural Transmission Improvements*

One type of architectural improvement the agencies project can reasonably be developed by manufacturers of all transmission architectures is increased number of gears. The benefit of adding more gears varies depending on whether the gears are added in the range where most operation occurs. The TIAX 2009 report projected that 8-speed transmissions could incrementally reduce fuel consumption by 2 to 3 percent over a 6-speed automatic transmission, for Class 3-6 box and bucket trucks, refuse haulers, and transit buses.[119] Although the agencies estimate the improvement could on average be about two percent for the adding of two gears in the range where significant vehicle operation occurs, we are not assigning a fixed improvement based solely on number of transmission gears. Manufacturers would enter the number of gears and gear ratios into GEM and the model would simulate the efficiency benefit over the applicable test cycle. The agencies estimate the total cost to add two gears to a vocational vehicle transmission at $495 in MY 2021 and $457 in MY 2027, as described in draft RIA 2.12.3.1.

Transmission efficiency could also be improved in the time frame of the proposed rules by changes in the architecture of conventional transmissions. Most vocational vehicles currently use torque converter automatic transmissions (AT), especially in Classes 2b-6. According to the 2009 TIAX report, approximately 70 percent of Class 3-6 box and bucket trucks use AT, and all refuse trucks, urban buses, and motor coaches use AT.[118] AT's offer acceleration benefits over drive cycles with frequent stops, which can enhance productivity. However, with the diversity of vocational vehicles and drive cycles, other kinds of transmission architectures can meet customer needs, including automated manual transmissions (AMT) and even some manual transmissions (MT).[120]

Other architectural changes that the agencies project would offer efficiency improvements include improved automated manual transmissions (AMT) and introduction of dual clutch transmissions (DCT). Newer versions of AMT are showing significant improvements in reliability, such that the current generation of transmissions with this architecture is more likely to retain resale value and win customer acceptance than early models.[121] The agencies believe AMT generally compare favorably to manual transmissions in fuel efficiency, and while the degree of improvement is highly driver-dependent, it can be two percent or greater, depending on the drive cycle. See Chapter 2.4.4 for additional discussion of AMT. The agencies are not assigning fixed average performance levels to compare an AMT with a traditional automatic transmission. Although the lack of a torque converter offers AMT an efficiency advantage in one respect, the lag in power during shifts is a disadvantage. For Phase 2, the agencies have developed validated models of both AMT and AT, as described in the draft RIA Chapter 4. Manufacturers installing AMT or AT would enter the relevant inputs to GEM and the simulation would calculate the performance. Dual clutch transmissions (DCT) are already in production for light-duty vehicles, and are expected to become available in the vocational vehicle market prior to the proposed beginning of Phase 2 in MY 2021.[122] Based on supplier conversations, manufacturers intend to match varying DCT designs with the diverse needs of the heavy-duty market. The agencies do not yet have a validated DCT model in GEM, and we are not assigning a fixed performance level for DCT, though we expect the per-vehicle fuel efficiency improvement due to switching from automatic to DCT to be in the range of three percent over the GEM vocational vehicle test cycles. Selection of transmission architecture type (Manual, AMT, AT, DCT) would be made by manufacturers at the time of certification, and GEM would either use this input information to simulate that transmission using algorithms as described in the draft RIA Chapter 4, or fixed improvements may be assigned. The agencies are proposing to assign fixed levels of improvement that vary by test cycle in GEM for AMT when replacing a manual, which for vocational vehicles would be in the HHD Regional subcategory. If a manufacturer elected not to conduct powertrain testing to obtain specific improvements for use of a DCT, GEM would simulate a DCT as if it were an AMT, with no fixed assigned benefit.

According to EPA's light-duty teardown report, the direct incremental cost to build a six-speed wet dual clutch transmission was determined to be roughly $100 less than the cost of a six-speed automatic transmission.[123] We estimate the components and engineering to design a heavy-duty torque converter automatic transmission are at least as costly and complex as those to design a dual clutch transmission. Therefore, the agencies estimate switching from AT to DCT would have zero incremental cost for vocational vehicles.

The agencies have estimated the costs of upgrading from HHD manual transmissions to AT, AMT, and DCT, as summarized in Table 2-48, and described in detail below in 2.12.3.

Table 2-48 Incremental Costs for HHD Transmissions Relative to Manual Transmissions[a]

TECHNOLOGY	2021 COST	2027 COST
Manual to AMT	$4,472	$3,795
Manual to AT	$3,764	$3,470
Manual to DCT	$4,472	$3,795

Note:
[a] Costs include markups (2012$)

2.9.3.1.3 *Deep Integration - Hybrid*

The agencies are including hybrid powertrains as a technology on which the proposed vocational vehicle standards are predicated. We project a variety of mild and strong hybrid systems, with a wide range of effectiveness. Mild hybrid systems that offer an engine stop-start feature are discussed below under workday idle reduction. For hybrid powertrains, we are estimating a 22 to 25 percent fuel efficiency improvement over the powertrain test, depending on the duty cycle in GEM for the applicable subcategory. The agencies obtained these estimates by projecting a 27 percent effectiveness over the ARB Transient cycle, and zero percent over the highway cruise cycles. With the proposed cycle weightings, depending on the subcategory, this is projected to yield a 25 to 26 percent improvement over the Urban cycle, and 22 to 23 percent improvement over the Multi-Purpose cycle. According to the NREL Final Evaluation of UPS Diesel Hybrid-Electric Delivery Vans, the improvement of a hybrid over a conventional diesel in gallons per ton-mile on a chassis dynamometer over the NYC Composite test cycle was 28 percent.[124] NREL characterizes the NYC Composite cycle as more aggressive than most of the observed field data points from the study, and may represent an ideal hybrid cycle in terms of low average speed, high stops per mile, and high kinetic intensity (KI). NREL noted that most of the observed field data points were reasonably represented by the HTUF4 cycle, over which the chassis dynamometer results showed a 31 percent improvement in gallons per ton-mile. In units of grams CO_2 per mile, NREL reported these test results as 22 percent improvement over the NYC Composite cycle and 26 percent improvement over the HTUF4 cycle. Based on these results, and the fact that any improvement from strong hybrids in Phase 2 would not be simulated in GEM, rather evaluated using the powertrain test, the agencies deemed it reasonable to estimate a conservative 27 percent effectiveness over the ARB Transient in setting the stringency of the standards.

Hybrid powertrain systems are included under transmission technologies because, depending on the design and degree of hybridization, they may either replace a conventional transmission or be deeply integrated with a conventional transmission. Further, these systems are often manufactured by companies that also manufacture conventional transmissions.

The Phase 1 standards were not predicated on any adoption of hybrid powertrains in the vocational vehicle sector. Because the first implementation year of Phase 1 came just three years after promulgation, it did not offer an opportunity to provide the lead time for development of technology. The agencies believe the Phase 2 rulemaking would offer sufficient lead time to develop, demonstrate, and conduct reliability testing for technologies that are still maturing.

Several types of vocational vehicles are well suited for hybrid powertrains, and tend to be early adopters of this technology. Vehicles such as utility or bucket trucks, delivery vehicles, refuse haulers, and buses have operational usage patterns with either a significant amount of stop-and-go activity or spend a large portion of their operating hours idling the main engine to operate a PTO unit.

The industry is currently developing many variations of hybrid powertrain systems. There are a few hybrid systems in the heavy-duty market today and several more under development. In addition, energy storage systems are getting better.[125] Heavy-duty customers are getting used to these systems with the number of demonstration products on the road. Even so, manufacturers are uncertain how much investment to make in this technology without clear signals from regulators. A list of hybrid manufacturers and their products intended for the vocational market is provided in Table 2-49.

Table 2-49 Examples of Hybrid Manufacturers

MANUFACTURER	PRODUCT	EXAMPLE APPLICATION
Hino	Class 5 cab-over-engine battery-electric hybrid	Delivery Trucks
Allison	HHD parallel hybrid	Transit Bus
BAE	HHD series or parallel hybrid	Transit Bus
XL	Class 3-4 mild electric hybrid	Shuttle Bus
Crosspoint Kinetics	Class 3-7 mild electric hybrid	Delivery trucks, shuttle buses
Lightning Hybrids	Class 2-5 hydraulic hybrid	Delivery trucks
Parker Hannifin	MHD hydraulic hybrid	Delivery trucks
Freightliner Custom Chassis	MHD hydraulic hybrid	Delivery trucks
Morgan Olson	MHD hydraulic hybrid	Delivery trucks
Autocar-Parker	Runwise hydraulic hybrid	Refuse Trucks
Eaton[a]	HHD parallel electric hybrid	Trucks and Buses
Odyne	Plug-in electric hybrid, E-PTO	Utility Trucks

Note:
[a] Currently selling in markets outside the U.S.

Some low cost products on the simple end of the hybrid spectrum are available that minimize battery demand through the use of ultra-capacitors or only provide power assist at low speeds. Our regulations define a hybrid system as one that has the capacity for energy storage.[M] Unofficially, some systems are commonly known as mild hybrids, where some accessories are electrified, the engine is not downsized and there may or may not be capacity for regenerative braking. Strong hybrids are typically referred to as those that have larger energy storage capacity such that the engine may be downsized in some cases. Depending on the drive cycle and units of measurement, strong hybrids developed to date have seen fuel consumption and CO_2 emissions reductions between 20 and 50 percent in the field.[126]

The agencies estimate the total cost of a hybrid powertrain system for a LHD vocational vehicle at $15,207 in MY 2021 and $11,791 in MY 2027. For a MHD vocational vehicle, the total cost is estimated at $23,904 in MY 2021 and $18,534 in MY 2027. For a HHD vocational vehicle, the total cost is estimated at $39,919 in MY 2021 and $30,952 in MY 2027, as described in draft RIA 2.12.7. The estimated higher costs for heavier vehicles are related to higher power demands and greater energy storage needs. These estimates assume no engine downsizing in the design of hybrid packages. This is in part to be conservative in our cost estimates, and in part because in some applications a smaller engine may not be acceptable if it would risk that performance could be sacrificed during some portion of a work day.

[M] NHTSA's and EPA's regulations define a hybrid vehicle as one that "includes energy storage features … in addition to an internal combustion engine or other engine using consumable chemical fuel…." 49 CFR 535.4 and 40 CFR 1037.801.

2.9.3.2 Axles

The agencies are considering two axle technologies for the vocational sector. The first is advanced low friction axle lubricants. SwRI tested improved driveline lubrication and found measurable improvements by switching from current mainstream products to top-tier formulations focusing on modified viscometric effects.[127] The agencies believe that a 0.5 percent improvement in vocational vehicle efficiency (as for tractors) is achievable through the application of low friction axle lubricants, and have included that value as a fixed technology improvement value in GEM. If a manufacturer wishes to demonstrate a greater benefit, an axle efficiency test could be performed to support an application for an innovative technology credit. See draft RIA Chapter 3 for a description of a test procedure for axle efficiency. We are estimating the axle lubricating costs for HHD to be the same as for tractors since those vehicles likewise typically have three axles. However, for LHD and MHD vocational vehicles, we scaled down the cost of this technology to reflect the presence of a single rear axle. The agencies estimate the total cost of low friction axle lubricants on a LHD or MHD vocational vehicle (with 2 axles) at $132 in MY 2021 and $114 in MY 2027. For HHD vocational vehicles (with 3 axles), the agencies estimate the cost at $197 in MY 2021 and $172 in MY 2027, as described in draft RIA 2.12.5.4.

The second axle technology the agencies are considering is a design that enables one of the tandem axles to temporarily disconnect or permanently be a non-driven axle, on vehicles with two rear (drive) axles, commonly referred to as a 6x2 configuration. The agencies have considered two types of 6x2 configurations for vocational vehicles: those that are engaged full time on a vehicle, and those that may be engaged only during some types of vehicle operation, such as only when operating at highway cruise speeds. In prior years, manufacturers offered versions of this technology that were not accepted by vehicle owners. When the second drive axle is no longer powered, traction may be sacrificed in some cases. Vehicles with earlier versions of this technology have seen reduced residual values in the secondary market.[128] Over the model years covered by the Phase 2 rules, the agencies expect the market to offer significantly improved versions of this technology, with traction control maintained at lower speeds and efficiency gains at highway cruise speeds.[129] Mechanisms to automatically disconnect or reconnect drive axles would likely function in a similar manner as with two axle vehicles that can seamlessly switch from four-wheel drive to two-wheel drive and back. Further information about 6x2 axle technology is provided in the feasibility of the tractor standards, preamble Section III, as well as in draft RIA Chapter 2.4.

The efficiency benefit of a 6x2 axle configuration is highly duty-cycle dependent. In many instances, vocational vehicles need to operate off-highway, such as at a construction site delivering materials or dumping at a refuse collection facility. Under these conditions, vehicles with two drive axles may need the full tractive benefit of both drive axles. The 6x2 axle disconnect technology is not expected to measurably improve a vehicle's efficiency for vehicles whose normal duty cycle is performing off-highway work, but the agencies do expect this technology to be recognized on a cycle with a significant weighting of highway cruise. The agencies estimate the total cost of full time 6x2 at $197 in MY 2021 and $172 in MY 2027. The agencies estimate the total cost of part time 6x2 on a vocational vehicle at $120 in MY 2021 and $116 in MY 2027, as described in draft RIA 2.12.5.2.

Some vocational vehicles in the HHD Regional subcategory may see a 6x2 axle disconnect technology as a reasonable option for improving fuel efficiency. As in Phase 1, our vehicle simulation model assumes that only HHD vehicles have two rear axles, so only these could be recognized for adopting this technology. Further, the agencies don't believe vehicles in the Multipurpose and Urban subcategories operate with a significant enough highway time to make this technology worthwhile. While the agencies project this can achieve over 2 percent benefit at highway cruise, we propose to assign a fixed 2.5 percent value in GEM for part time 6x2 over the highway cruise cycles and zero over the ARB Transient cycle, where the specific benefit would be calculated according to the composite weighting of the applicable vocational vehicle test cycle.[130]

2.9.3.3 Lower Rolling Resistance Tires

Tires are the second largest contributor to energy losses of vocational vehicles, as found in the energy audit conducted by Argonne National Lab.[131] There is a wide range of rolling resistance of tires used on vocational vehicles today. This is in part due to the fact that the competitive pressure to improve rolling resistance of vocational vehicle tires has been less than that found in the line haul tire market. In addition, the drive cycles typical for these applications often lead vocational vehicle buyers to value tire traction and durability more heavily than rolling resistance. The agencies acknowledge there can be tradeoffs when designing a tire for reduced rolling resistance. These tradeoffs can include characteristics such as wear resistance, cost and scuff resistance. NHTSA, EPA, and ARB met with stakeholders from the tire industry (Bridgestone, Continental, Cooper, Goodyear, and Michelin) to discuss the next generation of lower rolling resistance (LRR) tires for the Phase 2 timeframe for all segments of Class 2b-8 vehicles, including trailers. Manufacturers discussed forecasts for rolling resistance levels and production availability in the Phase 2 timeframe, as well as their plans for improving rolling resistance performance while maintaining other performance parameters such as traction, handling, wear, mass reduction, retreadability, and structural durability.

The meetings included specific discussions of the impacts of the current generation of LRR tires on vehicle stopping distance and handling. Manufacturers indicated no known safety disbenefit in the current on-road fleet from use of LRR tires. While the next generation of tires may require some tradeoffs in wear performance and costs over the next 10 years to achieve better tire rolling resistance performance, manufacturers said they will not trade off safety for performance. They also emphasized that keeping tires inflated (through proper maintenance or automatic systems) was the best way to assure long term fuel efficiency and safety during vehicle operation.

According to the 2015 NHTSA Technology Study, vocational vehicles are likely to see the most benefits from reduced tire rolling resistance when they are driving at 55 mph.[132] This report also found an influence of vehicle weight on the benefits of LRR tires. The study found that both vocational vehicles tested had greater benefits of LRR tires at 100 percent payload than when empty. Also, the T270 delivery box truck that was 4,000 pounds heavier when fully loaded saw slightly greater efficiency gains from LRR tires than the F650 flatbed tow truck over the same cycles. At higher speeds, aerodynamic drag grows, which reduces the rolling resistance share of total vehicle power demand. In highly transient cycles, the power required to accelerate the vehicle inertia overshadows the rolling resistance power demand. In simulation, GEM represents vocational vehicles with fixed vehicle weights, payloads and aerodynamic coefficients. Thus, the benefit of LRR tires would be reflected in GEM differently for vehicles of different weight classes. There will also be further differences arising from the different test cycles. Based on preliminary simulations, it appears the vehicles in GEM most likely to see the greatest fuel efficiency gains from use of LRR tires are those in the MHD weight classes tested over the Regional or Multipurpose duty cycles, where one percent efficiency improvement could be achieved by reducing CRR by four to five percent. Those seeing the least benefit from LRR tires would likely be Class 8 vocational vehicles tested over the Urban or Multipurpose cycles, where one percent efficiency improvement could be achieved by reducing CRR by seven to eight percent.

As shown in draft RIA Chapter 2.12.8, the agencies estimate the total cost to apply LRR tires that have five percent lower CRR than baseline to be the same as the cost to apply baseline-level LRR tires. The agencies estimate the cost to apply LRR tires that have 10 percent lower CRR than baseline to be about $4 more than the cost of baseline tires. The agencies estimate the cost to apply LRR tires that have 15 percent lower CRR than baseline to be about $6 more than the cost of baseline tires. Based on these costs, some illustrations of the costs associated with LRR tires are provided. To fit a LHD or MHD vocational vehicle with two steer tires improved by 10 percent and 4 drive tires improved by 5 percent would be roughly $9 to $10 in MY 2021 as well as in MY 2024. Based on the estimated zero-cost to upgrade the drive tires by five percent, we estimate the cost to fit a HHD vocational vehicle (with 10 tires) with the same CRR upgrades would be roughly the same, $9 to $10.

As another example, to fit a LHD or MHD vocational vehicle with two steer tires improved by 15 percent and 4 drive tires improved by 10 percent, it is estimated to cost $33 in MY 2024. For a HHD vehicle (with 8 drive tires) to make the same CRR upgrades, we estimate the cost to be $54 in MY 2024. Detailed tables of LRR tire costs in each year are provided in draft RIA Chapter 2.12.8.

The agencies propose to continue the light truck (LT) tire CRR adjustment factor that was adopted in Phase 1. See generally 76 FR 57172-74. In Phase 1, the agencies developed this adjustment factor by dividing the overall vocational test average CRR of 7.7 by the LT vocational average CRR of 8.9. This yielded an adjustment factor of 0.87. After promulgation of the Phase 1 rules, the agencies conducted additional tire CRR testing on a variety of LT tires, most of which were designated as all-position tires. In addition, manufacturers have submitted to the agencies pre-certification data that include CRR values provided by tire suppliers. For the small subset of newer test tires that were designated as steer tires, the average CRR was 7.8 kg/ton. For the subset of newer test tires that were designated as drive tires, the average CRR was 8.6 kg/ton. However all-position tires had an average CRR of 8.9 kg/ton.[133] Therefore, for LT vocational vehicle tires, we propose to continue allowing the measured CRR values to be multiplied by the 0.87 adjustment factor before entering the values in the GEM for compliance, because this additional testing has not revealed compelling information that a change is needed.

2.9.3.4 Workday Idle Reduction

The Phase 2 idle reduction technologies considered for vocational vehicles are those that reduce workday idling, unlike the overnight idling of combination tractors. There are many potential such technologies. The agencies in particular evaluated neutral idle and stop-start technologies, and the proposed standards are predicated on projected amounts of penetrations of these technologies. While neutral idle is necessarily a transmission technology, stop-start could range from an engine technology to one that would be installed by a secondary manufacturer under a delegated assembly agreement.

The agencies are aware that for a vocational vehicle's engine to turn off during workday driving conditions, there must be a reserve source of energy to maintain functions such as power steering, cabin heat, and transmission pressure, among others. Stop-start systems can be viewed as having a place on the low-cost end of the hybridization continuum. The agencies are including the cost of energy storage sufficient to maintain critical onboard systems and restart the engine as part of the cost of vocational vehicle stop-start packages. The technologies to capture this energy could include a system of photovoltaic cells on the roof of a box truck, or regenerative braking. The technologies to store the captured energy could include a battery or a hydraulic pressure bladder. According to CALSTART's report to the NAFA 2014 Institute and Expo, examples of suppliers of on-vehicle energy storage systems that can enable idle reduction include Altec, Terex, and Time. More discussion of stop-start technologies is found in the draft RIA Chapter 2.4.

The agencies are also proposing a certification test cycle, as described in draft RIA Chapter 3.4.2, which measures the amount of fuel saved and CO_2 reduced by these two primary types of technologies: neutral idle and stop-start. Vocational vehicles frequently also idle while cargo is loaded or unloaded, and while operating a PTO such as compacting garbage or operating a bucket. In these rules, the agencies are proposing that the Regional duty cycle have ten percent idle, the Multi-purpose cycle have 15 percent idle, and the Urban cycle have 20 percent idle. These estimates are based on some publically available data published by NREL.[134] Figure 2-16 depicts a chart that illustrates the type of data on zero-speed operation data from delivery trucks available from NREL on its Fleet DNA web site. However, because engine parameters were not captured during the data-logging of this vehicle activity, these data cannot distinguish between zero speed conditions with the engine off and zero speed conditions with the engine idling.

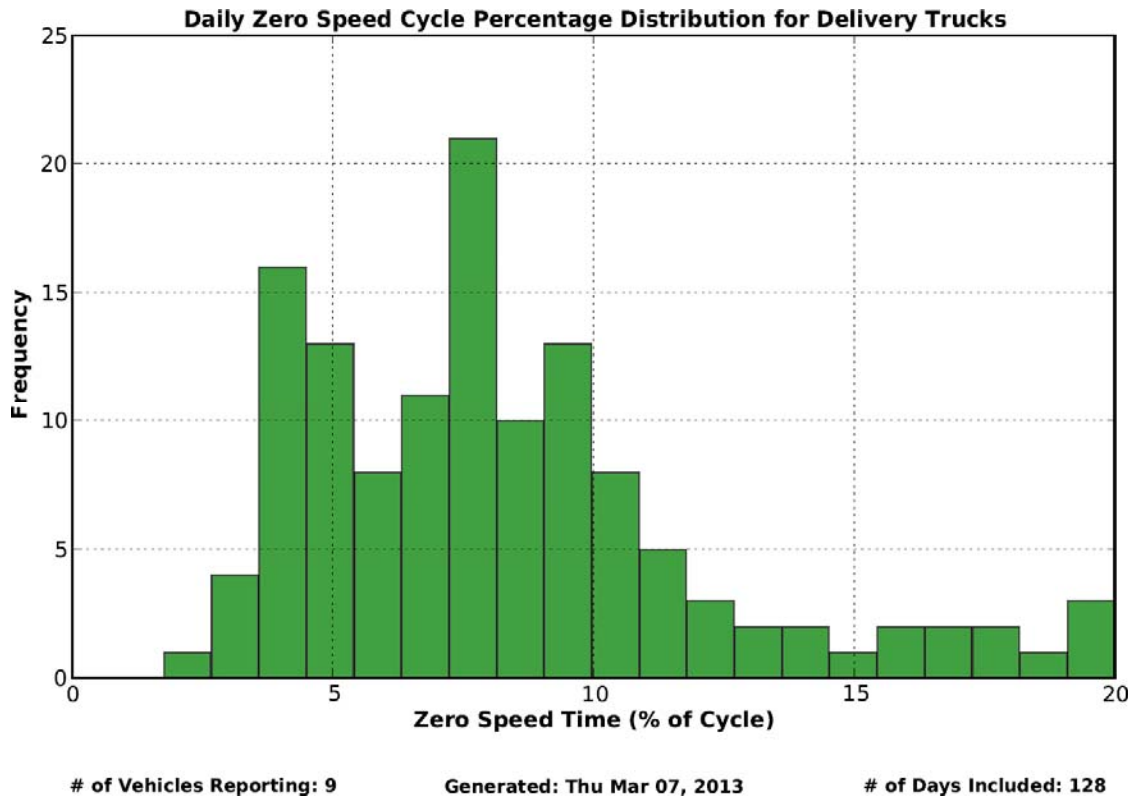


Figure 2-16 Example Fleet DNA Vehicle Activity Data from NREL

Combining the publically available zero-speed frequency charts from NREL on delivery trucks, service vans, delivery vans, and bucket trucks, the agencies observed that roughly half of the logged operating days had less than 10 percent time at zero speed, roughly 30 percent of the logged operating days had between 10 and 15 percent time at zero speed, roughly 20 percent of the logged operating days had between 15 and 20 percent time at zero speed, and roughly 6 percent of the logged operating days had over 20 percent time at zero speed. School buses were excluded from this average, because the given distribution had two modes: over 40 percent of the school bus operating days logged had less than five percent time at zero speed, while nearly half of the logged operating days for those buses had roughly 40 percent time at zero speed.

Without actual engine information, if we assume all the zero speed time is idling, then based on these rough estimates, it appears that 94 percent of these vehicles (excluding school buses) idle at frequencies of less than 20 percent on a daily basis. Thus, the agencies designed composite test cycles where the maximum weighting of idle was 20 percent. We assigned that value to the Urban cycle, where we expect a high incidence of traffic-related idling and city delivery routes involving frequent stops. The 15 percent and 10 percent idle weightings for the Multi-Purpose and Regional cycles, respectively, were selected as reasonably lesser values, given the distributions observed in the NREL charts. Table 2-50 presents a summary of this analysis.

Table 2-50 Daily Zero Speed Percentage Distribution by Vehicle Type

	LESS THAN 10	10 TO 14	15 TO 20	OVER 20
Service Vans	59%	18%	23%	0%
Delivery Trucks	76%	16%	9%	0%
Delivery Vans	38%	35%	2%	25%
Bucket Trucks	18%	45%	37%	0%
School Buses	41%	3%	7%	48%
Average	47%	23%	16%	15%
Average Without Buses	48%	28%	18%	6%

Because these data are not representative of the national vocational vehicle fleet, EPA has entered into an interagency agreement with NREL to further characterize workday idle among vocational vehicles. One task of this agreement is to estimate the nationally representative fraction of idle operation for vocational vehicles for each proposed regulatory subcategory. The preliminary range of daily idle operation per vehicle indicated by this work is about 18 to 33 percent when combining the data from all available vehicles. An analysis of possible vocational vehicle standards derived from alternate characterizations of idle operation has been prepared by the agencies, and is available for review in the public docket for this rulemaking.[135]

Based on GEM simulations using the currently proposed vocational vehicle test cycles, the agencies estimate neutral idle for automatic transmissions to provide fuel efficiency improvements ranging from one percent to four percent, depending on the regulatory subcategory. The agencies estimate stop-start to provide fuel efficiency improvements ranging from 0.8 percent to seven percent, depending on the regulatory subcategory. Because of the higher idle weighting factor in the Urban test cycle, vehicles certified in these subcategories would derive the greatest benefit from applying idle reduction technologies. This presumes there is a correlation between amount of urban driving and amount of idle time.

Although the primary program would not simulate vocational vehicles over a test cycle that includes PTO operation, the agencies are proposing to continue, with revisions, the hybrid-PTO test option that was in Phase 1. See 40 CFR 1037.525 and 76 FR 57247. Recall that we are proposing to regulate vocational vehicles at the incomplete stage when a chassis manufacturer may not know at the time of certification whether a PTO will be installed or how the vehicle will be used. Although chassis manufacturers will certainly know whether a vehicle's transmission is PTO-enabled, that is very different from knowing whether a PTO will actually be installed and how it will be used. Chassis manufacturers may rarely know whether the PTO-enabled vehicle will use this capability to maneuver a lift gate on a delivery vehicle, to operate a utility boom, or merely as a reserve item to add value in the secondary market. In cases where a manufacturer can certify that a PTO with an idle-reduction technology will be installed either by the chassis manufacturer or by a second stage manufacturer, the hybrid-PTO test cycle may be utilized by the certifying manufacturer to measure an improvement factor over the GEM duty cycle that would otherwise apply to that vehicle. In addition, the delegated assembly provisions would apply. See preamble Section V.E for a description of the delegated assembly provisions. See draft RIA Chapter 3 for a discussion of the proposed revisions to the hybrid PTO test cycle. In cases where a chassis manufacturer does not know whether a powertrain that is PTO-enabled will actually have a PTO-using tool installed, and whether there will be an energy storage system installed to save fuel during PTO operation, then the agencies do not see a way for the Phase 2 program to recognize hybrid PTO technology.

Our estimates are that applying neutral idle to a vocational vehicle with an automatic transmission would cost $9 in MY 2021, decreasing to $8 in MT 2027, as shown in draft RIA 2.12.6. These costs are based on a small amount of engineering development and testing costs, with no hardware required. Our estimates are that the cost of applying stop-start to a vocational vehicle would vary by vehicle weight class. For LHD vocational vehicles, we estimate the total cost would range from $855 in MY 2021 to $709 in MY 2027. For MHD vocational vehicles, we estimate the total cost would range from $902 in MY 2021 to $748 in MY 2027. For HHD vocational vehicles, we estimate the total cost would range from $1,657 in MY 2021 to $1,374 in MY 2027. These costs, presented in draft RIA Chapter 2.12.6, are derived from costs reported by Tetra Tech for stop-start, along with costs for electrified accessories used in the light-duty GHG program, and scaled up for heavier vehicles.

With either a stop-start engine feature or with a neutral idle transmission calibration, less fuel is burned at idle. Furthermore, it is expected that SCR catalyst function could be better managed when an engine shuts off than when it idles, because SCR systems are well insulated and can maintain temperature when an engine is shut off, however idling causes relatively cool air to flow through a catalyst. Therefore, the agencies have reason to believe there may be a NO_X co-benefit to stop-start idle reduction technologies, and possibly also to neutral idle. This would be true if the NO_X reductions from reduced fuel consumption and retained aftertreatment temperature were greater than any excess NO_X emissions due to engine re-starts.

2.9.3.5 Weight Reduction

The agencies believe there is opportunity for weight reduction in some vocational vehicles. The 2015 NHTSA Technology Study found that weight reduction provides a greater fuel efficiency benefit for vehicles driving under transient conditions than for those operating under constant speeds. In simulation, the study found that the two Class 6 trucks improved fuel efficiency by over two percent on the ARB transient cycle by removing 1,100 lbs. Further, SwRI observed that the improvements due to weight reduction behaved linearly.[136] The proposed menu of components available for a vocational vehicle weight credit in GEM is presented in Table 2-52. It includes fewer options than for tractors, but the agencies believe there are a number of feasible material substitution choices at the chassis level, which could add up to weight savings on the order of a few hundred pounds. The agencies estimate the total cost to reduce the weight of a vocational vehicle by 200 pounds to be $683 in MY 2021 and $578 in MY 2027, as described in draft RIA 2.12.10.3. This is in the range of $3 to $4 per pound, as reported by TIAX 2009.[137]

To assess the projected effectiveness of weight reduction of the proposed package of 200 pounds, the agencies simulated a HHD, MHD and LHD vocational vehicle in GEM over each of the separate test cycles. Based on the results of this simulation, the agencies project a reduction of 200 pounds may yield a fuel efficiency improvement ranging from 0.8 percent to 2 percent over the ARB Transient cycle, depending on vehicle weight class. The results of this example simulation are presented in Table 2-51. Consistent with the results of SwRI study mentioned above, these GEM results show a slightly greater benefit over transient operation than highway cruise.

Table 2-51 Projected Effectiveness of Vocational Weight Reduction

	HHD		MHD		LHD	
Weight Reduction	200	0	200	0	200	0
Static Test Weight (kg)	19,006	19,051	11,363	11,408	7,212	7,257
Dynamic Test Weight (kg)	19,573	19,618	11,703	11,748	7,552	7,597
Payload (ton)	7.55	7.5	5.65	5.6	2.9	2.85
Transient CO_2 Emission (g CO_2 ptm)	240	242	224	227	351	358
55mph CO_2 Emission (g CO_2 ptm)	181	182	182	184	332	338
65mph CO_2 Emission (g CO_2 ptm)	216	217	230	232	394	401
Effectiveness over Transient	-0.8%		-1.1%		-2.0%	
Effectiveness over 55 mph	-0.7%		-1.0%		-1.8%	
Effectiveness over 65 mph	-0.7%		-1.0%		-1.8%	
Urban Cycle Effectiveness (94% Transient, 6% 55 mph)	-0.8%		-1.1%		-2.0%	
Multi-Purpose Cycle Effectiveness (82% Transient, 15% 55 mph, 3% 65 mph)	-0.8%		-1.1%		-1.9%	
Regional Cycle Effectiveness (50% Transient, 28% 55 mph, 22% 65 mph)	-0.8%		-1.0%		-1.9%	

Without more specific data on which to base our assumptions, the agencies are proposing to allocate 50 percent of any mass reduction to increased payload, and 50 percent to reduce the chassis weight. We considered the data on which the tractor weight allocation (1/3:2/3) is based, but determined this would not be valid for vocational vehicles, as the underlying data pertained only to long haul tractor-trailers. The agencies propose that 50 percent of weight removed from vocational vehicle chassis would be added back as additional payload in GEM. This suggests an equal likelihood that a vehicle would be reducing weight for benefits of being lighter, or reducing weight to carry more payload.

One reason why this effectiveness appears greater than would be expected based on the SwRI results is the change in payload. As shown in Table 2-51, this payload attribute has a stronger influence on the effectiveness than the duty cycle. For the LHD vehicles, reducing 200 pounds would decrease the test weight by 0.6 percent and increase the payload by 1.8 percent. The agencies project the effectiveness of weight reduction for Phase 2 would be one percent or less for HHD and MHD vocational vehicles, and the effectiveness would be close to two percent for LHD vehicles over any of the vocational vehicle composite cycles.

Table 2-52 Proposed Vocational Weight Reduction Technologies

COMPONENT	MATERIAL	VOCATIONAL VEHICLE CLASS		
		Class 2b-5	Class 6-7	Class 8
Axle Hubs - Non-Drive	Aluminum	40		40
Axle Hubs - Non-Drive	High Strength Steel	5		5
Axle - Non-Drive	Aluminum	60		60
Axle - Non-Drive	High Strength Steel	15		15
Brake Drums - Non-Drive	Aluminum	60		60
Brake Drums - Non-Drive	High Strength Steel	8		8
Axle Hubs - Drive	Aluminum	40		80
Axle Hubs - Drive	High Strength Steel	10		20
Brake Drums - Drive	Aluminum	70		140
Brake Drums - Drive	High Strength Steel	5.5		11
Clutch Housing	Aluminum	34		40
Clutch Housing	High Strength Steel	9		10
Suspension Brackets, Hangers	Aluminum	67		100
Suspension Brackets, Hangers	High Strength Steel	20		30
Transmission Case	Aluminum	45		50
Transmission Case	High Strength Steel	11		12
Crossmember – Cab	Aluminum	10	14	15
Crossmember – Cab	High Strength Steel	2	4	5
Crossmember - Non-Suspension	Aluminum	15	18	21
Crossmember - Non-Suspension	High Strength Steel	5	6	7
Crossmember -Suspension	Aluminum	15	20	25
Crossmember -Suspension	High Strength Steel	4	5	6
Driveshaft	Aluminum	12	40	50
Driveshaft	High Strength Steel	5	10	12
Frame Rails	Aluminum	120	300	440
Frame Rails	High Strength Steel	24	40	87
Wheels - Dual	Aluminum	126	126	210
Wheels - Dual	High Strength Steel	48	48	80
Wheels - Dual	Lightweight Aluminum	180	180	300
Wheels - Wide Base Single	Aluminum	278	278	556

COMPONENT	MATERIAL	VOCATIONAL VEHICLE CLASS		
		Class 2b-5	Class 6-7	Class 8
Wheels - Wide Base Single	High Strength Steel	168	168	336
Wheels - Wide Base Single	Lightweight Aluminum	294	294	588
Permanent 6x2 Axle Configuration	Multi	N/A	N/A	300

2.9.3.6 HFC Leakage

EPA believes the capacity of vocational vehicle air conditioning systems are sufficiently similar to those of other HD vehicles to apply a similar leakage standard as was applied in the HD Phase 1 program for tractors and HD pickup trucks and vans. Emissions due to direct refrigerant leakage are significant in all vehicle types. EPA is proposing a1.50 percent refrigerant leakage per year standard, to assure that high-quality, low-leakage components are used in the design of each air conditioning system with a refrigerant capacity greater than 733 grams. Since refrigerant leakage past the compressor shaft seal is the dominant source of leakage in belt-driven air conditioning systems, the agency recognizes that this 1.50 percent leakage standard would not be feasible for systems with a refrigerant capacity of 733 grams or lower, as the minimum feasible leakage rate does not continue to drop as the capacity or size of the air conditioning system is reduced. The fixed leakage from the compressor seal and other system devices results in a minimum feasible yearly leakage rate, and further reductions in refrigerant capacity (the ‘denominator’ in the percent refrigerant leakage calculation) would result in a system which could not meet the 1.50 percent leakage per year standard. EPA does not believe that leakage reducing technologies will be available in MY 2021 to enable lower capacity systems to meet the percent per year standard, so we are proposing a maximum gram per year leakage standard of 11.0 grams per year for vocational vehicle air conditioning systems with a refrigerant capacity of 733 grams or lower, as was adopted in the HD Phase 1 program for tractors and HD pickup trucks and vans.

The proposed standard is derived from the vehicles with the largest system refrigerant capacity based on the Minnesota GHG Reporting database.[138] These are the same data on which the HD Phase 1 HFC leakage standard was based.[139]

By requiring that all vocational vehicles achieve the leakage level of 1.50 percent per year, roughly half of the vehicles in the 2010 data sample would need to reduce their leakage rates, and an emissions reduction roughly comparable to that necessary to generate direct emission credits under the light-duty vehicle program would result. See 75 FR at 25426-247. However, no credits or trading flexibilities are proposed under this standard for heavy-duty vocational vehicles. We believe that a yearly system leakage approach would assure that high-quality, low-leakage, components are used in each A/C system design, and we expect that manufacturers would reduce A/C leakage emissions by utilizing improved, leak-tight components. Some of the improved components available to manufacturers are low-permeation flexible hoses, multiple o-ring or seal washer connections, and multiple-lip compressor shaft seals. The availability of low leakage components in the market is being driven by the air conditioning credit program in the light-duty GHG rulemaking (which applies to 2012 model year and later vehicles). EPA believes that reducing A/C system leakage is both highly cost-effective and technologically feasible. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50 percent by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system.[140] All of these technologies are already in commercial use and exist on some of today's A/C systems in other heavy-duty vehicles.

EPA is proposing to adopt the same compliance method for control of leakage from A/C systems in vocational vehicles as was adopted for the HD Phase 1 HFC leakage standard. Under this approach, manufacturers would choose from a menu of A/C equipment and components used in their vehicles in order to establish leakage scores, which would characterize their A/C system leakage performance and calculate the percent leakage per year as this score divided by the system refrigerant capacity. The agencies estimate the total cost to apply low leakage A/C components to a vocational vehicle to be $22 in MY 2021 and $19 in MY 2027, as described in draft RIA 2.12.4.1.

Consistent with the Light-Duty Vehicle Greenhouse Gas Emissions rulemaking, a manufacturer would compare the components of its A/C system with a set of leakage reduction technologies and actions that is based closely on that being developed through IMAC and the Society of Automotive Engineers (as SAE Surface Vehicle Standard J2727, August 2008 version).[141] See generally 75 FR at 25426. The SAE J2727 approach was developed from laboratory testing of a variety of A/C related components, and EPA believes that the J2727 leakage scoring system generally represents a reasonable correlation with average real-world leakage in new vehicles. Like the IMAC approach, our proposed approach would associate each component with a specific leakage rate in grams per year identical to the values in J2727 and then sum together the component leakage values to develop the total A/C system leakage. As is currently done for other HD vehicles, for vocational vehicles, the total A/C leakage score would then be divided by the total refrigerant system capacity to develop a percent leakage per year value.

2.9.4 **Other Vocational Vehicle Technologies Considered**

2.9.4.1 Vocational Aerodynamics

The agencies are not predicating the proposed standards on improved aerodynamics of vocational vehicles. However, the agencies are proposing to offer an option for manufacturers to receive recognition for a few specific aerodynamic technologies on vehicles where the criteria would be met to qualify for this credit, should a manufacturer decide to utilize the technology.

We are partnering with CARB to incorporate into GEM some data from testing that is being conducted by CARB through NREL. A test plan is in place to assess the fuel efficiency benefit of three different devices to improve the aerodynamic performance of a Class 6 box truck, as well as two devices on a cutaway van. We propose that, if a manufacturer can certify that a final vehicle configuration will closely match one of the configurations on which testing was conducted, then an option may be selected to improve that vehicle's GEM score based on installation of the applicable aerodynamic devices. The amount of improvement would be set by

EPA based on NREL's test results. This credit provision would apply only to vocational vehicles certified over the Regional duty cycle. Manufacturers wishing to receive credit for other aerodynamic technologies or on other vehicle configurations would be able to apply for innovative credits using the established procedures.

Table 2-53 shows the vocational aerodynamic technologies that are being tested, for which credit could be available through GEM. The agencies have not estimated manufacturing costs for these technologies on vocational vehicles. We project that a manufacturer would only apply these where it was found to be cost-effective for the specific application. For a description of the costs estimated for applying aerodynamic technologies to tractors, see the draft RIA at Chapter 2.12.9, where the estimated cost for a Bin2 package on a low roof day cab tractor is shown to be roughly $1,000.

Table 2-53 Vocational Aerodynamic Technologies Being Assessed

VEHICLE	SKIRTS	FRONT FAIRING (NOSE CONE)	REAR FAIRING (TAIL)	WHEEL COVERS
Class 6 Box Truck	X	X		X
Class 4 Box Truck			X	

The vehicles eligible for this GEM-based credit would be those for which the chassis manufacturer can certify that, through a delegated assembly agreement, the final built configuration would be reasonably similar to the dimensions of one of the test vehicles. A description of vehicles and aerodynamic technologies that could be eligible for this option, as well as a description of the testing conducted to obtain the assigned GEM improvements due to these technologies, are presented in a memorandum to the docket.[142]

2.9.4.2 Electric Vehicles

Some heavy-duty vehicles can be powered exclusively by electric motors. Electric motors are efficient and able to produce high torque, giving e-trucks strong driving characteristics, particularly in stop-and-go or urban driving situations, and are well-suited for moving heavy loads. Electric motors also offer the ability to operate with very low noise, an advantage in certain applications. Currently, e-trucks have some disadvantages over conventional vehicles, primarily in cost, weight and range. Components are relatively expensive, and storing electricity using currently available technology is expensive, bulky, and heavy.

The West Coast Collaborative, a public-private partnership, has estimated the incremental costs for electric Class 3-6 trucks in the Los Angeles, CA, area.[143] Compared to a conventional diesel, the WCC estimates a battery-electric vehicle system would cost between $70,000 and $90,000 more than a conventional diesel system. The CalHEAT Technology Roadmap includes an estimate that the incremental cost for a fully-electric medium- or heavy- duty vehicle would be between $50,000 and $100,000. In draft RIA Chapter 2.12.7.6, the agencies estimate the cost of a full electric LHD or MHD vocational vehicle at $55,216 in MY 2021 and $52,128 in MY 2024. The CalHEAT roadmap report also presents several actions that must be taken by manufacturers and others, before heavy-duty e-trucks can reach what they call Stage 3 Deployment.[144]

Early adopters of electric drivetrain technology are medium-heavy-duty vocational vehicles that are not weight-limited and have drive cycles where they don't need to go far from a central garage. According to CALSTART's report to the NAFA 2014 Institute and Expo, there is an emerging market of MHD all-electric vocational vehicles, including models from Smith, EVI, Boulder, AMP, and others.[126] CalHEAT has published results of a comprehensive performance evaluation of three battery electric truck models using information and data from in-use data collection, on road testing and chassis dynamometer testing.[145]

Given the high costs and the developing nature of this technology, the agencies do not project fully electric vocational vehicles to be widely commercially available in the time frame of the proposed rules. For this reason, the agencies have not based the proposed Phase 2 standards on adoption of full-electric vocational vehicles. However, in the more stringent alternatives discussed in detail in draft RIA Chapter 9, the agencies do project three percent adoption of full electric LHD and MHD vocational vehicles (only applicable for MY 2024 for Alternative 5). To the extent this technology is able to be brought to market in the time frame of the Phase 2 program, there is currently a certification path for these chassis from Phase 1, as described in the Preamble Section V and in the regulations at 40 CFR 1037.150 and 49 CFR 535.8.

2.9.5 Derivation of the Proposed Vocational Vehicle Technology Packages

The agencies are proposing standards for vocational vehicles predicated on the same suite of technologies in both the 2021 and 2024 MY implementation years. The change in stringency between those years would be a result of different adoption rates of those technologies. Package costs for each model year are presented following each respective adoption rate discussion.

2.9.5.1 Projected Technology Adoption Rates for Vocational Vehicles

The agencies have estimated the extent to which technologies may be adopted by manufacturers to meet the proposed 2021 vocational vehicle standards.

2.9.5.1.1 *Transmissions*

The agencies project a compliance path whereby 30 percent of vocational vehicles would have one or more of the transmission technologies identified above in this chapter applied by MY 2021, increasing to nearly 60 percent by MY 2024 and over 80 percent by MY 2027. Most of this increase is due to a projected increase in adoption of technologies that represent deep driveline integration. The agencies project an adoption rate of 15 percent in MY 2021 and 30 percent in MY 2024 for of various non-hardware technologies that enable driveline optimization, including gear efficiencies, shift strategies, and torque converter lockups. Manufacturers would use the powertrain test to certify these technology improvements. Due to the relatively high efficiency gains available from driveline optimization for relatively low costs, the agencies are projecting a 70 percent application rate of driveline optimization (including the non-hardware enabling technologies) by MY 2027 across all subcategories. We do not have information about the extent to which integration may be deterred by barriers to information-sharing between component suppliers. Therefore we are projecting that major manufacturers would work to overcome these barriers, integrate and optimize their drivelines, and use the powertrain test on all eligible configurations, while smaller manufacturers may not adopt these technologies at all, or not to a degree that they would find value in this optional test procedure.

For the technology of adding two gears, we are predicating the proposed MY 2021 standard on a five percent adoption rate, except for zero in the HHD Regional subcategory, which is modeled with a 10-speed transmission. This adoption rate is projected to essentially remain at this level throughout the program, with an increase to ten percent only for two subcategories (Regional LHD and MHD) in MY 2027. This is because the manufacturers most likely to develop 8-speed transmissions are those that are also developing transmissions for HD pickups and vans, and the GEM-certified vocational market share among those manufacturers is relatively small.

The HHD Regional subcategory is the only one where we assume a manual transmission in the baseline configuration. For these vehicles, the agencies project upgrades to electronic transmissions such as either AMT, DCT, or automatic, at collective adoption rates of 51 percent in MY 2021, 68 percent in MY 2024, and five percent in MY 2027. The decrease in MY 2027 reflects a projection that a greater number of deeply integrated HHD powertrains would be used by MY 2027 (one consequence being that fewer HHD powertrains would be directly simulated in GEM in that year). The larger numbers in the phase-in years reflect powertrains that have been automated or electrified but not deeply integrated. The agencies have been careful to account for the cost of both electrifying and deeply integrating the MY 2027 powertrains. In draft RIA Chapter 11, the technology adoption rates for the HHD Regional subcategory presented in Table 11-42, Table 11-45, and Table 11-48 account for the assumption that a manual transmission cannot be deeply integrated, so there must also be an automation upgrade. These tables are inputs to the agencies' cost analysis, thus the costs of both upgrading and integrating HHD powertrains are included. The adoption rates of the upgraded but not integrated transmission architectures represent a projection of three percent of all vocational vehicles in MY 2021 and four percent in MY 2024. This is based on an estimate that seven percent of the vocational vehicles would be in the HHD Regional subcategory. For more information about the assumptions that were made about the populations of vehicles in different subcategories, see the agencies' inventory estimates in draft RIA Chapter 5.

In the eight subcategories in which automatic transmissions are the base technology, the agencies project that five percent would upgrade to a dual clutch transmission in MY 2021. This projection increases to 15 percent in MY 2024 and decreases in MY 2027 to ten percent for two subcategories (Regional LHD and MHD) and five percent for the remaining 6 subcategories. The low projected adoption rates of DCT reflect the fact that this is a relatively new technology for the heavy-duty sector, and it is likely that broader market acceptance would be achieved once fleets have gained experience with the technology. Similar to the pattern described for the HHD Regional subcategory, the decrease in MY 2027 reflects a projection of greater use of deeply integrated powertrains.

In determining the proposed standard stringency, we have projected that hybrids on vehicles certified in the Multipurpose subcategories would achieve on average 22 percent improvement, and those in the Urban subcategories would see a 25 percent improvement. We have also projected zero hybrid adoption rate by vehicles in the Regional subcategories, expecting that the benefit of hybrids for those vehicles would be too low to merit use of that type of technology. However, there is no fixed hybrid value assigned in GEM and the actual improvement over the applicable test cycle would be determined by powertrain testing. By the full implementation year of MY 2027, the agencies are projecting an overall vocational vehicle adoption rate of ten percent hybrids, which we estimate would be 18 percent of vehicles certified in the Multi-Purpose and Urban subcategories. We are projecting a low adoption rate in the early years of the Phase 2 program, just four percent in these subcategories in MY 2021, and seven percent in MY 2024 for vehicles certified in the Multi-Purpose and Urban subcategories. Based on our assumptions about the populations of vehicles in different subcategories, these hybrid adoption rates are about two percent overall in MY 2021 and four percent overall in MY 2024.

Considering the combination of the above technologies and adoption rates, we project the CO_2 and fuel efficiency improvements for all transmission upgrades to be approximately seven percent on a fleet basis by MY 2027. One subcategory in which we are projecting a very large advanced transmission adoption rate is the HHD Regional subcategory, in which we are projecting 75 percent of the transmissions would be either automated or automatic (upgraded from a manual) with 70 percent of those also being deeply integrated by MY 2027. By comparison, the agencies are projecting that HHD day cab tractors would have 90 percent adoption of automated or automatic transmissions by MY 2027. Although we are not prepared to predict what fraction of these would be upgraded in the absence of Phase 2, as noted above in Chapter 2.9.3, the agencies are confident that durable transmissions will be widely available in the Phase 2 time frame to support manufacture of HHD vocational vehicles.

If the above technologies do not reach the expected level of market adoption, the vocational vehicle Phase 2 program has several other technology options that manufacturers could choose to meet the proposed standards.

2.9.5.1.2 *Axles*

The agencies project that 75 percent of vocational vehicles in all subcategories would adopt advanced axle lubricant formulations in all implementation years of the Phase 2 program. Fuel efficient lubricant formulations are widespread across the heavy-duty market, though advanced synthetic formulations are currently less popular.[N] Axle lubricants with improved viscosity and efficiency-enhancing performance are projected to be widely adopted by manufacturers in the time frame of Phase 2. Such formulations are commercially available and the agencies see no reason why they could not be feasible for most vehicles. Nonetheless, we have refrained from projecting full adoption of this technology. The agencies do not have specific information regarding reasons why axle manufacturers may specify a specific type of

[N] Based on conversations with axle suppliers.

lubricant over another, and whether advanced lubricant formulations may not be recommended in all cases.

The agencies estimate that 45 percent of HHD Regional vocational vehicles would adopt either full time or part time 6x2 axle technology in MY 2021. This technology is most likely to be applied to Class 8 vocational vehicles (with 2 rear axles) that are designed for frequent highway trips. The agencies project a slightly higher adoption rate of 60 percent combined for both full and part time 6x2 axle technologies in MY 2024 and MY 2027. Based on our estimates of vehicle populations, this is about four percent of all vocational vehicles.

2.9.5.1.3 *Lower Rolling Resistance Tires*

The agencies estimate that the per-vehicle average level of rolling resistance from vocational vehicle tires could be reduced by 11 percent by full implementation of the Phase 2 program in MY 2027, based on the tire development achievements expected over the next decade. This is estimated by weighting the projected improvements of steer tires and drive tires using an assumed axle load distribution of 30 percent on the steer tires and 70 percent on the drive tires, as explained in the draft RIA Chapter 2.9. By applying the assumed axle load distribution, the average vehicle CRR improvements projected for the proposed MY 2021 standards would be four percent, which we project would achieve up to one percent reduction in fuel use and CO_2 emissions, depending on the vehicle subcategory. Using that same method, the agencies estimate the average vehicle CRR in MY 2024 would be seven percent, yielding reductions in fuel use and CO_2 emissions of between one and two percent, depending on the vehicle subcategory.

The agencies understand that the vocational vehicle segment has access to a large variety of tires, including some that are designed for tractors, some that are designed for HD pickups and vans, and some with multiple use designations. In spite of the likely availability of LRR tires during the Phase 2 program, the projected adoption rates are intended to be conservative. The agencies believe that these tire packages recognize the variety of tire purposes and performance levels in the vocational vehicle market, and maintain choices for manufacturers to use the most efficient tires (i.e. those with least rolling resistance) only where it makes sense given these vehicles' differing purposes and applications. The projected adoption rates and expected improvements in CRR are presented in Table 2-54.

Table 2-54 Projected LRR Tire Adoption Rates

TIRE POSITION	LEVEL OF ROLLING RESISTANCE	MY 2021 ADOPTION RATE	MY 2024 ADOPTION RATE	MY 2027 ADOPTION RATE
Drive	Baseline CRR (7.7)	50	20	10
Steer	Baseline CRR (7.7)	20	10	0
Drive	5% Lower CRR (7.3)	50	50	25
Steer	10% Lower CRR (6.9)	80	30	20
Drive	10% Lower CRR (6.9)	0	30	50
Steer	15% Lower CRR (6.5)	0	60	30
Drive	15% Lower CRR (6.5)	0	0	15
Steer	20% Lower CRR (6.2)	0	0	50

Drive	Average Improvement in CRR	3%	6%	9%
Steer	Average Improvement in CRR	8%	12%	17%

For comparison purposes, the reader may note that these levels of tire CRR generally correspond with levels of tire CRR projected for tractors built for the Phase 1 standards. For example, the baseline level CRR for vocational tires is very similar to the baseline tractor steer tire CRR. Vocational vehicle tires with 10 percent better CRR have a similar CRR level as tractor tires of Drive Level 1. Vocational vehicle tires with 15 percent better CRR have a similar CRR level as tractor tires of Steer Level 1. Vocational vehicle tires with 20 percent better CRR have a similar CRR level as tractor tires of Drive Level 2, as described in preamble Section III.D.2.

2.9.5.1.4 *Workday Idle Reduction*

In this proposal, we are projecting a progression of idle reduction technology development that begins with 70 percent adoption rate of neutral idle for the MY 2021 standards, which by MY 2027 is replaced by a 70 percent adoption rate of stop-start idle reduction technology. Although it is possible that a vehicle could have both neutral idle and stop-start, we are only considering emissions reductions for vehicles with one or the other of these technologies. Also, as the program phases in, we do not see a reduction in the projected adoption rate of neutral idle to be a concern in terms of stranded investment, because it is a very low cost technology that could be an enabler for stop-start systems in some cases.

We are not projecting any adoption of neutral idle for the HHD Regional subcategory, because any vehicle with a manual transmission must shift to neutral when stopped to avoid stalling the engine, vehicles in the HHD Regional subcategory would already essentially be idling in neutral, and no additional technology would be needed to achieve this. A similar case can be made for any vocational vehicle with an automated manual transmission, since these share inherently similar architectures with manual transmissions. The agencies are not projecting an adoption rate of 85 percent neutral idle until MY 2024, because it may take some additional development time to apply this technology to high-torque automatic transmissions designed for the largest vocational vehicles. Based on stakeholder input, the designs needed to avoid an uncomfortable re-engagement bump when returning to drive from neutral may require some engineering development time as well as some work to enable two-way communication between engines and transmissions.

We are projecting a five percent adoption rate of stop-start in the six MHD and LHD subcategories for MY 2021 and zero for the HHD vehicles, because this technology is still developing for vocational vehicles and is most likely to be feasible in the early years of Phase 2 for vehicles with lower power demands and lower engine inertia. Stopping a heavy-duty engine is not challenging. The real challenge is designing a robust system that can deliver multiple smooth restarts daily without loss of function while the engine is off. Many current light-duty products offer this feature, and some heavy-duty manufacturers are exploring this.[146] The agencies are projecting an adoption rate of 15 percent stop-start across all subcategories in the intermediate year of MY 2024. The agencies are projecting this technology to have a relatively high adoption rate (70 percent as stated above) by MY 2027 because we see it being technically feasible on the majority of vocational vehicles, and especially effective on those with the most time at idle in their workday operation. Although we are not prepared to predict what fraction of vehicles would adopt stop-start in the absence of Phase 2, above in draft RIA Chapter 2.9.3 the agencies explain why we are confident that this technology, which is on the entry-level side of the hybrid and electrification spectrum, will be widely available in the Phase 2 time frame.

Based on these projected adoption rates and the effectiveness values described above in this section, we expect overall GHG and fuel consumption reductions from workday idle on vocational vehicles to be approximately three percent in MY 2027.

2.9.5.1.5 *Weight Reduction*

As described in the draft RIA Chapter 2.12, weight reduction is a relatively costly technology, at approximately $3 to $4 per pound for a 200-lb package. Even so, for vehicles in service classes where dense, heavy loads are frequently carried, weight reduction can translate directly to additional payload. The agencies project weight reduction would most likely be used for vocational vehicles in the refuse and construction service classes, as well as some regional delivery vehicles. The agencies are predicating the proposed standards on an adoption rate of five to eight percent, depending on the subcategory, in MY 2027, with slightly lower adoption rates in MY 2021 and MY 2024.

For this technology package, NHTSA and EPA project manufacturers would use material substitution in the amount of 200 pounds. An example of how this weight could be reduced would be a complete set of aluminum wheels for a Class 8 vocational vehicle, or an aluminum transmission case plus high strength steel wheels, frame rails, and suspension brackets on a MHD or LHD vocational vehicle. The agencies have limited information about how popular the use of aluminum components is in the vocational vehicle sector.

2.9.5.1.6 *HFC Leakage*

We project 100 percent adoption rate in all implementation years of the Phase 2 program for use of low leakage air conditioning system components to reduce direct emissions of HFC compounds from vocational vehicles.

2.9.5.2 Proposed Vocational Vehicle Standards

The agencies applied the technology adoption rates shown in Table 2-55 through Table 2-57 as GEM inputs, but have not directly transferred the GEM results from these inputs as the proposed standards. Rather, the proposed standards are the result of the normalizing process described in Chapter 2.9.2.1. The proposed standards are presented in Table 2-58 through Table 2-63.

Table 2-55 GEM Inputs Used to Derive Proposed MY 2021 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
CI Engine[a]								
2021 MY 7L, 200 hp Engine			2021 MY 7L, 270 hp Engine			2021 MY 11L, 345 hp Engine		2021 MY 15L 455hp Engine
Transmission (improvement factor)								
0.023	0.021	0.008	0.023	0.021	0.009	0.023	0.022	0.022
Axle (improvement factor)								
0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.012
Stop-Start (adoption rate)								
5%	5%	5%	5%	5%	5%	0%	0%	0%
Neutral Idle (adoption rate)								
70%	70%	70%	70%	70%	70%	70%	70%	0%
Steer Tires (CRR kg/metric ton)								
7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Drive Tires (CRR kg/metric ton)								
7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Weight Reduction (lb)								
8	8	14	8	8	12	8	8	10

Note:
[a] SI engines were not simulated in GEM, rather a gas/diesel adjustment factor was applied to the results

Table 2-56 GEM Inputs Used to Derive Proposed MY 2024 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
CI Engine[a]								
2024 MY 7L, 200 hp Engine			2024 MY 7L, 270 hp Engine			2024 MY 11L, 345 hp Engine		2024 MY 15L 455hp Engine
Transmission (improvement factor)								
0.045	0.04	0.017	0.045	0.041	0.018	0.045	0.042	0.035
Axle (improvement factor)								
0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.014
Stop-Start (adoption rate)								
15%	15%	15%	15%	15%	15%	15%	15%	15%
Neutral Idle (adoption rate)								
85%	85%	85%	85%	85%	85%	85%	85%	0%
Steer Tires (CRR kg/metric ton)								
6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Drive Tires (CRR kg/metric ton)								
7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Weight Reduction (lb)								

8	8	14	8	8	12	8	8	10

Note:
[a] SI engines were not simulated in GEM, rather a gas/diesel adjustment factor was applied to the results

Table 2-57 GEM Inputs Used to Derive Proposed MY 2027 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
CI Engine[a]								
2027 MY 7L, 200 hp Engine			2027 MY 7L, 270 hp Engine			2027 MY 11L, 345 hp Engine		2027 MY 15L 455hp Engine
Transmission (improvement factor)								
0.096	0.085	0.034	0.096	0.088	0.037	0.097	0.089	0.036
Axle (improvement factor)								
0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.014
Stop-Start (adoption rate)								
75%	70%	70%	75%	70%	70%	70%	70%	70%
Neutral Idle (adoption rate)								
25%	30%	30%	25%	30%	30%	30%	30%	0%
Steer Tires (CRR kg/metric ton)								
6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Drive Tires (CRR kg/metric ton)								
7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Weight Reduction (lb)								
10	10	16	10	10	14	10	10	12

Note:
[a] SI engines were not simulated in GEM, rather a gas/diesel adjustment factor was applied to the results

Table 2-58 and Table 2-59 present EPA's proposed CO_2 standards and NHTSA's proposed fuel consumption standards, respectively, for chassis manufacturers of Class 2b through Class 8 vocational vehicles for the beginning model year of the program, MY 2021. As in Phase 1, the standards would be in the form of the mass of emissions, or gallons of fuel, associated with carrying a ton of cargo over a fixed distance. The EPA standards would be measured in units of grams CO_2 per ton-mile and the NHTSA standards would be in gallons of fuel per 1,000 ton-miles. With the mass of freight in the denominator of this term, the program is designed to measure improved efficiency in terms of freight efficiency. As in Phase 1, the Phase 2 program would assign a fixed default payload in GEM for each vehicle weight class group (heavy heavy-duty, medium heavy-duty, and light heavy-duty). Even though this simplification does not allow individual vehicle freight efficiencies to be recognized, the general capacity for larger vehicles to carry more payload is represented in the numerical values of the proposed standards for each weight class group.

Table 2-58 Proposed EPA CO_2 Standards for MY2021 Class 2b-8 Vocational Vehicles

EPA Standard for Vehicle with CI Engine Effective MY2021 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	296	188	198
Multi-Purpose	305	190	200
Regional	318	186	189
EPA Standard for Vehicle with SI Engine Effective MY2021 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	320	203	214
Multi-Purpose	329	205	216
Regional	343	201	204

Table 2-59 Proposed NHTSA Fuel Consumption Standards for MY2021 Class 2b-8 Vocational Vehicles

NHTSA Standard for Vehicle with CI Engine Effective MY 2021 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	29.0766	18.4676	19.4499
Multi-Purpose	29.9607	18.6640	19.6464
Regional	31.2377	18.2711	18.5658
NHTSA Standard for Vehicle with SI Engine Effective MY 2021 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	36.0077	22.8424	24.0801
Multi-Purpose	37.0204	23.0674	24.3052
Regional	38.5957	22.6173	22.9549

EPA's proposed vocational vehicle CO_2 standards and NHTSA's proposed fuel consumption standards for the MY 2024 stage of the program are presented in Table 2-60 and Table 2-61, respectively. These reflect broader adoption rates of vehicle technologies already considered in the technology basis for the MY 2021 standards. The standards for vehicles powered by CI engines also reflect that in MY 2024, the separate engine standard would be more stringent, so the vehicle standard keeps pace with the engine standard.

Table 2-60 Proposed EPA CO_2 Standards for MY2024 Class 2b-8 Vocational Vehicles

EPA Standard for Vehicle with CI Engine Effective MY2024 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	284	179	190
Multi-Purpose	292	181	192
Regional	304	178	182
EPA Standard for Vehicle with SI Engine Effective MY2024 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	312	197	208
Multi-Purpose	321	199	210
Regional	334	196	199

Table 2-61 Proposed NHTSA Fuel Consumption Standards for MY2024 Class 2b-8 Vocational Vehicles

NHTSA Standard for Vehicle with CI Engine Effective MY 2024 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	27.8978	17.5835	18.6640
Multi-Purpose	28.6837	17.7800	18.8605
Regional	29.8625	17.4853	17.8782
NHTSA Standard for Vehicle with SI Engine Effective MY 2024 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	35.1075	22.1672	23.4050
Multi-Purpose	36.1202	22.3923	23.6300
Regional	37.5830	22.0547	22.3923

EPA's proposed vocational vehicle CO_2 standards and NHTSA's proposed fuel consumption standards for the full implementation year of MY 2027 are presented in Table 2-62 and Table 2-63, respectively. These reflect even greater adoption rates of the same vehicle technologies considered in the basis for the previous stages of the Phase 2 standards. The proposed MY 2027 standards for vocational vehicles powered by CI engines reflect additional engine technologies consistent with those on which the separate proposed MY 2027 CI engine standard is based. The proposed MY 2027 standards for vocational vehicles powered by SI engines reflect improvements due to additional engine friction reduction technology, which is not among the technologies on which the separate SI engine standard is based.

Table 2-62 Proposed EPA CO_2 Standards for MY2027 Class 2b-8 Vocational Vehicles

EPA Standard for Vehicle With CI Engine Effective MY2027 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	272	172	182
Multi-Purpose	280	174	183
Regional	292	170	174
EPA Standard for Vehicle with SI Engine Effective MY2027 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	299	189	196
Multi-Purpose	308	191	198
Regional	321	187	188

Table 2-63 Proposed NHTSA Fuel Consumption Standards for MY2027 Class 2b-8 Vocational Vehicles

NHTSA Standard For Vehicle With CI Engine Effective MY 2027 (Fuel Consumption Gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	26.7191	16.8959	17.8782
Multi-Purpose	27.5049	17.0923	17.9764
Regional	28.6837	16.6994	17.0923
NHTSA Standard for Vehicle with SI Engine Effective MY 2027 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	33.6446	21.2670	22.0547
Multi-Purpose	34.6574	21.4921	22.2797
Regional	36.1202	21.0420	21.1545

2.9.5.3 Summary of Vocational Vehicle Package Costs

The agencies have estimated the costs of the technologies expected to be used to comply with the proposed standards. Table 2-64 presents estimated incremental costs for MY2021 for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, in MY 2021 these range from approximately $600 for MHD and LHD Regional vehicles, up to $3,400 for HHD Regional vehicles. Those two lower-cost packages reflect zero hybrids, and the higher-cost package reflects significant adoption of automated transmissions. In the draft RIA Chapter 2.13, the agencies present vocational vehicle technology package costs differentiated by MOVES vehicle type. For example, in Table 2-231, intercity buses are estimated to have an average package cost of $2,900 and gasoline motor homes are estimated to have an average package cost of $450 in MY 2021. These costs do not indicate the per-vehicle cost that may be incurred for any individual technology. Chapter 2.12.7 describes why a complex technology such as hybridization is estimated to range between $15,000 and $40,000 per vehicle for vocational vehicles in MY 2021. The engine costs listed represent the cost of an average package of diesel engine technologies. Individual technology adoption rates for engine packages are described above in Chapter 2.7. The details behind these costs are presented in draft RIA Chapter 2.12, including the markups and learning effects applied and how the costs shown here are weighted to generate an overall cost for the vocational sector.

Table 2-64 Technology Package Incremental Costs for Vocational Vehicles for MY2021[a,b] (2012$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$293	$293	$293	$270	$270	$270	$270	$270	$270
Tires	$7	$7	$7	$7	$7	$7	$7	$7	$7
Transmission	$81	$81	$81	$81	$81	$81	$81	$81	$2,852
Axle related	$99	$99	$99	$99	$99	$99	$148	$148	$219
Weight Reduction	$27	$27	$48	$27	$27	$41	$27	$27	$34
Idle reduction	$49	$49	$49	$51	$51	$51	$6	$6	$0
Electrification & hybridization	$547	$547	$0	$861	$861	$0	$1,437	$1,437	$0
Air Conditioning	$22	$22	$22	$22	$22	$22	$22	$22	$22
Total	$1,125	$1,125	$598	$1,418	$1,418	$571	$1,998	$1,998	$3,404

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to draft RIA Chapter 2.12.

[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.

[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting no additional engine-based costs beyond Phase 1.

Table 2-65 presents estimated incremental costs for MY2024 for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, these range from approximately $800 for MHD and LHD Regional vehicles, up to $4,800 for HHD Regional vehicles. The increased costs above the MY 2021 values reflect increased adoption rates of individual technologies, while the individual technology costs are generally expected to remain the same or decrease, as explained in the draft RIA Chapter 2.12. For example, Chapter 2.12.7 presents MY 2024 hybridization costs that range from $13,000 to $33,000 per vehicle for vocational vehicles.

Table 2-65 Technology Package Incremental Costs for Vocational Vehicles for MY2024[a,b] (2012$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$437	$437	$437	$405	$405	$405	$405	$405	$405
Tires	$17	$17	$17	$17	$17	$17	$23	$23	$23
Transmission	$123	$123	$123	$123	$123	$123	$123	$123	$3,915
Axle related	$90	$90	$90	$90	$90	$90	$136	$136	$224
Weight Reduction	$24	$24	$43	$24	$24	$37	$24	$24	$30
Idle reduction	$119	$119	$119	$125	$125	$125	$224	$224	$217
Electrification & hybridization	$906	$906	$0	$1,423	$1,423	$0	$2,377	$2,377	$0
Air Conditioning	$20	$20	$20	$20	$20	$20	$20	$20	$20
Total	$1,737	$1,737	$849	$2,228	$2,228	$817	$3,332	$3,332	$4,834

Notes:
[a] Costs shown are for the 2024 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to draft RIA Chapter 2.12.
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.
[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting no additional engine-based costs beyond Phase 1.

Table 2-66 presents estimated incremental costs for MY2027 for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, these range from approximately $1,400 for MHD and LHD Regional vehicles, up to $7,400 for HHD Urban and Multipurpose vehicles. These two subcategories are projected to have the higher-cost packages in MY 2027 due to an estimated 18 percent adoption of HHD hybrids, which are estimated to cost $31,000 per vehicle in MY 2027, as shown in Chapter 2.12.7 of the draft RIA. The engine costs shown represent the average costs associated with the proposed MY 2027 vocational diesel engine standard described in Section II.D. For gasoline vocational vehicles, the agencies are projecting adoption of Level 2 engine friction reduction with an estimated $68 added to the average SI vocational vehicle package cost in MY 2027, which represents about 56 percent of those vehicles upgrading beyond Level 1 engine friction reduction. Further details on how these SI vocational vehicle costs were estimated are provided above in Chapter 2.9.1.

Table 2-66 Technology Package Incremental Costs for Vocational Vehicles for MY2027[a,b] (2012$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$471	$471	$471	$437	$437	$437	$437	$437	$437
Tires	$20	$20	$20	$20	$20	$20	$29	$29	$29
Transmission	$244	$244	$267	$244	$244	$267	$244	$244	$2,986
Axle related	$86	$86	$86	$86	$86	$86	$129	$129	$215
Weight Reduction	$29	$29	$46	$29	$29	$40	$29	$29	$35
Idle reduction	$498	$499	$499	$526	$526	$526	$964	$964	$962
Electrification & hybridization	$2,122	$2,122	$0	$3,336	$3,336	$0	$5,571	$5,571	$0
Air Conditioning	$19	$19	$19	$19	$19	$19	$19	$19	$19
Total	$3,489	$3,490	$1,407	$4,696	$4,696	$1,395	$7,422	$7,422	$4,682

Notes:
[a] Costs shown are for the 2024 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to draft RIA Chapter 2.12.
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.
[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting $68 of additional engine-based costs beyond Phase 1.

2.9.6 Technologies and Costs of Alternative 4

2.9.6.1 Derivation of Alternative 4 Standards

2.9.6.1.1 *Adoption Rates*

In developing the Alternative 4 standards, the agencies are projecting a set of technology packages in MY 2024 that is identical to those projected for the final phase-in year of the preferred alternative. In the package descriptions below, the agencies outline technology-specific adoption rates in MY 2021 for Alternative 4 and offer insights on what market conditions could enable reaching adoption rates that would achieve the full implementation levels of stringency with less lead time.

For transmissions including hybrids, the agencies project for Alternative 4 that 50 percent of vocational vehicles would have one or more of the transmission technologies identified above in this Section applied by MY 2021. This includes 25 percent deeply integrated conventional transmissions that would be recognized over the powertrain test, 10 percent DCT, 11 percent adding two gears (except zero for HHD Regional), and nine percent hybrids for vehicles certified in the Multi-Purpose and Urban subcategories, which we estimate would be five percent overall. In this alternative, the agencies project 21 percent of the vocational vehicles with manual transmissions in the HHD Regional subcategory would upgrade to either an AMT, DCT, or automatic transmission. The increased projection of driveline integration would mean that more manufacturers would need to overcome data-sharing barriers. In this alternative, we project that manufacturers would need to conduct additional research and development to achieve overall application of five percent hybrids. In the draft RIA Chapter 7.1, the agencies have estimated costs for this additional accelerated research. In the preamble at Section V, the agencies request comment on the expected costs to accelerate hybrid development to meet the projected adoption rates of this alternative.

For advanced axle lubricants, the agencies are projecting the same 75 percent adoption rate in MY 2021 as in the proposed program. For part time or full time 6x2 axles, the agencies project the HHD Regional vocational vehicles could apply this at the 60 percent adoption rate in MY 2021, where this level wouldn't be reached until MY 2024 in the proposed program. One action that could enable this to be achieved is if information on the reliability of these systems were to be disseminated to more fleet owners by trustworthy sources.

For lower rolling resistance tires in this alternative, the agencies project the same adoption rates of LRR tires as in the proposed program for MY 2021, because we don't expect tire suppliers would be able to make greater improvements for the models that are fitted on vocational vehicles in that time frame. The tire research that is being conducted currently is focused on models for tractors and trailers, and we project further improved LRR tires would not be commercially available for vocational vehicles in the early implementation years of Phase 2.

For the adoption rate of LRR tires in MY 2024 to reach the level projected for MY 2027 in the proposed program, tire suppliers could promote their most efficient products to vocational vehicle manufacturers to achieve equivalent improvements with less lead time. Depending on how tire manufacturers focus their research and product development, it is possible that more of the LRR tire advancements being applied for tractors and trailers could be applied to vocational vehicles. To see the specific projected adoption rates of different levels of LRR tires for Alternative 4, see columns three and five of Table 2-54 above.

For workday idle technologies, the agencies project an adoption rate of 12 percent stop-start in the six MHD and LHD subcategories for MY 2021 and zero for the HHD vehicles, on the expectation that manufacturers would have fewer challenges in the short term in bringing this technology to market for vehicles with lower power demands and lower engine inertia. In this alternative, the agencies project the overall workday idle adoption rate would approach 100 percent, such that any vehicle without stop-start (except HHD Regional) would apply neutral idle in MY 2021. These adoption raters consider a more aggressive investment by manufacturers in developing these technologies. Estimates of research and development costs for this alternative are presented in the draft RIA Chapter 7.1.

For weight reduction, in this alternative, the agencies project the same adoption rates of a 200-lb lightweighting package as in the proposal for each subcategory in MY 2021, which is four to seven percent.

2.9.6.1.2 *Costs Associated with Alternative 4 Standards*

The agencies have estimated the costs of the technologies expected to be used to comply with the Alternative 4 standards, as shown in Table 2-67 for MY2021. Fleet average costs are shown for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, in MY 2021 these range from approximately $800 for MHD and LHD Regional vehicles, to $4,300 for HHD Urban and

Multipurpose vehicles. Those two subcategories are projected to have the higher-cost packages in MY 2021 due to an estimated 9 percent adoption of HHD hybrids, which are estimated to cost $40,000 per vehicle in MY 2021, as shown in Chapter 2.12.7 of the draft RIA. The engine costs listed represent the cost of an average package of diesel engine technologies with Alternative 4 adoption rates described in the preamble at Section II.D.2(e).

Table 2-67 Vocational Vehicle Technology Incremental Costs for Alternative 4Standards in the 2021 Model Year[a,b] (2012$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$372	$372	$372	$345	$345	$345	$345	$345	$345
Tires	$7	$7	$7	$7	$7	$7	$7	$7	$7
Transmission	$148	$148	$148	$148	$148	$148	$148	$148	$2,042
Axle related	$99	$99	$99	$99	$99	$99	$148	$148	$243
Weight Reduction	$27	$27	$48	$27	$27	$41	$27	$27	$34
Idle reduction	$110	$110	$110	$116	$116	$116	$8	$8	$0
Electrification & hybridization	$1,384	$1,384	$0	$2,175	$2,175	$0	$3,633	$3,633	$0
Air Conditioning	$22	$22	$22	$22	$22	$22	$22	$22	$22
Total	$2,169	$2,169	$805	$2,938	$2,938	$777	$4,337	$4,337	$2,693

Notes:
[a] Costs shown are for the 2021 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to draft RIA Chapter 2.12.
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle classes.
[c] Engine costs are for a light HD, medium HD or heavy HD diesel engine. We are projecting no additional costs beyond Phase 1 for gasoline vocational engines in MY2021 under this alternative.

The estimated costs of the technologies expected to be used to comply with the Alternative 4 standards for MY2024 are shown in Table 2-68. Fleet average costs are shown for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, these range from approximately $1,500 for MHD and LHD Regional vehicles to $7,900 for HHD Urban and Multipurpose vehicles. These two subcategories are projected to have the higher-cost packages in MY 2024 due to an estimated 18 percent adoption of HHD hybrids, which are estimated to cost $33,000 per vehicle in MY 2024, as shown in Chapter 2.12.7 of the draft RIA. The engine costs listed represent the cost of an average package of diesel engine technologies with Alternative 4 adoption rates described in the preamble at Section II.D.2(e). For gasoline vocational vehicles, the agencies are projecting adoption of Level 2 engine friction reduction with an estimated $74 added to the average SI vocational vehicle package cost in MY 2024, which represents about 56 percent of those vehicles upgrading beyond Level 1 engine friction reduction. Further details on how these SI vocational vehicle costs were estimated are provided above in Chapter 2.9.1. The details behind all these costs are presented in draft RIA Chapter 2.12, including the markups and learning effects applied and how the costs shown here are weighted to generate an overall cost for the vocational vehicle segment.

Table 2-68 Vocational Vehicle Technology Incremental Costs for Alternative 4 Standards in the 2024 Model Year[a,b] (2012$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$493	$493	$493	$457	$457	$457	$457	$457	$457
Tires	$26	$26	$26	$26	$26	$26	$40	$40	$40
Transmission	$256	$256	$280	$256	$256	$280	$256	$256	$3,123
Axle related	$90	$90	$90	$90	$90	$90	$136	$136	$224
Weight Reduction	$30	$30	$49	$30	$30	$43	$30	$30	$37
Idle reduction	$561	$524	$524	$592	$553	$553	$1,014	$1,014	$1,011
Electrification & hybridization	$2,264	$2,264	$0	$3,559	$3,559	$0	$5,943	$5,943	$0
Air Conditioning	$20	$20	$20	$20	$20	$20	$20	$20	$20
Total	$3,741	$3,704	$1,482	$5,030	$4,992	$1,469	$7,895	$7,895	$4,912

Notes:
[a] Costs shown are for the 2024 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to draft RIA Chapter 2.12.
[b] Note that values in this table include adoption rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories. Estimated technology costs exclusive of adoption rates are discussed in RIA 2.12.
[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting $74 of additional engine-based costs beyond Phase 1 in MY2024.

2.10 Technology Application and Estimated Costs – Trailers

The agencies are proposing standards for trailers specifically designed to be pulled by Class 7 and 8 tractors. These proposed standards are expressed as CO_2 and fuel consumption standards, and would apply to each trailer with respect to the emissions and fuel consumption that would be expected for a specific standard type of tractor pulling such a trailer. EPA and NHTSA believe it is appropriate to establish standards for trailers separately from tractors because they are separately manufactured by distinct companies; the agencies are not aware of any manufacturers that currently assemble both the finished tractor and the trailer. This section of the draft RIA describes the analyses performed by the agencies as we developed the proposed trailer program.

2.10.1 Trailer Subcategories Evaluated

The agencies evaluated several trailer subcategories for this proposal. Though many of the same technologies are available for dry and refrigerated vans, the agencies evaluated these trailer types separately. The transport refrigeration unit (TRU) commonly located at the front of refrigerated trailers adds weight, has the potential to impact the aerodynamic characteristics of the trailer, and may limit the type of aerodynamic devices that can be applied. Additionally, “long box” trailers in lengths 50 feet or longer and “short box” trailers less than 50 feet in length were evaluated separately due to differences in both weight and use patterns.

The agencies identified a list of work-performing devices that are sometimes added to standard box trailers, which may inhibit the use of some aerodynamic devices. The agencies are proposing to recognize box trailers that are restricted from using aerodynamic devices in one location on the trailer as "partial-aero" box trailers. We believe these trailers have the ability to adopt some aerodynamic technologies, but do not expect them to be able to meet the same stringencies as the standard box vans.

Additionally, we propose to consider box trailers that have work-performing devices in two locations such that they inhibit the use of *all* practical aerodynamic devices to be "non-aero" box trailers that would be not be expected to adopt aerodynamic technologies at any point in the program. The agencies are proposing that the non-aero box trailer subcategory include box trailers with more than three axles, since they are designed to be used in heavy-haul applications where aerodynamic devices are not generally practical.

The agencies evaluated all non-box highway trailers (e.g., tankers, platforms, and car haulers) as a single representative trailer assuming a single stringency level for all trailers within the subcategory. These stringency levels did not include the use of aerodynamic technologies.

In summary, the agencies are proposing ten trailer subcategories:

- Long box (longer than 50 feet) dry vans
- Long box (longer than 50 feet) refrigerated vans
- Short box (50 feet and shorter) dry vans
- Short box (50 feet and shorter) refrigerated vans
- Partial-aero long box dry vans
- Partial-aero long box refrigerated vans
- Partial-aero short box dry vans
- Partial-aero short box refrigerated vans
- Non-aero box vans (all lengths of dry and refrigerated vans)
- Non-box highway (tanker, platform, container chassis, and all other types of highway trailers that are not box trailers).

The partial-aero box trailers would have similar stringencies as their corresponding full-aero trailers in the early phase-in years, but would have separate, reduced standards as the program becomes fully implemented.

The analysis in the following sections describes our evaluation of two alternative stringencies with similar technologies. In the first analysis we projected adoption rates that were used to develop the proposed standards in MY 2027. The second analysis considers the same technologies with less lead time to achieve similar adoption rates.

The agencies did consider an alternative that differentiated tanker trailers, platform trailers, and container chassis from the other non-box highway trailers to include aerodynamic technologies on a fraction of these trailer types. However, an evaluation of this alternative is not included here. As discussed in Section IV of the preamble for this proposal, a majority of the non-box trailer manufacturers meet the definition of small business.[O] EPA convened and the agencies are proposing to follow the recommendations of the Small Business Advocacy Review panel required by the Small Business Regulatory Enforcement Fairness Act (SBREFA). This panel concluded that aerodynamic requirements for non-box trailer manufacturers would disproportionately burden small manufacturers and they recommended that no aerodynamic requirements be proposed.

2.10.2 **Defining the Proposed Trailer Technology Packages**

The impact of a trailer on the overall fuel efficiency and CO_2 emissions of a tractor-trailer vehicle varies depending on three main characteristics of the trailer: aerodynamic drag, rolling resistance, and weight. In this section, we outline the technologies that the agencies evaluated for the proposed standards.

2.10.2.1 Aerodynamic Drag Reduction

The rigid, rectangular shape of box trailers creates significant aerodynamic drag and makes them ideal candidates for aerodynamic technologies that can reduce drag and improve fuel consumption and CO_2 emissions. Current aerodynamic technologies for box trailers have shown significant drag reductions, as discussed below. These technologies are designed to create a smooth transition of airflow from the tractor, around the trailer, and beyond the trailer. Box trailers provide opportunities to address drag at the front, rear, and underside of the trailer, and the agencies considered several types of aerodynamic devices designed to address drag at all of these points. Table 2-69 lists general aerodynamic technologies that the EPA SmartWay program has evaluated for use on box trailers and a description of their intended impact. Several versions of each of these technologies are commercially available and have seen increased adoption over the past decade. Performance of these devices varies based on their design, their location and orientation on the trailer, and the vehicle speed.

Table 2-69 Aerodynamic Technologies for Box Trailers

LOCATION ON TRAILER	EXAMPLE TECHNOLOGIES	INTENDED IMPACT ON AERODYNAMICS
Front	Front fairings and gap-reducing fairings	Reduce cross-flow through gap and smoothly transition airflow from tractor to the trailer
Rear	Rear fairings, boat tails and flow diffusers	Reduce pressure drag induced by the trailer wake
Underside	Side fairings and skirts, and underbody devices	Manage flow of air underneath the trailer to reduce turbulence, eddies and wake

2.10.2.1.1 ***Performance of Aerodynamic Technologies***

SmartWay-verified technologies are evaluated on 53-foot dry vans. The verified technologies are grouped into bins that represent one percent, four percent, or five percent fuel

[O] The Regulatory Flexibility Act defines small entities as including “small businesses,” “small governments,” and “small organizations” (5 USC 601) and references the Small Business Act for the definition of “small businesses” using size standards based on the North American Industry Classification System (NAICS) (13 CFR 121.201).

savings relative to a typical long-haul tractor-trailer at 65-mph cruise conditions. Use of verified aerodynamic devices totaling at least five percent fuel savings, along with verified tires, qualifies a 53-foot dry van trailer for the "SmartWay Trailer" designation. In 2014, EPA expanded the program to include refrigerated vans and provided a "SmartWay Elite" designation if fleets adopt verified tires and aerodynamic equipment providing nine percent or greater fuel savings. To-date, nine aerodynamic technology packages from five manufacturers have received the SmartWay Elite designation. We may refer to SmartWay verification levels in this analysis, since the trailer industry is most familiar with these values as a measure of trailer performance.

It is important to note that the cruise speed results presented in SmartWay do not necessarily represent performance that would be observed in real world operation. Additionally, EPA's Greenhouse gas Emissions Model (GEM), which is the tool the agencies are proposing to use for trailer compliance, uses a weighted average of three drive cycles in its vehicle simulation. The CO_2 and fuel consumption reductions calculated in GEM may differ from those measured in SmartWay's performance tests. Figure 2-17 shows a comparison of the CO_2 reductions observed for the three individual drive cycles simulated in GEM and the reductions using a combination of the three GEM cycles with the cycle weightings assigned to long-haul tractor-trailers in this proposed rulemaking (i.e., 86 percent 65-mph cruise, 9 percent 55-mph cruise, and 5 percent transient). These results could be used to estimate the difference in performance when comparing a constant, 65-mph cruise test similar to SmartWay's performance tests or the results from GEM simulations used for compliance to other driving conditions. These results suggest that the SmartWay Elite target improvement of nine percent would be closer to eight percent using GEM's long-haul simulation. It can also be seen that very little benefit is seen for tractor-trailers driving under highly transient conditions. These results are for illustrative purposes only and do not provide an exact correlation between test results, real-world results, and results from GEM.

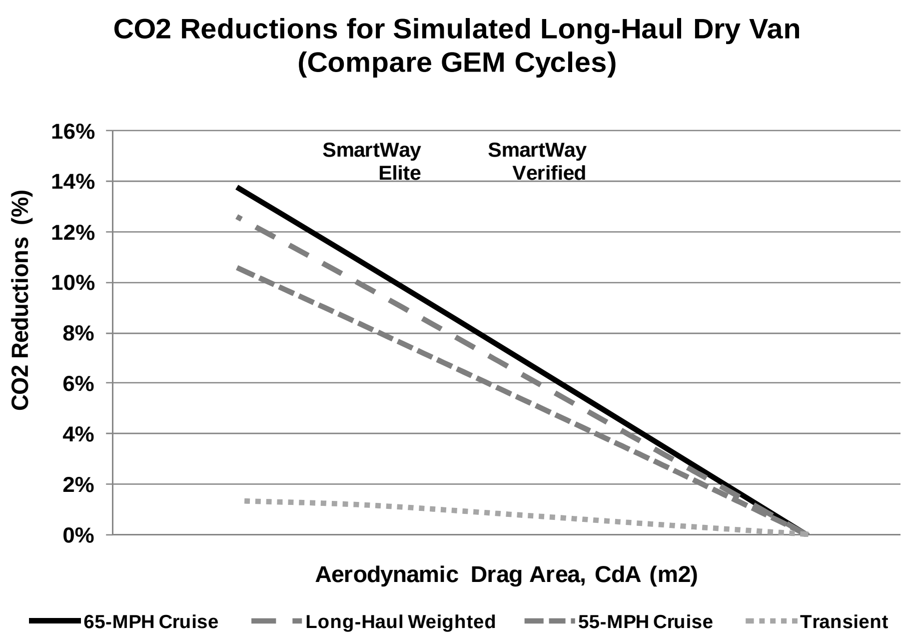


Figure 2-17 Comparison of Weighted and 65-mph Cruise Results using EPA's GEM for a Long Dry Van

In this analysis, the aerodynamic performance of a tractor-trailer vehicle is quantified by the aerodynamic drag area, CdA (coefficient of drag multiplied by frontal area), which is a function of both tractor and trailer aerodynamic characteristics. EPA's aerodynamic testing of Class 8 high roof sleeper cab tractors pulling standard 53-foot dry vans with zero aerodynamic technologies produced an average CdA value of 6.2 m^2 in coastdown testing and an average zero-yaw CdA value of 5.5 m^2 in wind tunnel testing (see Chapter 3.2.4.1). EPA also performed wind tunnel tests on a Class 7 high roof day cab pulling several configurations of a solo 28-foot dry van trailer and two tandem 28-foot dry van trailers. The average zero-yaw CdA value for the solo 28-foot trailer configuration with zero aerodynamic technologies was 5.4 m^2 (a two percent difference compared the corresponding test of the 53-foot trailer).

For this analysis, EPA grouped these common aerodynamic devices into packages of individual or combined technologies. Front fairings and gap reducers provide the smallest benefit of the aerodynamic technologies considered. Skirts and boat tails come in ranges of sizes and vary in effectiveness. For the purpose of this analysis, the agencies grouped these two technologies into "basic" and "advanced". Basic boat tails and skirts achieve SmartWay's verification threshold of four percent at cruise speeds. Advanced tails and skirts achieve SmartWay's five percent verification. These technologies can be used individually, or in combination. The overall performance of a combination of devices could be nearly additive in terms of the effectiveness of its individual devices. Some devices may work synergistically to achieve greater reductions or counteract and provide less reduction. The trailer aerodynamics industry continues to evolve and the agencies anticipate further optimization of these devices in the future. In addition to these bolt-on technologies, some manufacturers are experimenting with physical changes to the trailer design such that the overall construction of the trailer is more aerodynamic.

EPA collected aerodynamic test data for many of the technologies mentioned previously on several tractor-trailer configurations, including 53-foot dry vans and 28-foot dry van pup trailers. As described in Chapter 3, EPA's aerodynamic testing included four tractor models, three trailer models, and several aerodynamic technologies. The wind tunnel results shown in Figure 2-18 indicate there is very little difference in performance between trailer manufacturers for their basic trailer models.

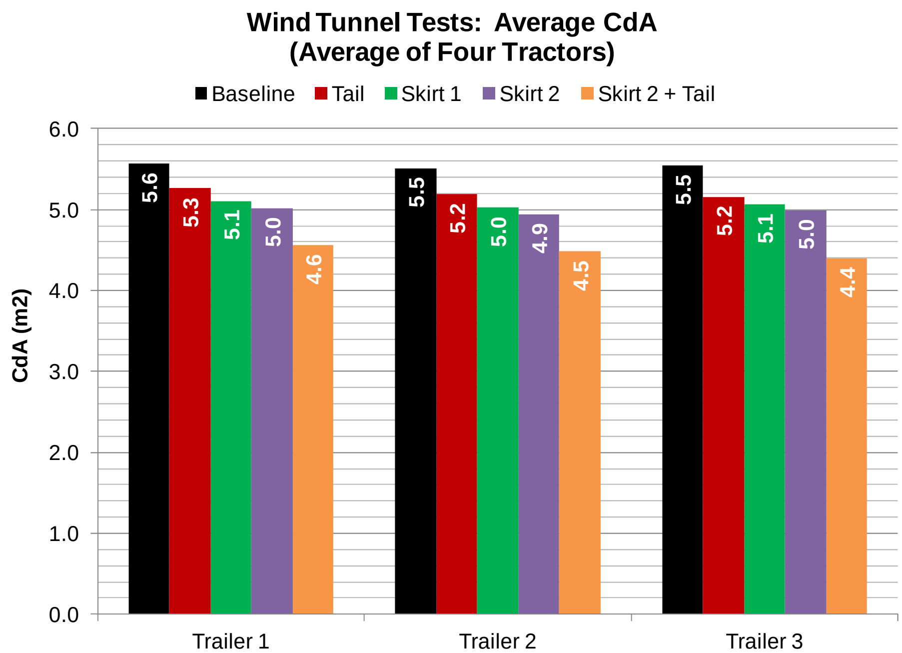


Figure 2-18 Variation in Performance of Trailer Devices due to Trailer Manufacturer

However, the results showed some variation in aerodynamic performance depending on the tractor type, device manufacturer, and test method. Figure 2-19 illustrates these variations for a single trailer. While there is some variability in the numerical CdA values of the baseline (zero technology) tractor-trailers tested, there is less variation in the effect of adding devices. For example, the wind tunnel CdA result for adding a skirt and tail to Tractor 1 (orange bar in the first column of Figure 2-19) is 4.5 m^2 and the coastdown CdA result for adding the same skirt and tail to Tractor 3 (orange bar in the last column of Figure 2-19) is 5.8 m^2. However, when we compare the effect of adding the devices by taking into account the change from the baseline result, we get a change in CdA (delta CdA) of 0.9 m^2 for Tractor 1 and 0.8 m^2 for Tractor 3. This reduced variation is one of the motivating factors in our decision to use a delta CdA approach for trailers in lieu of requiring an absolute CdA test.[P]

[P] Additional considerations include the fact that an absolute test would require a specific standard tractor for testing to ensure an apples-to-apples comparison of all trailer test results and a delta CdA approach makes it possible to allow device manufacturers to perform tests on their devices and have them pre-approved for any trailer manufacturer to apply on their trailers.

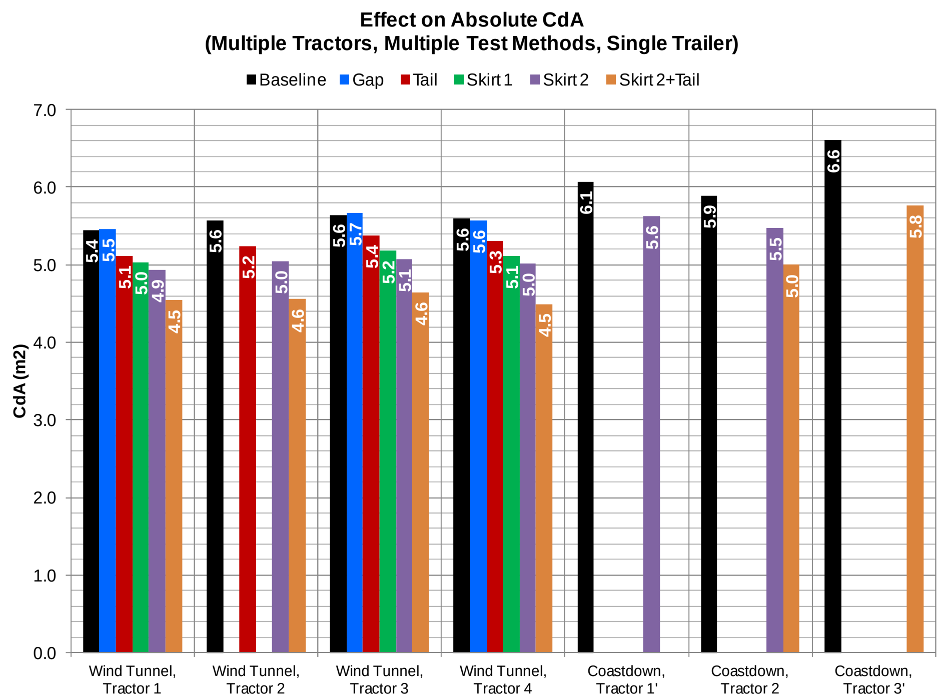


Figure 2-19 Variation in Aerodynamic Performance of Trailer Devices due to Tractor Manufacturer and Test Method

2.10.2.1.2 *Performance Bins for Aerodynamic Technologies*

The agencies developed bins based on changes in CdA (or "delta CdA") to encompass technologies that are expected to provide similar improvements in drag (e.g., most skirts would fall into the same bin) and cover the variability due to tractor model, test method, device manufacturer, and trailer manufacturer. Figure 2-20 summarizes the trailer aerodynamic test results that were used to establish the trailer certification bins. These results show the average delta CdA over four tractor types, and two test methods (i.e., wind tunnel and coastdown) using a single trailer.

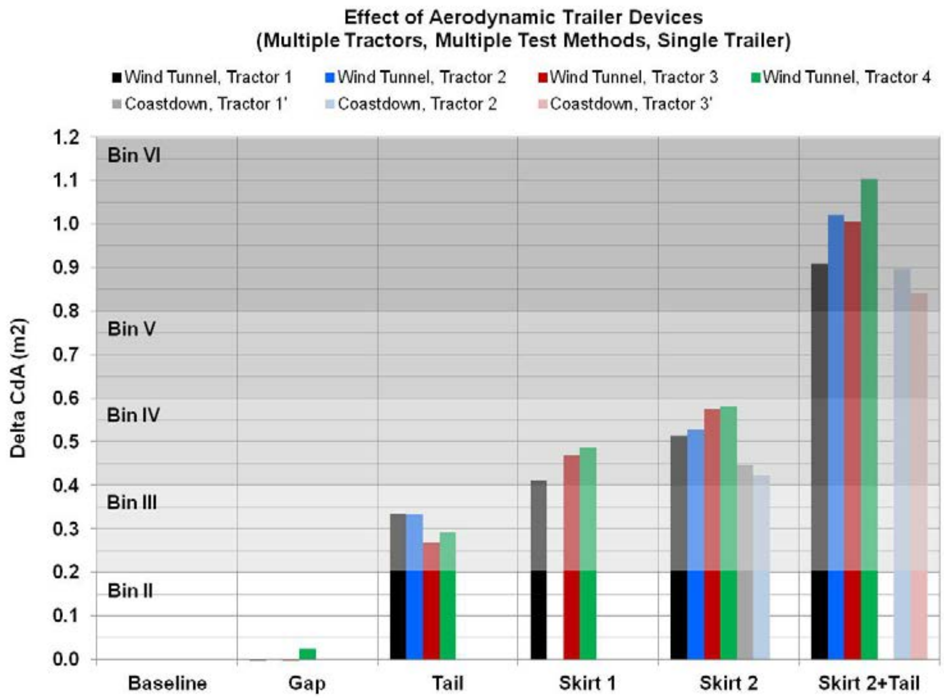


Figure 2-20 Aerodynamic Trailer Testing Results used to Establish Bins for Trailer Certification

As seen in Figure 2-21, results from EPA's testing of solo 28-foot trailers show that a basic skirt would fall into Bin II and the addition of a gap reducer improves the aerodynamic performance to Bin III or Bin IV levels of drag reduction. It should be noted that while the agencies have chosen to test and regulate 28-foot box trailers individually, they are often pulled in a tandem configuration, which restricts the type of aerodynamic devices that can be applied on the rear of the trailers. We expect rear devices such as boat tails would not be practical for 28-foot box trailers, since those devices are only deployable when the trailer is in the rear position. However, we recognize that other trailer lengths within the short box trailer subcategory (e.g., 40-foot and 48-foot) would be able to use rear aerodynamic devices and achieve the improvements observed in the higher bins.

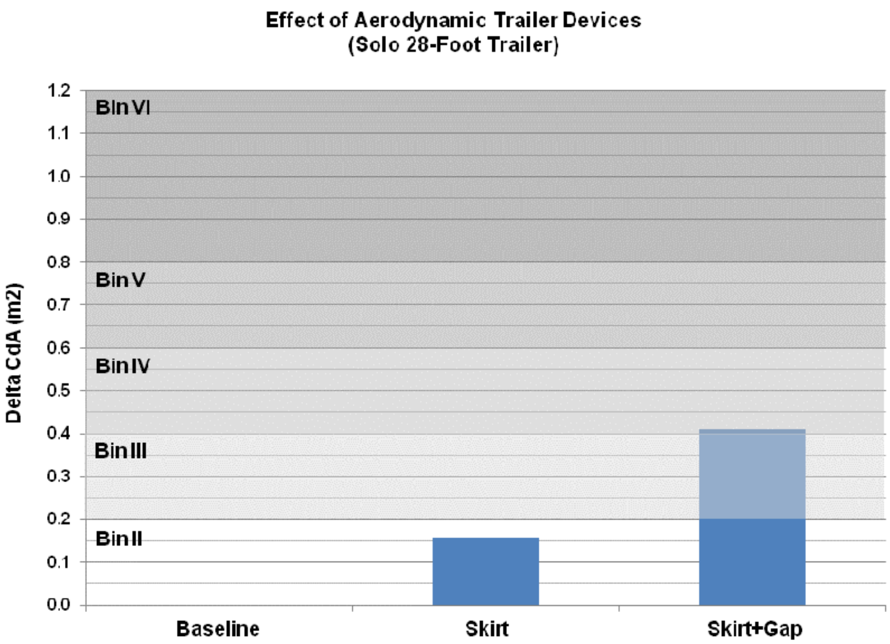


Figure 2-21 Aerodynamic Trailer Testing Results for a Solo 28-Foot Dry Van Relative to Proposed Bins

Table 2-70 below illustrates the bin structure that the agencies are proposing as the basis for compliance. The table summarizes example technology packages that might be included in each bin for two example trailers.

Table 2-70 Aerodynamic Technology Bins used to Evaluate Trailer Benefits and Costs

BIN	DELTA CDA	AVERAGE DELTA CDA	EXAMPLE TECHNOLOGIES	
			53-FOOT DRY VAN	28-FOOT DRY VAN
Bin I	< 0.09	0.0	No Aero Devices	No Aero Devices
Bin II	0.10 - 0.19	0.1	Gap Reducer	Skirt
Bin III	0.20 - 0.39	0.3	Basic Skirt or Basic Tail	Skirt + Gap Reducer
Bin IV	0.40 - 0.59	0.5	Advanced Skirt or Tail	Adv. Skirt + Gap Reducer
Bin V	0.60 - 0.79	0.7	Basic Combinations	
Bin VI	0.80 - 1.19	1.0	Advanced Combinations (including SmartWay Elite)	
Bin VII	1.20 - 1.59	1.4	Optimized Combinations	
Bin VIII	> 1.60	1.8	Changes to Trailer Construction	

Within GEM, the aerodynamic performance of each trailer subcategory is evaluated by comparing the delta CdA from Table 2-70 to a CdA value representative of a tractor-trailer vehicle with zero aerodynamic trailer technologies (i.e., Bin I). The agencies chose to model the zero-technology long box dry van using a CdA value of 6.2 m^2 (the average CdA from EPA's coastdown testing). For long box refrigerated vans, a two percent reduction in CdA was assumed to account for the aerodynamic benefit of the TRU at the front of those trailers. A short box dry van also received a two percent lower CdA value compared to its 53-foot counterpart, consistent with the reduction observed in EPA's wind tunnel testing. The CdA value assigned to a refrigerated short box van was an additional two percent lower than the short box dry van. Special purpose trailers of all lengths are modeled as a short dry van trailer in GEM and have the same Bin I CdA value of 6.1 m^2. Since there are no aerodynamic requirements for special purpose trailers, the rest of the bins are unnecessary. Non-box highway trailers, which are modeled as flatbed trailers, were assigned a drag area of 5.0 m^2, as was done in the Phase 1 tractor program for low roof day cabs. Table 2-71 illustrates the absolute drag areas (CdA) associated with each aerodynamic bin for each trailer subcategory.

Table 2-71 Baseline CdA Values Associated with Aerodynamic Bin I (Zero Trailer Technologies) within GEM

TRAILER SUBCATEGORY	DRY VAN
Long Dry Van	6.2
Short Dry Van	6.1
Long Ref. Van	6.1
Short Ref. Van	6.0
Special Purpose Box	6.1
Non-Box Highway	4.9

2.10.2.1.3 *Effect of Wind-Averaged Drag*

The agencies recognize that the benefits of aerodynamic devices for trailers can be better seen when measured considering multiple yaw angles. To evaluate the effect of wind, we compared the zero yaw and wind-averaged results from EPA's wind tunnel tests. The wind-average results were calculated at 55 mph vehicle speeds, consistent with the procedures in 40 CFR 1037.810. The results for three trailers, each an average of tests performed on four tractors, are shown in Figure 2-22. The wind-averaged analysis consistently results in a larger improvement (i.e., delta CdA). The gap reducer technology shows minimal benefit under a zero yaw analysis, but a measurable benefit when yaw angles are considered.

The performance bins and the resulting proposed standards were developed using zero yaw drag results. The agencies are not proposing to accept wind averaged drag results, in order to maintain consistency between test methods, as was shown in Figure 2-19. The use of wind-averaged drag data would result in larger benefits for trailers tested using a wind tunnel or CFD compared to same trailers tested using coastdown procedures. The tractor program, which is proposing to use wind-averaged drag results, has a reference test method and a correction factor to maintain consistency between methods. The trailer program is not proposing to require a reference test, in order to reduce the test burden for manufacturers and allow them to choose an appropriate test method for their needs and resources.

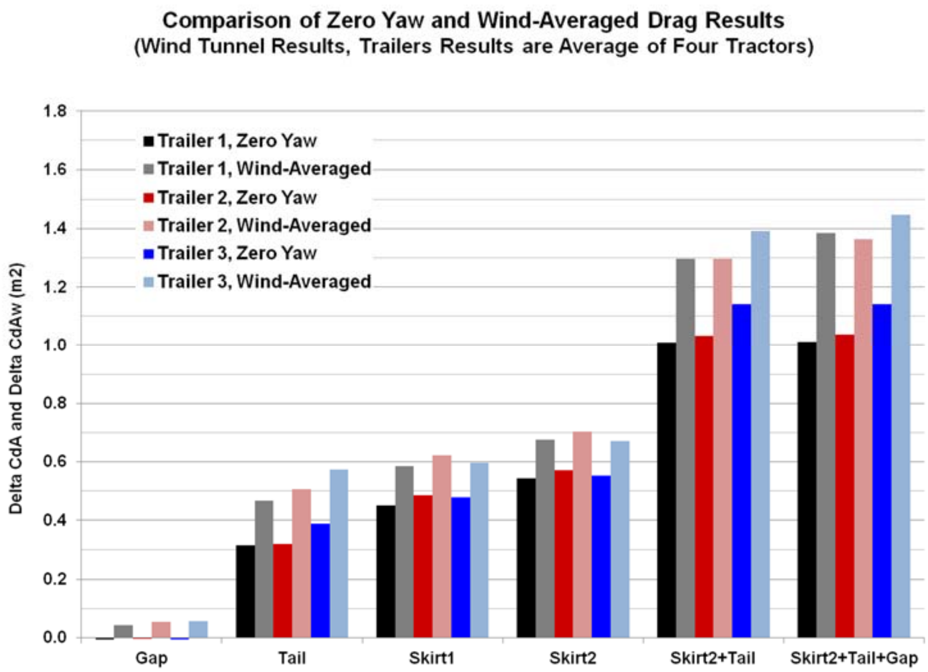


Figure 2-22 Comparison of Zero Yaw and Wind-Averaged Drag Results

2.10.2.2 Tire Rolling Resistance

2.10.2.2.1 *Lower Rolling Resistance Tires*

On a typical Class 8 long-haul tractor-trailer, over 40 percent of the total energy loss from tires is attributed to rolling resistance from the *trailer* tires.[147] Trailer tire rolling resistance values collected by the agencies for Phase 1 indicate that the average coefficient of rolling resistance (CRR) for new trailer tires was 6.0 kg/ton. This value was applied for the standard trailer used for tractor compliance in the Phase 1 tractor program. For Phase 2, the agencies consider all trailer tires with CRR values below 6.0 kg/ton to be "lower rolling resistance" (LRR) tires. For reference, a trailer tire that qualifies as a SmartWay-verified tire must meet a CRR value of 5.1 kg/ton, a 15 percent CRR reduction from the trailer tire identified in Phase 1. Our research of rolling resistance indicates an additional CRR reduction of 15 percent or more from the SmartWay verification threshold is possible with tires that are available in the commercial market today.

For this proposal, the agencies are proposing to use the same rolling resistance baseline value of 6.0 kg/ton for all trailer subcategories. In the preamble at Section IV, the agencies request comments including information on current adoption rates of and CRR values for models of LRR tires in use by the various trailer types today.

Similar to the case of tractor tires, LRR tires are available as either dual or as single wide-based tires for trailers. Single wide-based tires achieve CRR values that are similar to their dual counterparts, but have an added benefit of weight reduction, which can be an attractive option for trailers that frequently maximize cargo weight.

2.10.2.2.2 *Performance Levels for LRR Tires*

Similar to the proposed Phase 2 tractor and vocational vehicle programs, the agencies are proposing a tire program based on adoption of lower rolling resistance tires. Feedback from several box trailer manufacturers indicates that the standard tires offered on their new trailers are SmartWay-verified tires (i.e., CRR of 5.1 kg/ton or better). An informal survey of members from the Truck Trailer Manufacturers Association (TTMA) indicates about 35 percent of box trailers sold today have SmartWay tires.[148] While some trailers continue to be sold with tires of higher rolling resistances, the agencies believe most box trailer tires currently achieve the Phase 1 trailer tire CRR of 6.0 kg/ton or better.

The agencies evaluated two levels of tire performance for this proposal beyond the baseline trailer tire with a CRR of 6.0 kg/ton. The first performance level was set at the criteria for SmartWay-verification for trailer tires, 5.1 kg/ton, which is a 15 percent reduction in CRR from the baseline. As mentioned previously, several tire models available today achieve rolling resistance values well below the present SmartWay threshold. Given the multiple year phase-in of the standards, the agencies expect that tire manufacturers will continue to respond to demand for more efficient tires and will offer increasing numbers of tire models with rolling resistance values significantly better than today's typical LRR tires. In this context, we believe it is reasonable to expect a large fraction of the trailer industry could adopt tires with rolling resistances at a second performance level that would achieve an additional eight percent reduction in rolling resistance (a 22 percent reduction from the Level 1 tire), especially in the later stages of the program. The agencies project the CRR for this second level of performance to be a value of 4.7 kg/ton. The agencies evaluated these three tire rolling resistance levels, summarized in Table 2-72, in the feasibility analysis of the following sections. GEM simulations that apply Level 1 and 2 tires result in CO_2 and fuel consumption reductions of two and three percent from the Level 1 tire, respectively.

Table 2-72 Summary of Trailer Tire Rolling Resistance Levels Evaluated

ROLLING RESISTANCE LEVEL	CRR (KG/TON)
Baseline	6.0
Level 1	5.1
Level 2	4.7

2.10.2.3 Tire Pressure Systems

The inflation pressure of tires also impacts the rolling resistance. Tractor-trailers operating with all tires under-inflated by 10 psi have been shown to increase fuel consumed by up to one percent.[149] Tires can gradually lose pressure from small punctures, leaky valves or simply diffusion through the tire casing. Changes in ambient temperature can also affect tire pressure. Trailers that remain unused for long periods of time between hauls may experience any of these conditions. A 2003 FMCSA report found that nearly one in five trailers had at least one tire under-inflated by 20 psi or more. If drivers or fleets are not diligent about checking and attending to under-inflated tires, the trailer may have much higher rolling resistance and much higher CO_2 emissions and fuel consumption.

2.10.2.3.1 *Types of Tire Pressure Monitoring Systems*

Tire pressure monitoring (TPM) and automatic tire inflation (ATI) systems are designed to address under-inflated tires. Both systems alert drivers if a tire's pressure drops below its set point. TPM systems simply monitor the tires and require user-interaction to reinflate to the appropriate pressure. Today's ATI systems take advantage of trailers' air brake systems to supply air back into the tires (continuously or on demand) until a selected pressure is achieved. In the event of a slow leak, ATI systems have the added benefit of maintaining enough pressure to allow the driver to get to a safe stopping area.[150] The agencies believe TPM systems cannot sufficiently guarantee the proper inflation of tires due to the inherent user-interaction required. Therefore, ATI systems are the only pressure systems the agencies are proposing to recognize in Phase 2.

2.10.2.3.2 *Performance of ATI Systems*

Estimates of the benefits of ATI systems vary depending on the base level of maintenance already performed by the driver or fleet, as well as the number of miles the trailer travels. Trailers that are well maintained or that travel fewer miles would experience less benefits from ATI systems compared to trailers that often drive with poorly inflated tires or log many miles. The agencies believe ATI systems can provide a CO_2 and fuel consumption benefit to most trailers. With ATI use, trailers that have lower annual vehicle miles traveled (VMT) due to long periods between uses would be less susceptible to low tire pressures when they resume activity. Trailers with high annual VMT or frequent changes in ambient conditions would experience the fuel savings associated with consistent tire pressures. Automatic tire inflation systems could provide a CO_2 and fuel consumption savings of 0.5-2.0 percent, depending on the degree of under-inflation in the trailer system.

Maintaining tire pressure is important to fuel consumption. Tire manufacturers estimate a tire pressure 10 psi below target results in a 0.9 percent increase in fuel consumption. Two studies have evaluated truck and trailer tire inflation including FMCSA (2003) and TMC (2002).[151,152] In the 2003 FMCSA study, tire inflation (psi) was measured in 3,200 tractors and 1,300 trailers. The TMC study measured tire inflation rates in two fleets and found that only 38 percent of sampled trailer tires were within +/- 5 psi of target pressure as prescribed by tire manufacturers. The study also found that more than 20 percent of tires were 20 psi or more underinflated and four percent of tires were 50 psi or more underinflated compared to the target. The FMCSA study found similar results. These figures suggest under inflation of tractor and trailer tires in the U.S. fleet could result in an increase in fuel consumption of approximately one to two percent. Most recently, FMCSA (2014) evaluated trailer ATI systems in two test fleets.[153] The study found ATI systems improved fuel consumption 1.4 percent in test trucks as compared to control trucks in two fleets.

NHTSA and EPA recognize the role of proper tire inflation in maintaining optimum tire rolling resistance during normal trailer operation. For this proposal, rather than require performance testing of ATI systems, the agencies are proposing to recognize the benefits of ATI systems with a single default reduction for manufacturers that incorporate ATI systems into their trailer designs. Based on information available today, we believe that there is a narrow range of performance among technologies available and among systems in typical use. We propose to assign a 1.5 percent reduction in CO_2 and fuel consumption for all trailers that implement ATI systems, based on information available today.[154] We believe the use of these systems can consistently ensure that tire pressure and tire rolling resistance are maintained. We selected the levels of the proposed trailer standards with the expectation that a high rate of adoption of ATI systems would occur across all on-highway trailers and during all years of the phase-in of the program. For a target tire pressure of 100 psi, a 1.5 percent reduction could be achieved assuming 30 percent of trailer tires are at their target pressure, 30 percent are 10 psi below target, 20 percent are 20 psi low, 10 percent are 30 psi low, 5 percent are 40 psi low and 5 percent are 50 psi or more below target pressure.

2.10.2.4 Weight Reduction

Reduction in trailer tare (or empty) weight can lead to fuel consumption reductions in two ways. For applications where payload is not limited by weight restrictions, the overall weight of the tractor and trailer would be reduced and would lead to improved fuel efficiency. For applications where payload is limited by weight restrictions, the lower trailer weight would allow additional payload to be transported during the truck's trip, so g/ton-mile emissions would decrease. Weight reduction opportunities in trailers exist in both the structural components and in the wheels and tires. Manufacturers commonly replace components such as roof posts, bows, side posts, cross members, floor joists, and floor sections with lighter weight options.

Major lower-weight options are not offered consistently by all trailer manufacturers across the industry. For example, some manufacturers have already marketed lower-weight major components for many years, while others to date have not done so. There is no clear "baseline" for current trailer weight against which lower-weight designs could be compared for regulatory purposes. For this reason, the agencies do not believe it would be appropriate or fair across the industry to apply overall weight reductions toward compliance. However, the agencies do believe it would be appropriate to allow a manufacturer to account for weight reductions that involve substituting very specific, traditionally heavier components with lower-weight options that are not currently widely adopted in the industry.

The agencies recognize that when weight reduction is applied to a trailer, some operators will replace that saved weight with additional payload. To account for this in EPA's GEM vehicle simulation tool, it is assumed that one-third of the weight reduction is applied to the payload. For tractor-trailers simulated in GEM, it takes a weight reduction of nearly 1,000 pounds before a one percent fuel savings is achieved and about a 2,500 pound reduction to reach three percent savings. The component substitutions identified by the agencies result in weight reductions of less than 500 pounds, yet can cost over $1,000. The agencies believe that few trailer manufacturers would apply weight reduction solely as a means of achieving reduced fuel consumption and CO_2 emissions, and we are proposing standards that can be met without reducing weight. However, we are proposing to offer weight reduction as an option for box trailer manufacturers who wish to apply it to some of their trailers as part of their emissions averaging strategy.

2.10.2.4.1 *Weight Reduction Options Recognized in this Proposal*

The agencies are proposing compliance provisions that would limit the weight-reduction options to the substitution of specified components that can be clearly isolated from the trailer as a whole. For this proposal, the agencies have identified several conventional components with available lighter-weight substitutes (e.g., substituting conventional dual tires with steel wheels with single wide-based tires and aluminum wheels). We are proposing values for the associated weight-related savings that would be applied with these substitutions for compliance. We believe that the initial cost of these component substitutions is currently substantial enough that only a relatively small segment of the industry has adopted these technologies today.

In addition to weight reduction associated with replacing standard steel wheels with aluminum versions, and adopting single wide-based tires in place of dual tires, the agencies have identified 11 common trailer components that have lighter weight options available.[155,156,157,158] Some of the references include confidential data that outlined weight savings and costs associated with these material substitutions. Table 2-73 lists the components, and estimates of weight savings and costs obtained by the agencies. Manufacturers that adopt these technologies would sum the associated weight reductions and apply those values in GEM. Steel wheels can be replaced with aluminum wheels and two dual tires can be replaced with single wide-based tires on aluminum wheels. Relatively large weight savings are possible by replacing steel upper coupler assemblies or suspension sub-frames with aluminum versions, but these substitutions are more expensive and more labor-intensive to install.

Table 2-73 Weight Reduction Options for Trailers

COMPONENT	MATERIAL SUBSTITUTION	WEIGHT REDUCTION (LB)
Hub and Drum (per axle)	Cast Iron to Aluminum	80
Floor	Hardwood to Aluminum	375
Floor	Hardwood to Composite	245
Floor Crossmembers	Steel to Aluminum	203
Landing Gear	Steel to Aluminum	50
Rear Door	Steel to Aluminum	187
Rear Door Surround	Steel to Aluminum	150
Roof Bows	Steel to Aluminum	100
Side Posts	Steel to Aluminum	300
Slider Box	Steel to Aluminum	150
Structure for Suspension Assembly	Steel to Aluminum	280
Upper Coupler Assembly	Steel to Aluminum	430

2.10.2.5 Effectiveness of Technologies

The agencies are proposing to recognize trailer improvements via four performance parameters: aerodynamic drag reduction, tire rolling resistance reduction, and the adoption of ATI and weight reduction. Table 2-74 summarizes the performance levels for each of these parameters based on the technology characteristics outlined in Section 2.10.2.

Table 2-74 Performance Parameters for the Proposed Trailer Program

AERODYNAMICS (DELTA CDA, M^2)	
Bin I	0.0
Bin II	0.1
Bin III	0.3
Bin IV	0.5
Bin V	0.7
Bin VI	1.0
Bin VII	1.4
Bin VIII	1.8
Tire Rolling Resistance (CRR, kg/ton)	
Tire Baseline	6.0
Tire Level 1	5.1
Tire Level 2	4.7
Tire Inflation System (% reduction)	
ATI System	1.5
Weight Reduction (pounds)	
Weight	1/3 added to payload, remaining reduces overall vehicle weight

These performance parameters have different effects on each trailer subcategory due to differences in the simulated trailer characteristics. Table 2-75 shows the agencies' estimates of the effectiveness of each parameter for four box trailer types. Each technology was evaluated in GEM using the baseline parameter values for the other technology categories. For example, each aerodynamic bin was evaluated using the Tire Level 1 (6.0 kg/ton) and the Base weight reduction option (zero pounds). The table shows that aerodynamic improvements offer the largest potential for CO_2 emissions and fuel consumption reductions, making them relatively effective technologies.

Table 2-75 Effectiveness (Percent Change in CO_2 Emissions and Fuel Consumption) of Technologies for the Proposed Trailer Program

AERODYNAMICS	DELTA CDA (M^2)	DRY VAN		REFRIGERATED VAN	
		Long	Short	Long	Short
Bin I	0.0	0%	0%	0%	0%
Bin II	0.1	-1%	-1%	-1%	-1%
Bin III	0.3	-2%	-2%	-2%	-2%
Bin IV	0.5	-3%	-4%	-3%	-3%
Bin V	0.7	-5%	-5%	-5%	-5%
Bin VI	1.0	-7%	-7%	-7%	-7%
Bin VII	1.4	-10%	-10%	-9%	-10%
Bin VIII	1.8	-13%	-13%	-12%	-12%
Tire Rolling Resistance	CRR (kg/ton)	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
Baseline	6.0	0%	0%	0%	0%
Level 1	5.1	-2%	-1%	-2%	-1%
Level 2	4.7	-3%	-2%	-3%	-2%
Weight Reduction	Weight (lb)	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
Baseline	0.0	0.0%	0.0%	0.0%	0.0%
Option 1	168	-0.2%	-0.3%	-0.2%	-0.3%
Option 2	280	-0.3%	-1%	-0.3%	-1%
Option 3	430	-0.5%	-1%	-0.5%	-1%
Option 4	556	-1%	-1%	-1%	-1%

2.10.3 **Defining the Baseline Trailers**

2.10.3.1 Baseline Tractor-Trailer Vehicles within GEM

The regulatory purpose of EPA's heavy-duty vehicle compliance tool, GEM, is to combine the effects of trailer technologies through simulation so that they can be expressed as kg/ton-mile and gal/100 ton-mile and thus avoid the need for direct testing of each trailer model being certified. The proposed trailer program has separate standards for each trailer subcategory, and a unique tractor-trailer vehicle was chosen to represent each subcategory for compliance. In the Phase 2 update to GEM, each trailer subcategory is modeled as a particular trailer being pulled by a standard tractor depending on the physical characteristics and use pattern of the trailer. Table 2-76 highlights the relevant vehicle characteristics for the zero-technology baseline of each subcategory. Level 1 trailer tires are used, and the drag area, which is a function of the aerodynamic characteristics of both the tractor and trailer, is set to the Bin I values shown previously in Table 2-71. Weight reduction and ATI systems are not applied in these baselines. Chapter 2.10 of the draft RIA provides a detailed description of the development of these baseline tractor-trailers.

Table 2-76 Characteristics of the Zero-Technology Baseline Tractor-Trailer Vehicles

	DRY VAN		REFRIGERATED VAN		AERO-EXCLUDED BOX	NON-BOX HIGHWAY
Trailer Length	Long	Short	Long	Short	All Lengths	All Lengths
Tractor Class	Class 8	Class 8	Class 8	Class 8	Class 8	Class 8
Tractor Cab Type	Sleeper	Day	Sleeper	Day	Day	Day
Tractor Roof Height	High	High	High	High	High	Low
Engine	2018 MY 15L, 455 HP	2018 MY 15L, 455 HP	2018 MY 15L, 455 HP	2018 MY 15L, 455 HP	2018 MY 15L, 455 HP	2018 MY 15L, 455 HP
Frontal Area (m^2)	10.4	10.4	10.4	10.4	10.4	6.9
Baseline Drag Area, CdA (m^2)	6.2	6.1	6.1	6.0	6.1	4.9
Steer Tire RR (kg/ton)	6.54	6.54	6.54	6.54	6.54	6.54
Drive Tire RR (kg/ton)	6.92	6.92	6.92	6.92	6.92	6.92
Trailer Tire RR (kg/ton)	6.00	6.00	6.00	6.00	6.00	6.00
Total Weight (kg)	31978	21028	33778	22828	21028	29710
Payload (tons)	19	10	19	10	10	19
ATI System Use	0	0	0	0	0	0
Weight Reduction (lb)	0	0	0	0	0	0
Drive Cycle Weightings						
65-MPH Cruise	86%	64%	86%	64%	64%	64%
55-MPH Cruise	9%	17%	9%	17%	17%	17%
Transient Driving	5%	19%	5%	19%	19%	19%

2.10.3.2 Reference Case Tractor-Trailer Vehicles to Evaluate Benefits and Costs

In order to evaluate the benefits and costs of the proposed standards, it is necessary to establish a reference point for comparison. The technologies described in Section 2.10.2 exist in the market today, and their adoption is driven by available fuel savings as well as by the voluntary SmartWay Partnership and California's Heavy Duty Greenhouse Gas Emission Reduction Measure tractor-trailer requirements. For this proposal, the agencies identified reference case tractor-trailers for each trailer subcategory based on the technology adoption rates we project would exist if this proposed trailer program was not implemented.

The agencies believe research funded and conducted by the federal government, industry, academia and other organizations is likely to result in the adoption of some technologies beyond the levels required to comply with existing regulatory and voluntary programs. One example of such research is the Department of Energy Super Truck program[159] which has a goal of demonstrating cost-effective measures to improve the efficiency of Class 8 long-haul freight trucks by 50 percent by 2015. For purposes of our reference case, we project that by 2018, absent further California regulation, EPA's SmartWay program and these research programs will result in about 20 percent of 53-foot dry and refrigerated vans adopting basic SmartWay-level aerodynamic technologies (meeting SmartWay's four percent verification level and Bin III from Table 2-74),[160,161,162] 30 percent adopting more advanced aerodynamic technologies at the five percent SmartWay-verification level (Bin IV), and five percent adding combinations of technologies (Bin V). In addition, we project half of these 53' box trailers will be equipped with SmartWay-verified tires (i.e., 5.1 kg/ton) and ATI systems as well. The agencies project market forces will drive an additional one percent increase in adoption of the advanced SmartWay and tire technologies each year through 2027. For analytical purposes, the agencies assumed manufacturers of the shorter box trailers and other trailer subcategories would not adopt these technologies in the timeframe considered and a zero-technology baseline is assumed. We are not assuming any weight reduction for any of the trailer subcategories in the reference cases. Table 2-77 summarizes the reference case trailers for each trailer subcategory.

Table 2-77 Adoption Rates and Average Performance Parameters for the Reference Case Trailers

TECHNOLOGY	LONG BOX DRY & REFRIGERATED VANS				SHORT BOX, NON-AERO BOX, & NON-BOX TRAILERS
Model Year	2018	2021	2024	2027	2018 - 2027
Aerodynamics					
Bin I	45%	41%	38%	35%	100%
Bin II	-	-	-	-	-
Bin III	20%	20%	20%	20%	-
Bin IV	30%	34%	37%	40%	-
Bin V	5%	5%	5%	5%	-
Bin VI	-	-	-	-	-
Bin VII	-	-	-		-
Bin VIII	-	-	-	-	-
Average Delta CdA (m^2) [a]	*0.2*	*0.3*	*0.3*	*0.3*	*0.0*
Tire Rolling Resistance					
Baseline tires	50%	47%	43%	40%	100%
Level 1 tires	50%	53%	57%	60%	-
Level 2 tires	-	-	-	-	-
Average CRR (kg/ton) [a]	*5.55*	*5.52*	*5.49*	*5.46*	*6.0*
Tire Inflation					
ATI	50%	53%	57%	60%	0%
Average % Reduction [a]	*0.8%*	*0.8%*	*0.9%*	*0.9%*	*0.0%*
Weight Reduction (pounds)					
Weight [b]	*0*	*0*	*0*	*0*	*0*

Notes:
[a] Combines adoption rates with performance levels shown in Table 2-74
[b] Weight reduction was not projected for the reference case trailers

Also shown in Table 2-77 are average aerodynamic performance (delta CdA), average tire rolling resistance (CRR), and average reductions due to use of ATI and weight reduction for each stage of the proposed program. These values indicate the performance of theoretical average tractor-trailers that the agencies project would be in use if no federal regulations were in place for trailer CO_2 and fuel consumption. The average tractor-trailer vehicles serve as reference cases for each trailer subcategory.

In addition to the reference case described above, a second reference case was developed by the agencies. This alternative reflects the possibility that absent a Phase 2 regulation, there will be continuing adoption of technologies in the trailer market after 2027 that reduce fuel consumption and CO_2 emissions. This alternative assumes that by 2040, 75 percent of new trailers will be equipped with SmartWay-verified aerodynamic devices and low rolling resistance tires, and ATI. Table 2-78 shows the adoption rates of technologies in the alternative reference case.

Table 2-78 Adoption Rates and Average Performance Parameters for the Alternative Reference Case

TECHNOLOGY	LONG BOX DRY & REFRIGERATED VANS					SHORT BOX, NON-AERO BOX, & NON-BOX TRAILERS
Model Year	2018	2021	2024	2027	2040	2018 - 2027
Aerodynamics						
Bin I	45%	41%	38%	35%	20%	100%
Bin II	-	-	-	-	-	-
Bin III	20%	20%	20%	20%	20%	-
Bin IV	30%	34%	37%	40%	55%	-
Bin V	5%	5%	5%	5%	5%	-
Bin VI	-	-	-	-	-	-
Bin VII	-	-	-		-	-
Bin VIII	-	-	-	-	-	-
Average Delta CdA (m^2) [a]	*0.2*	*0.3*	*0.3*	*0.3*	*0.4*	*0.0*
Tire Rolling Resistance						
Baseline tires	50%	47%	43%	40%	25%	100%
Level 1 tires	50%	53%	57%	60%	75%	-
Level 2 tires	-	-	-	-	-	-
Average CRR (kg/ton) [a]	*5.6*	*5.5*	*5.5*	*5.5*	*5.3*	*6.0*
Tire Inflation						
ATI	50%	53%	57%	60%	75%	0%
Average % Reduction [a]	*0.8%*	*0.8%*	*0.9%*	*0.9%*	*1.1%*	*0.0%*
Weight Reduction (pounds)						
Weight [b]	*0*	*0*	*0*	*0*	*0*	*0*

The agencies applied the vehicle attributes from Table 2-77 and the average performance values from Table 2-74 in the proposed Phase 2 GEM vehicle simulation to calculate the CO_2 emissions and fuel consumption performance of the reference tractor-trailers. The results of these simulations are shown in Table 2-79. We used these CO_2 and fuel consumption values to calculate the relative benefits of the proposed standards. Note that the large difference between the per ton-mile values for long and short trailers is due primarily to the large difference in assumed payload (19 tons compared to 10 tons) as seen in and discussed further in the Chapter 2.10.3. The alternative baseline in Table 2-78 impacts the long-term projections of benefits beyond 2027, which are analyzed in Chapters 5 through 7 of this draft RIA. The non-box trailers and non-aero box vans are not included in this reference case analysis, because we are proposing design standards for these trailers. As such, these trailers would not have standards to meet. Instead, they would have minimum tire requirements.

Table 2-79 CO_2 Emissions and Fuel Consumption Results for the Reference Case Tractor-Trailers

	DRY VAN		REFRIGERATED VAN	
Length	Long	Short	Long	Short
CO_2 Emissions (kg/ton-mile)	85	147	87	151
Fuel Consumption (gal/100 ton-miles)	8.3497	14.4401	8.5462	14.8330

2.10.4 **Effectiveness and Costs of the Proposed Standards**

The agencies evaluated several alternatives for the proposed trailer program. The analysis below is for the alternative we believe reflects the agencies' statutory authorities. This alternative is fully implemented in model year (MY) 2027. The agencies believe that a period of more than 10 years provides the industry sufficient lead time to meet the stringency requirements proposed.

2.10.4.1 Projected Technology Adoption Rates for the Proposed Standards

Table 2-80 and Table 2-81 provide a set of adoption rates that a manufacturer could apply to meet the standards of this proposed rulemaking. These adoption rates begin with 60 percent of long box trailers achieving current SmartWay level aerodynamics (Bin IV) and progress to 90 percent achieving SmartWay Elite or better over the following nine years. Short box trailers adopt single aero devices in 2021 MY and combinations of devices by 2027 MY. Both long and short refrigerated vans have less stringent aerodynamic requirements in the later years to reflect the reduced number of aerodynamic options they have due to their TRUs. Similarly, we are proposing that partial-aero trailers of the various sizes would continue to be subject to the corresponding 2024 MY standards in 2027 and later model years to account for the work-performing devices that may inhibit the use of some technology combinations. The adoption rates for the long box trailers include some technologies that meet SmartWay Elite verification levels. The short box trailers would also include some combinations of devices. The agencies expect these adoption rates could be feasible in the next decade. The agencies believe trailer manufacturers and manufacturers of bolt-on aerodynamic devices will have incentive to design single-components or trailer features that accommodate work-performing devices and achieve these levels of performance by MY 2027.

The agencies project that nearly all box trailers would adopt tire technologies to comply with the standards and the agencies projected consistent adoption rates across all lengths of dry and refrigerated vans. As mentioned previously, the agencies did not include weight reduction in their technology adoption projections, but manufacturers can use weight reduction as part of their compliance strategy.

The adoption rates shown in these tables are one set of many possible combinations that box trailer manufacturers could apply to achieve the same average stringency. If a manufacturer chose these adoption rates, a variety of technology options exist within the aerodynamic bins, and several models of LRR tires exist for the levels shown. Alternatively, technologies from both higher and lower aero bins and tire levels could be used to comply. It should be noted that manufacturers are not limited to aerodynamic and tire technologies. Certain types of weight reduction, for example, may be used as a compliance pathway. Similar to the reference cases, the agencies derived a single set of performance parameters for each subcategory by weighting the performance levels included in Table 2-74 by the corresponding adoption rates. These performance parameters represent an average compliant vehicle for each trailer subcategory.

Table 2-80 Adoption Rates and Average Performance Parameters for the Long Box Trailers

TECHNOLOGY	LONG BOX DRY VANS				LONG BOX REFRIGERATED VANS			
Model Year	2018	2021	2024	2027	2018	2021	2024	2027
Aerodynamic Technologies								
Bin I	5%	-	-	-	5%	-	-	-
Bin II	-	-	-	-	-	-	-	-
Bin III	30%	5%	-	-	30%	5%	-	-
Bin IV	60%	55%	25%	-	60%	55%	25%	-
Bin V	5%	10%	10%	10%	5%	10%	10%	20%
Bin VI	-	30%	65%	50%	-	30%	65%	60%
Bin VII	-	-	-	40%	-	-	-	20%
Bin VIII	-	-	-	-	-	-	-	-
Average Delta CdA (m^2) [a]	*0.4*	*0.7*	*0.8*	*1.1*	*0.4*	*0.7*	*0.8*	*1.0*
Trailer Tire Rolling Resistance								
Baseline tires	15%	5%	5%	5%	15%	5%	5%	5%
Level 1 tires	85%	95%	-	-	85%	95%	-	-
Level 2 tires	-	-	95%	95%	-	-	95%	95%
Average CRR (kg/ton) [a]	*5.2*	*5.1*	*4.8*	*4.8*	*5.2*	*5.1*	*4.8*	*4.8*
Tire Inflation System								
ATI	85%	95%	95%	95%	85%	95%	95%	95%
Average ATI Reduction (%) [a]	*1.3%*	*1.4%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.4%*
Weight Reduction (pounds)								
Weight [b]	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Notes:

[a] Combines adoption rates with performance levels shown in Table 2-74

[b] This set of adoption rates did not apply weight reduction to meet the proposed standards for these trailers

Table 2-81 Adoption Rates and Average Performance Parameters for the Short Box Trailers

TECHNOLOGY	SHORT BOX DRY VANS				SHORT BOX REFRIGERATED VANS			
Model Year	2018	2021	2024	2027	2018	2021	2024	2027
Aerodynamic Technologies [a]								
Bin I	100%	5%	-	-	100%	5%	-	-
Bin II	-	95%	70%	30%	-	95%	70%	55%
Bin III	-	-	30%	60%	-	-	30%	40%
Bin IV	-	-	-	10%	-	-	-	5%
Bin V	-	-	-	-	-	-	-	-
Bin VI	-	-	-	-	-	-	-	-
Bin VII	-	-	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-	-	-
Average Delta CdA (m^2) [b]	*0.4*	*0.7*	*0.8*	*1.1*	*0.4*	*0.7*	*0.8*	*1.0*
Trailer Tire Rolling Resistance								
Baseline tires	15%	5%	5%	5%	15%	5%	5%	5%
Level 1 tires	85%	95%	-	-	85%	95%	-	-
Level 2 tires	-	-	95%	95%	-	-	95%	95%
Average CRR (kg/ton) [b]	*5.2*	*5.1*	*4.8*	*4.8*	*5.2*	*5.1*	*4.8*	*4.8*
Tire Inflation System								
ATI	85%	95%	95%	95%	85%	95%	95%	95%
Average ATI Reduction (%) [c]	*1.3%*	*1.4%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.4%*
Weight Reduction (pounds)								
Weight [b]	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Notes:
[a] The majority of short box trailers are 28 feet in length. We recognize that they are often operated in tandem, which limits the technologies that can be applied (for example, boat tails). We established standards assuming these shorter trailers were run solo, but projected reduced aerodynamic improvements compared to the longer trailers with similar technologies to reflect their frequent tandem operation.
[b] Combines adoption rates with performance levels shown in Table 2-74
[c] This set of adoption rates did not apply weight reduction to meet the proposed standards for these trailers

Non-box and non-aero box trailers, with two or more work-related special components, are not shown in the tables above. These trailers are projected to adopt tire technologies with zero adoption of aerodynamic technologies. As shown in Table 2-82, we are projecting 100 percent adoption rates of these technologies at each stage of the program, which would significantly reduce the compliance burden for manufacturers by reducing the amount of tracking and eliminating the need to run GEM. The agencies are proposing these tire-only requirements in two stages. In 2018 MY, manufacturers would be required to use tires meeting a rolling resistance of Level 2 or better and apply ATI systems on all non-box and non-aero box trailers. In 2024 MY, ATI and LRR tires at a Level 3 or better would be required. The agencies are proposing ATI at all stages of the program.

Table 2-82 Adoption Rates and Average Performance Parameters for the Non-Aero Box and Non-Box Trailers

TECHNOLOGY	NON-AERO BOX & NON-BOX TRAILERS		
Model Year	2018	2021	2024+
Aerodynamic Technologies			
Bin I	100%	100%	100%
Bin II	-	-	-
Bin III	-	-	-
Bin IV	-	-	-
Bin V	-	-	-
Bin VI	-	-	-
Bin VII	-	-	-
Bin VIII	-	-	-
Average Delta CdA (m^2) [a]	*0.0*	*0.0*	*0.0*
Trailer Tire Rolling Resistance			
Baseline tires	-	-	-
Level 1 tires	100%	100%	-
Level 2 tires	-	-	100%
Average CRR (kg/ton) [a]	*5.1*	*5.1*	*4.7*
Tire Inflation System			
ATI	100%	100%	100%
Average ATI Reduction (%) [a]	1.5%	1.5%	1.5%
Weight Reduction (pounds)			
Weight [b]	*0*	*0*	*0*

Notes:
[a] Combines adoption rates with performance levels shown in Table 2-74
[b] This set of adoption rates did not apply weight reduction to meet the proposed standards for these trailers

2.10.4.2 Derivation of the Proposed Standards

The average performance parameters from Table 2-80 and Table 2-81 were applied as input values to the GEM vehicle simulation to derive the proposed HD Phase 2 fuel consumption and CO_2 emissions standards for each subcategory of box trailers.

The proposed standards are shown in Table 2-83. Over the four phases of the proposed rules, box trailers longer than 50 feet would, on average, reduce their CO_2 emissions and fuel consumption by three percent, five percent and seven percent compared to their reference cases for each year in Table 2-79. Box trailers 50-foot and shorter would achieve reductions of two percent, four percent and five percent compared to their reference cases. The tire technologies used on non-box and special purpose box trailers would provide reductions of three percent in the first two stages and achieve four percent by 2027.

Table 2-83 CO_2 Emissions and Fuel Consumption Based on Projected Technology Adoption Rates for Proposed Standards

MODEL YEAR	SUBCATEGORY	DRY VAN		REFRIGERATED VAN	
	Length	Long	Short	Long	Short
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	83	144	84	147
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.1532	14.1454	8.2515	14.4401
2021 - 2023	EPA Standard (CO_2 Grams per Ton-Mile)	81	142	82	146
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.9568	13.9489	8.0550	14.3418
2024 - 2026	EPA Standard (CO_2 Grams per Ton-Mile)	79	141	81	144
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.7603	13.8507	7.9568	14.1454
2027 +	EPA Standard (CO_2 Grams per Ton-Mile)	77	140	80	144
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.5639	13.7525	7.8585	14.1454

2.10.4.3 Projected Cost of Proposed Trailer Standards

The agencies evaluated technology costs for 53-foot dry and refrigerated vans and 28-foot dry vans, which we believe are representative of the majority of trailers in the long and short box trailer categories, respectively. Similar tire technology costs were assumed for the non-box trailer subcategory. We identified costs for each technology package evaluated and projected out the costs for each year of the program. A summary of the technology costs is included in Table 2-84 through Table 2-86 for model years 2018, 2021 and 2024, respectively, with additional details available in Chapter 2.12. Costs shown in the following tables are for the specific model year indicated and are incremental to the average reference case costs, which includes some level of adoption of these technologies as shown in Table 2-77. Therefore, the technology costs in the following tables reflect the average cost expected for each of the indicated trailer subcategories. Note that these costs do not represent actual costs for the individual components, because some fraction of the component costs has been subtracted to reflect some use of these components in the reference case. These costs include indirect costs via markups along with learning impacts and also reflect estimated costs of the compliance process. For more on the estimated technology costs exclusive of adoption rates, refer to Chapter 2.12.

Table 2-84 Trailer Technology Incremental Costs in the 2018 Model Year for the Proposed Alternative (2012 $)

	53-FOOT DRY VAN	53-FOOT REF. VAN	28-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$285	$285	$0	$0
Tires	$65	$65	$78	$185
Tire inflation system	$239	$239	$435	$683
Total	$588	$588	$514	$868

Table 2-85 Trailer Technology Incremental Costs in the 2021 Model Year for the Proposed Alternative (2012 $)

	53-FOOT DRY VAN	53-FOOT REF. VAN	28-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$602	$602	$468	$0
Tires	$65	$65	$79	$175
Tire inflation system	$234	$234	$426	$632
Total	$901	$901	$974	$807

Table 2-86 Trailer Technology Incremental Costs in the 2024 Model Year for the Proposed Alternative (2012 $)

	53-FOOT DRY VAN	53-FOOT REF. VAN	28-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$836	$836	$608	$0
Tires	$61	$61	$76	$160
Tire inflation system	$220	$220	$412	$578
Total	$1,116	$1,116	$1,097	$739

Table 2-87 Trailer Technology Incremental Costs in the 2024 Model Year for the Proposed Alternative (2012 $)

	53-FOOT DRY VAN	53-FOOT REF. VAN	28-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$1,163	$1,034	$788	$0
Tires	$54	$54	$74	$155
Tire inflation system	$192	$192	$391	$549
Total	$1,409	$1,280	$1,253	$704

2.10.5 **Effectiveness and Costs of a More Stringent Trailer Alternative**

The agencies also evaluated a more stringent alternative that considered the same technologies with less lead time. The reference cases from Section 2.10.3.2 apply for this alternative. Additionally, the projected adoption rates for the non-aero box and non-box trailer subcategories remain unchanged in this alternative, so their results are not repeated in this section.

2.10.5.1 Projected Adoption Rates for More Stringent Alternative

From Table 2-88 and Table 2-89, it can be seen that the 2018 MY aerodynamic technology adoption rates and the tire technology adoption rates for all model years are identical to those presented previously for the proposed standards. The aerodynamic projections for 2021 MY and 2024 MY in this more stringent alternative are the same as those projected for 2024 MY and 2027 MY of the proposed standards, but are applied three years earlier. In this alternative, the 2021 MY adoption rates would continue to apply for the partial-aero box trailers in 2024 and later model years.

Table 2-88 Adoption Rates and Average Performance Parameters for the Long Box Trailers in the More Stringent Alternative

TECHNOLOGY	LONG BOX DRY VANS			LONG BOX REFRIGERATED VANS		
Model Year	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies [a]						
Bin I	5%	-	-	5%	-	-
Bin II	-	-	-	-	-	-
Bin III	30%	-	-	30%	-	-
Bin IV	60%	25%	-	60%	25%	-
Bin V	5%	10%	10%	5%	10%	20%
Bin VI	-	65%	50%	-	65%	60%
Bin VII	-	-	40%	-	-	20%
Bin VIII	-	-	-	-	-	-
Average Delta CdA (m^2) [a]	*0.4*	*0.8*	*1.1*	*0.4*	*0.8*	*1.0*
Trailer Tire Rolling Resistance						
Baseline tires	15%	5%	5%	15%	5%	5%
Level 1 tires	85%	95%	-	85%	95%	-
Level 2 tires	-	-	95%	-	-	95%
Average CRR (kg/ton) [a]	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*
Tire Inflation System						
ATI	85%	95%	95%	85%	95%	95%
Average ATI Reduction (%) [a]	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*
Weight Reduction (pounds)						
Weight [b]	*0*	*0*	*0*	*0*	*0*	*0*

Notes:
[a] Combines adoption rates with performance levels shown in Table 2-74
[b] This set of adoption rates did not apply weight reduction to meet the proposed standards for these trailers

Table 2-89 Adoption Rates and Average Performance Parameters for the Short Box Trailers in the More Stringent Alternative

TECHNOLOGY	SHORT BOX DRY VANS			SHORT BOX REFRIGERATED VANS		
Model Year	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies [a]						
Bin I	100%	-	-	100%	-	-
Bin II	-	70%	30%	-	70%	55%
Bin III	-	30%	60%	-	30%	40%
Bin IV	-	-	10%	-	-	5%
Bin V	-	-	-	-	-	-
Bin VI	-	-	-	-	-	-
Bin VII	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-
Average Delta CdA (m^2) [b]	*0.4*	*0.8*	*1.1*	*0.4*	*0.8*	*1.0*
Trailer Tire Rolling Resistance						
Baseline tires	15%	5%	5%	15%	5%	5%
Level 1 tires	85%	95%	-	85%	95%	-
Level 2 tires	-	-	95%	-	-	95%
Average CRR (kg/ton) [b]	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*
Tire Inflation System						
ATI	85%	95%	95%	85%	95%	95%
Average ATI Reduction (%) [b]	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*
Weight Reduction (pounds)						
Weight [c]	*0*	*0*	*0*	*0*	*0*	*0*

Notes:
[a] The majority of short box trailers are 28 feet in length. We recognize that they are often operated in tandem, which limits the technologies that can be applied (for example, boat tails). We established standards assuming these shorter trailers were run solo, but projected reduced aerodynamic improvements compared to the longer trailers with similar technologies to reflect their frequent tandem operation.
[b] Combines adoption rates with performance levels shown in Table 2-74
[c] This set of adoption rates did not apply weight reduction to meet the proposed standards for these trailers

2.10.5.2 Derivation of the More Stringent Alternative Standards

Similar to the proposed standards of Section 2.10.4.2, the agencies applied the technology performance values from Table 2-88 and Table 2-89 as GEM inputs to derive the proposed standards for each subcategory.

Table 2-90 shows the resulting standards for the more stringent alternative. Over the three phases of the alternative, box trailers longer than 50 feet would, on average, reduce their CO_2 emissions and fuel consumption by four percent, six percent and eight percent. Box trailers 50-foot and shorter would achieve reductions of two percent, four percent, and five percent compared to the reference case. Partial-aero box trailers would continue to be subject to the 2021 MY standards for MY 2024 and later. The non-aero box and non-box trailers would meet the same standards and achieve the same three and four percent benefits as shown in the proposed alternative.

Table 2-90 Trailer CO_2 and Fuel Consumption Standards for Box Trailers in the More Stringent Alternative

MODEL YEAR	SUBCATEGORY	DRY VAN		REFRIGERATED VAN	
	Length	Long	Short	Long	Short
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	83	144	84	147
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.1532	14.1454	8.2515	14.4401
2021 - 2023	EPA Standard (CO_2 Grams per Ton-Mile)	80	142	81	145
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.8585	13.9489	7.9568	14.2436
2024 +	EPA Standard (CO_2 Grams per Ton-Mile)	77	140	80	144
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.5639	13.7525	7.8585	14.1454

2.10.5.3 Projected Cost of the More Stringent Trailer Alternative

A summary of the technology costs is included in Table 2-91 to Table 2-93 for MYs 2018, 2021 and 2024, with additional details available in Chapter 2.12. Costs shown in the following tables are for the specific model year indicated and are incremental to the average reference case costs, which includes some level of adoption of these technologies as shown in Table 2-77. Therefore, the technology costs in the following tables reflect the average cost expected for each of the indicated trailer classes. Note that these costs do not represent actual costs for the individual components because some fraction of the component costs has been subtracted to reflect some use of these components in the reference case. For more on the estimated technology costs exclusive of adoption rates, refer to Chapter 2.12 of this draft RIA. These costs include indirect costs via markups along with learning impacts. It can be seen that, despite the similar stringencies for MY 2024 of this more stringent alternative and MY 2027 of the proposed alternative, the costs shown below are slightly higher. The lower cost in the proposed MY 2027 can be partially attributed to the reduced costs due to three years of additional learning. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to the draft RIA Chapter 2.12.

Table 2-91 Trailer Technology Incremental Costs in the 2018 Model Year for the More Stringent Alternative (2012$)

	>50-FOOT DRY VAN	>50-FOOT REF. VAN	<35-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$285	$285	$0	$0
Tires	$65	$65	$78	$185
Tire inflation system	$239	$239	$435	$683
Total	$588	$588	$514	$868

Table 2-92 Trailer Technology Incremental Costs in the 2021 Model Year for the More Stringent Alternative (2012$)

	>50-FOOT DRY VAN	>50-FOOT REF. VAN	<35-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$908	$908	$641	$0
Tires	$65	$65	$79	$175
Tire inflation system	$234	$234	$426	$632
Total	$1,207	$1,207	$1,146	$807

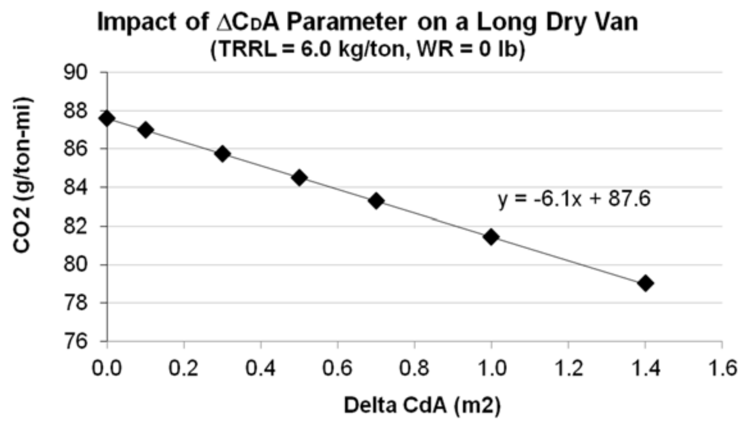
Table 2-93 Trailer Technology Incremental Costs in the 2024 Model Year for the More Stringent Alternative (2012$)

	>50-FOOT DRY VAN	>50-FOOT REF. VAN	<35-FOOT DRY VAN	NON-BOX HIGHWAY
Aerodynamics	$1,223	$1,090	$816	$0
Tires	$61	$61	$76	$160
Tire inflation system	$220	$220	$412	$578
Total	$1,504	$1,371	$1,304	$739

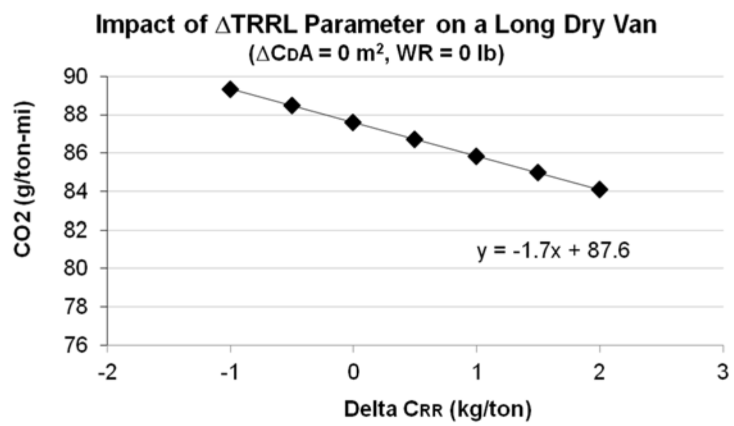
2.10.6 **Evaluation of Compliance Option using GEM-Based Equation**

EPA created the Greenhouse gas Emissions Model (GEM) as a compliance tool for heavy-duty vehicles. Users provide specific performance parameters to the model and GEM calculates CO_2 emissions and fuel consumption results. As described previously, the proposed Phase 2 GEM is designed to accept four performance variables as trailer inputs: change in drag area (delta C_DA), tire rolling resistance level (TRRL), automatic tire inflation (ATI) and weight reduction (WR). The reduction applied when using an automatic tire inflation system is accounted for after the vehicle simulation is complete. The other performance parameters directly impact the results of the vehicle simulation, by changing the drag, rolling resistance and weight of the simulated vehicle.

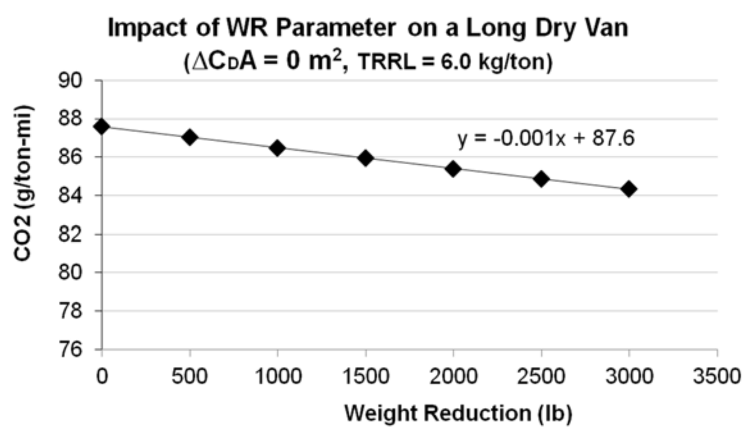
We performed a sensitivity analysis for delta C_DA, TRRL and WR to evaluate their effect on the model's results. In the analysis to follow, all of the calculations are shown in terms of CO_2 emissions; use a conversion of 10,180 grams CO_2 per gallon of diesel fuel to calculate the corresponding fuel consumption values. Figure 2-23 through Figure 2-26 show GEM's CO_2 results for a parameter sweep of a simulated Class 8 tractor pulling each of the four box van trailers. It can be seen that each of the three parameters has a linear impact on CO_2 emissions. A curve fit was applied to each data set and the equation is displayed on each plot. The intercept in each parameter sweep data set is the baseline CO_2 result considering a zero-technology trailer, and this value is consistent for all parameters for a given trailer. The coefficients indicate the relationship between the assessed parameter and the model's CO_2 result.



(a)

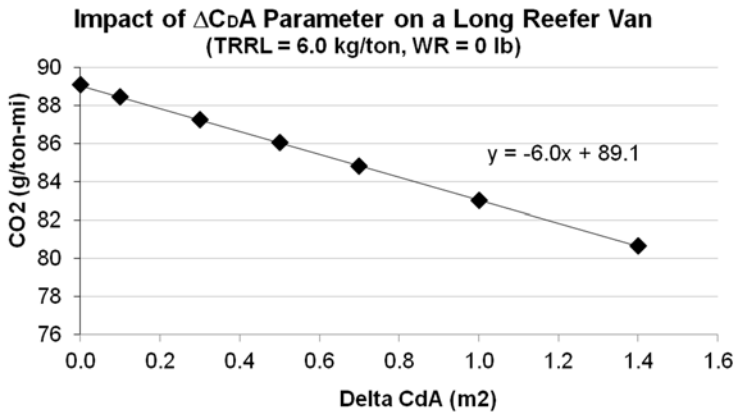


(b)

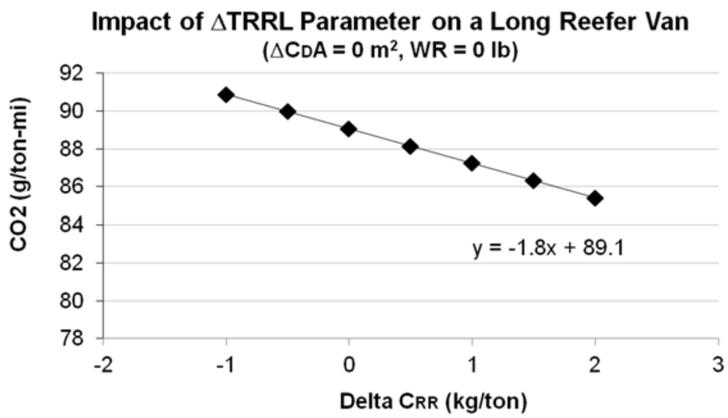


(c)

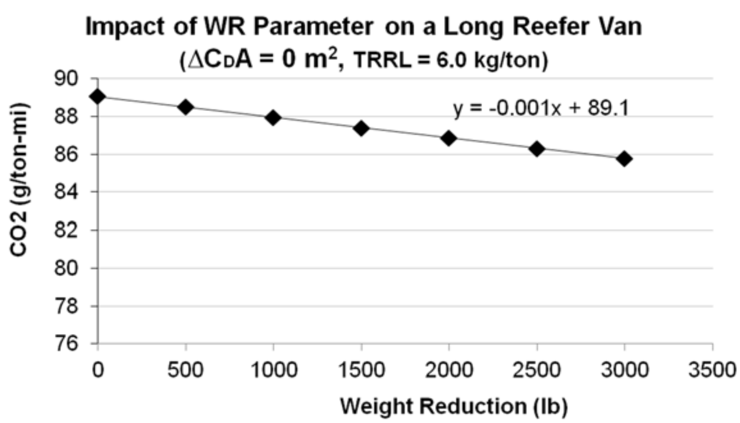
Figure 2-23 Impact of (a) Delta C_DA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Long Dry Van



(a)

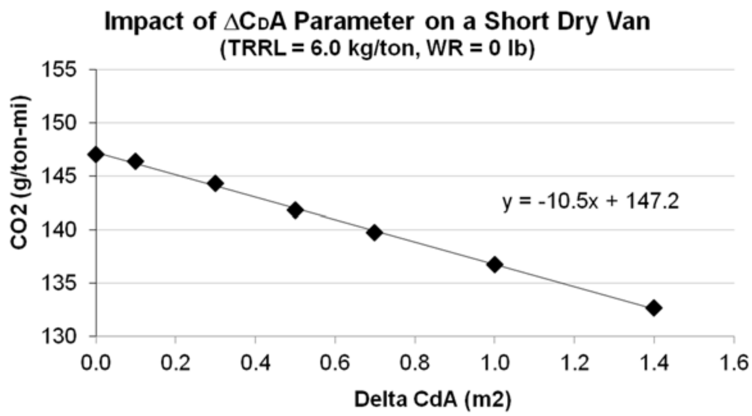


(b)

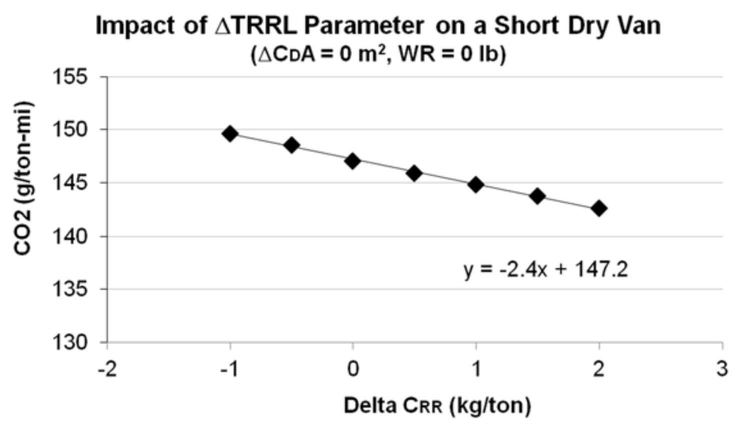


(c)

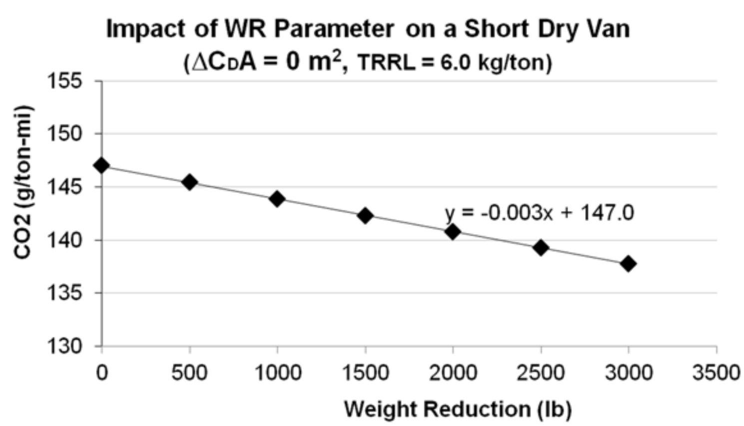
Figure 2-24 Impact of (a) Delta C_DA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Long Refrigerated Van



(a)

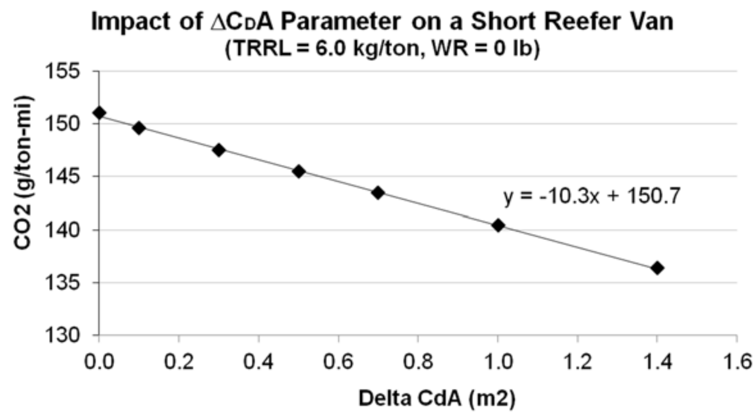


(b)

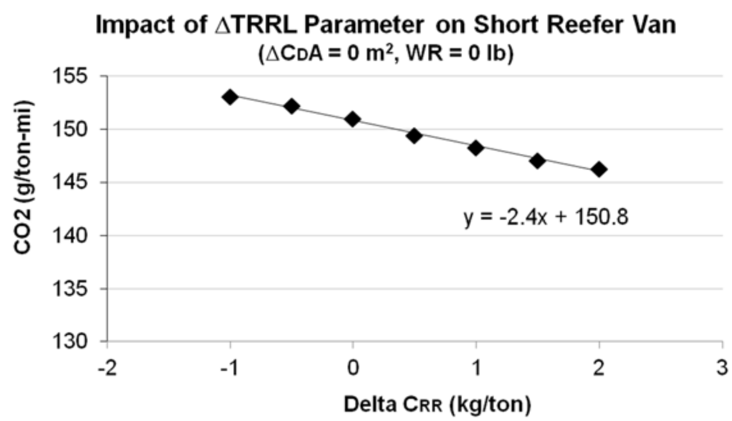


(c)

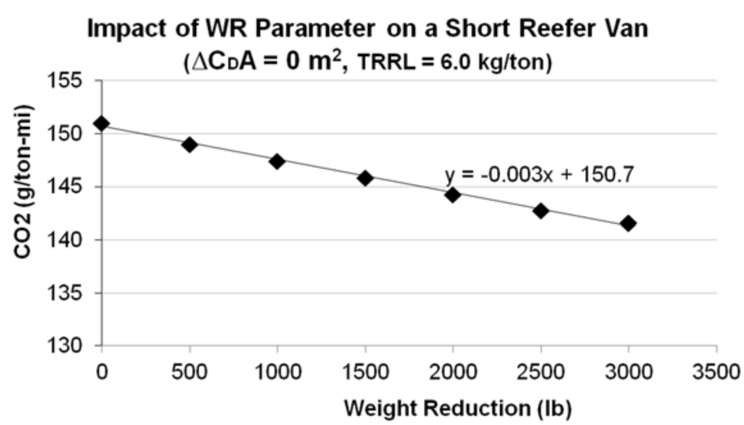
Figure 2-25 Impact of (a) Delta C_DA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Short Dry Van



(a)



(b)



(c)

Figure 2-26 Impact of (a) Delta C_DA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Short Refrigerated Van

Additional GEM simulations were performed for each of the four box trailer subcategories to assess the combined effect of these parameters. As seen in Figure 2-27 and Figure 2-28 for the long dry van simulation, the coefficients of the curve fit equations did not change, indicating that the combined impacts of these parameters on GEM's CO_2 results were additive. Similar trends were seen with the simulations for the other trailer subcategories, though the results are not shown here.

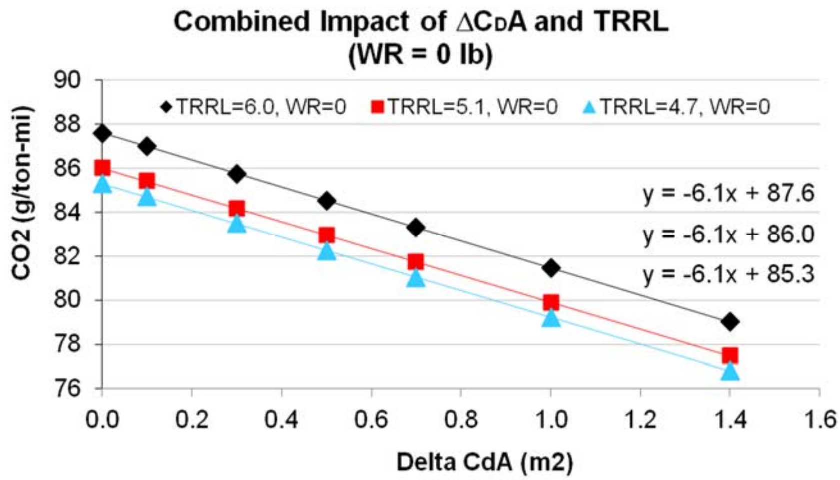


Figure 2-27 Combined Impact of Drag Area and Tire Rolling Resistance Level on CO_2 Results of a GEM-Simulated Long Dry Van with No Weight Reduction

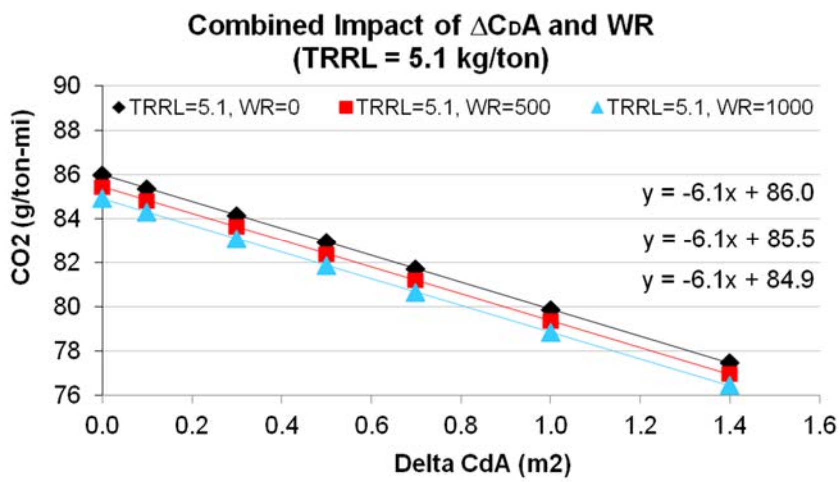


Figure 2-28 Combined Impact of Drag Area and Weight Reduction on CO_2 Results of a GEM-Simulated Long Dry Van at a Tire Rolling Resistance Level of 5.1 kg/ton

The results presented Figure 2-27 and Figure 2-28 suggest that these parameters could be combined into a single equation to calculate CO_2 emissions. Equation 1 is the result of combining the curve fit equations for long box dry vans.

$$y = 87.6 - 6.1(\Delta C_D A) - 1.7(\Delta TRRL) - 0.001(WR) \quad (1)$$

Our proposed regulations specify that TRRL be an absolute measure of a tire's coefficient of rolling resistance (not a *change* in rolling resistance). As a result, Equation 1 was modified such that the variables of the equation matched the trailer inputs required by GEM. Equation 2 is the resulting equation.

$$y = 77.4 - 6.1(\Delta C_D A) + 1.7(TRRL) - 0.001(WR) \quad (2)$$

Each of the trailer subcategories follows the same general format and a generic equation is shown in Equation 3. Table 2-94 summarizes the corresponding constants for each of the trailer subcategories.

$$e_{CO2} = C_1 + C_2(\Delta C_D A) + C_3(TRRL) + C_4(WR) \quad (3)$$

Table 2-94 Constants for GEM-Based CO_2 Equation for Trailer Subcategories (See Equation 3)

TRAILER SUBCATEGORY	C_1	C_2	C_3	C_4
Long Dry Van	77.4	-6.1	1.7	-0.001
Long Refrigerated Van	78.3	-6.0	1.8	-0.001
Short Dry Van	134.0	-10.5	2.2	-0.003
Short Refrigerated Van	136.3	-10.3	2.4	-0.003

Over 100 GEM vehicle simulations were performed for a range of delta $C_D A$, TRRL and weight reduction values. The results of these simulations were compared to CO_2 results calculated using Equation 3 for each trailer subcategory. The following figures show the equation and GEM have nearly identical CO_2 results.

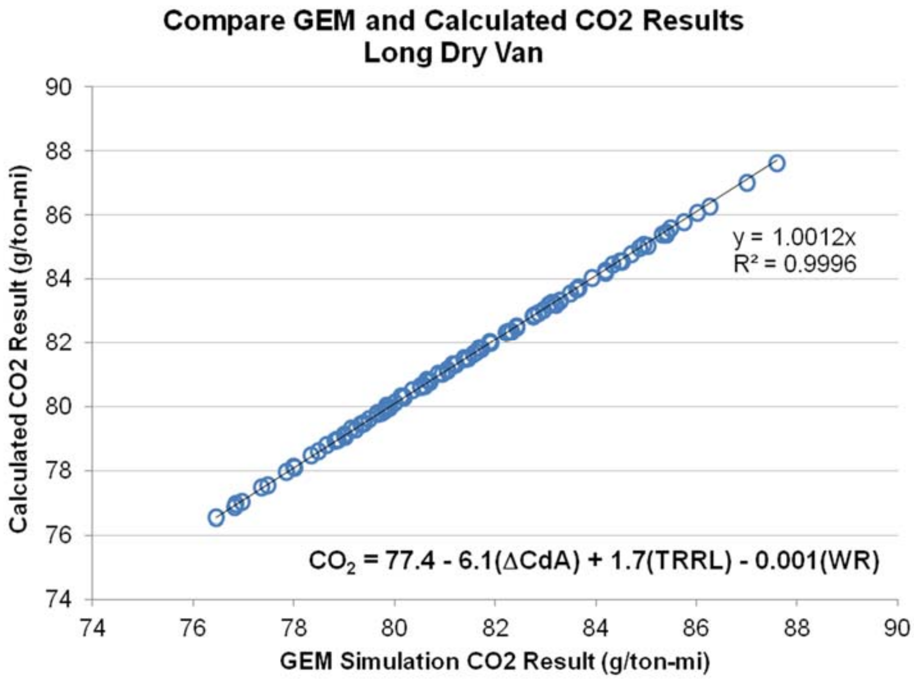


Figure 2-29 Comparison of GEM and Calculated CO_2 Results for a Long Dry Van

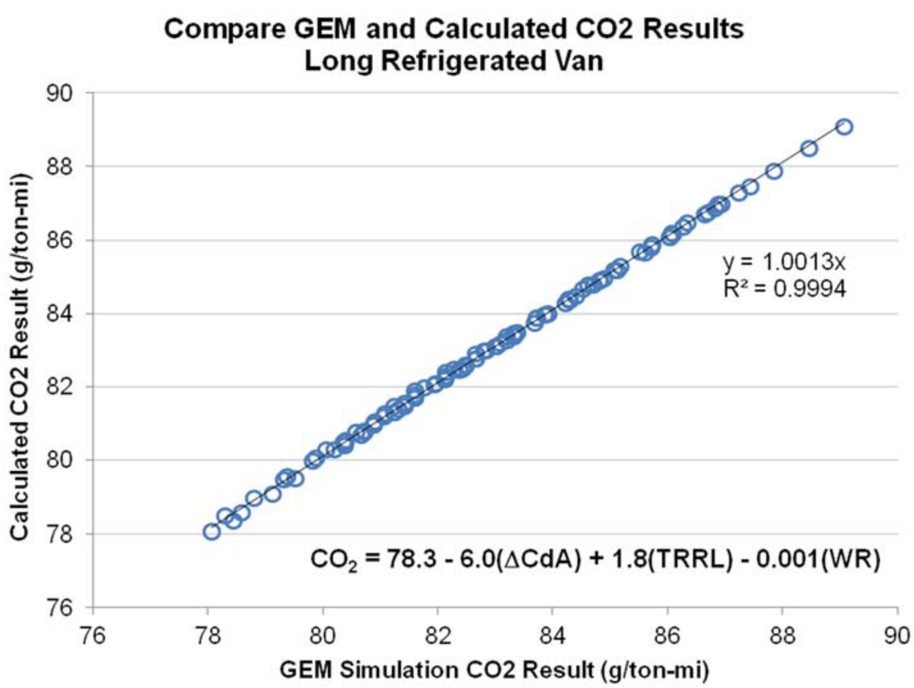


Figure 2-30 Comparison of GEM and Calculated CO_2 Results for a Long Refrigerated Van

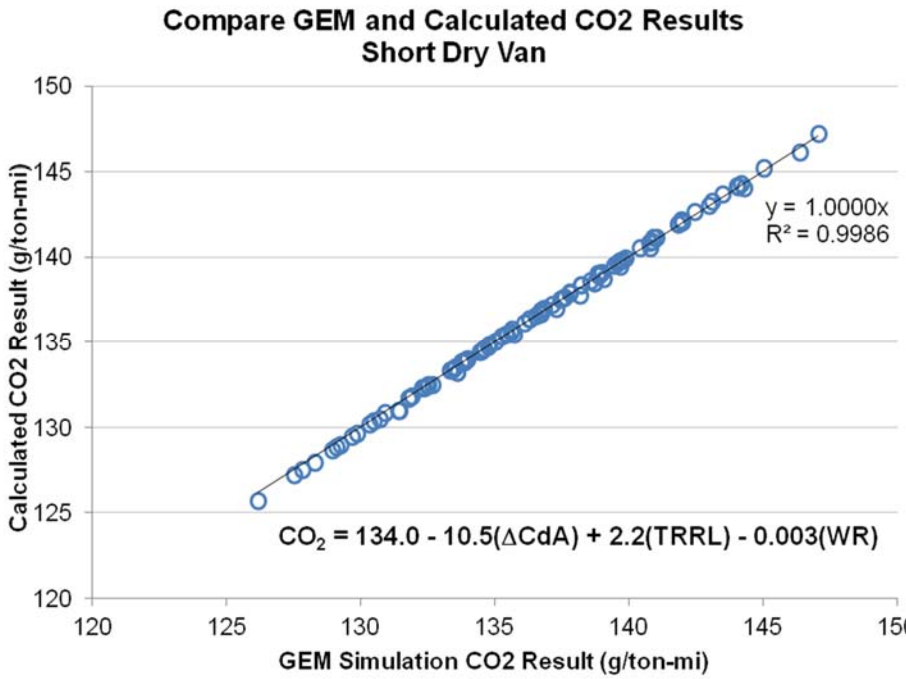


Figure 2-31 Comparison of GEM and Calculated CO_2 Results for a Short Dry Van

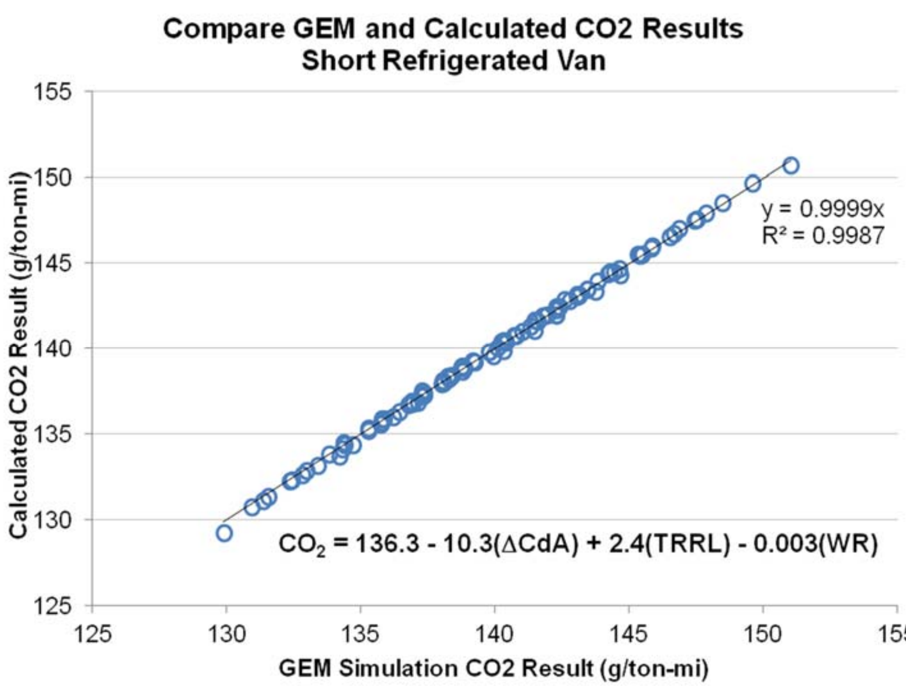


Figure 2-32 Comparison of GEM and Calculated CO_2 Results for a Short Refrigerated Van

The comparisons shown in Figure 2-29 through Figure 2-32 suggest that an equation may offer a simplified approach for trailer manufacturers to calculate CO_2 without the use of GEM. Equation 4 below is a slight modification to Equation 3. The constants shown in Table 2-94 and used in Equation 3 were rearranged slightly to place the tire rolling resistance effect at the beginning of the equation, since we anticipate most trailers would adopt LRR tires. Equation 4 and the corresponding Table 2-95 illustrate the rearrangement. As mentioned previously, the proposed trailer program is also offering the use of automatic tire inflation (ATI) systems as a means achieving the proposed standards. This parameter is not considered in Equation 3. Equation 4 includes a constant, C_5, to address the use of ATI. Constant C_5 is equal to unity for trailers that do not have ATI systems installed and equal to 0.985 (accounting for the 1.5% reduction assigned to ATI) for trailers that do include ATI systems. As mentioned previously, one can use a conversion factor of 10,180 grams CO_2 per gallon of diesel fuel to calculate the corresponding fuel consumption values.

$$e_{CO2} = [C_1 + C_2 \cdot (TRRL) + C_3 \cdot (\Delta C_D A) + C_4 \cdot (WR)] \cdot C_5 \quad (4)$$

Table 2-95 Constants for GEM-Based CO_2 Equation for Trailer Subcategories (See Equation 4)

TRAILER SUBCATEGORY	C_1	C_2	C_3	C_4
Long Dry Van	77.4	1.7	-6.1	-0.001
Long Refrigerated Van	78.3	1.8	-6.0	-0.001
Short Dry Van	134.0	2.2	-10.5	-0.003
Short Refrigerated Van	136.3	2.4	-10.3	-0.003

2.11 Natural Gas

2.11.1 Sealed Crankcase

EPA regulations allow venting to the atmosphere crankcase emissions from compression-ignition engines, provided these vented crankcase emissions are measured and accounted for as part of an engine's tailpipe emissions. This allowance has historically been in place to address the technical limitations related to recirculating diesel-fueled engines' crankcase emissions, which have high PM emissions, back into the engine's air intake. High PM emissions vented into the intake of an engine can foul turbocharger compressors and after-cooler heat exchangers. In contrast, historically EPA has mandated closed crankcase technology on all gasoline-fueled engines and all natural gas engines certified as spark-ignition. The inherently low PM emissions from these engines posed no technical barrier to a closed crankcase mandate. Because natural gas-fueled compression ignition engines also have inherently low PM emissions, there is no technological limitation that would prevent manufacturers from closing the crankcase and recirculating all crankcase gases into a natural gas-fueled compression ignition engine's air intake. It is expected that costs for this requirement would be negligible.

2.11.2 **Require 5 Day Hold Time**

Boil-off emissions from LNG vehicles were not addressed in the Phase 1 rulemaking. However, it is our understanding that the majority or all of the NG vehicles are already compliant with National Fire Protection Association standard NFPA 52 and the similar SAE standard SAE J2343, which are recommended practices for 3 and 5 day hold times, respectively. These are very similar to one another, but the SAE standards calls for more rigorous control. Although these standards were developed largely to address fire safety issues (boil-off emissions can lead to explosive mixtures in enclosed spaces), it is clear that following the industry recommended practice spelled out in SAE J2343 for five day hold time would substantially limit boil-off emissions from LNG vehicles. Therefore, EPA is proposing to require compliance with SAE J2343 as part of certification for LNG vehicles. Since the majority or all of the NG vehicles are already compliant with these requirements, there would be negligible costs associated with the requirement for 5 day hold time based on the SAE standard practice.

2.12 **Technology Costs**

2.12.1 **Overview of Technology Cost Methodology Learning Effects on Technology Costs**

Section 2.12.1.2 presents the methods used to address indirect costs in this analysis. Section 2.12.1.3 presents the learning effects applied throughout this analysis. In Section 2.12.2 through 2.12.10 we present individual technology costs including: the direct manufacturing costs (DMC), their indirect costs (IC) and their total costs (TC, TC=DMC+IC). Note that we also present technology adoption rates for most technologies and the resultant total cost as applied to a technology package (which we have denoted as TCp, where TCp=TC x Adoption Rate). The tables presented show the adoption rate for, generally, alternatives 1a and 3 where 1a represents the reference case (or the “no action” case) and 3 represents the preferred policy case. For TCp values under alternative 4, one would replace the alternative 3 adoption rates with the appropriate alternative 4 adoption rates to arrive at the TCp costs under alternative 4. Note also that some TCp values appear as negative values in some tables (notably the lower rolling resistance (LRR) tire tables). This is because certain LRR tires are expected in the reference case but are then expected to be removed in the policy case and replaced by more aggressive LRR tires. In such cases, the reference case tires show negative TCp costs since they are being removed and replaced.

2.12.1.1 Direct Manufacturing Costs

The direct manufacturing costs (DMCs) used throughout this analysis are derived from several sources. Many of the tractor, vocational and trailer DMCs can be sourced to the Phase 1 rules which, in turn, were sourced largely from a contracted study by ICF International for EPA.[163] There was no serious disagreement regarding these estimated costs in the public comments to the Phase 1 rules. We have updated those costs by converting them to 2012 dollars, as described in Section IX.B.1.e of the Preamble, and by continuing the learning effects described in the Phase 1 rules and in Section IX. B.1.c of the Preamble. The new tractor, vocational and trailer costs can be sourced to a more recent study conducted by Southwest Research Institute (SwRI) under contract to NHTSA.[164] The cost methodology used by SwRI in that study was to estimate retail costs then work backward from there to derive a DMC for each technology. The agencies did not agree with the approach used by Tetra Tech to move from retail cost to DMC. As such, the agencies have used an approach consistent with past GHG/CAFE/fuel consumption rules by dividing estimated retail prices by our estimated retail price equivalent markups to derive an appropriate DMC for each technology. We describe our RPEs in Section 2.12.1.2.

For HD pickups and vans, we have relied primarily on the Phase 1 rules and the light-duty 2017-2025 model year rule since most technologies expected on these vehicles are, in effect, the same as those used on light-duty pickups. Many of those technology DMCs are based on cost teardown studies which the agencies consider to be the most robust method of cost estimation. However, many of the HD versions of those technologies would be expected to be more costly than their light-duty counterparts because of the heavier HD vehicles and/or the higher power and torque characteristics of their engines. Therefore, we have scaled upward where appropriate many of the light-duty DMCs for this analysis. We have also used some costs developed under contract to NHTSA by SwRI (the study mentioned above).[165]

Importantly, in our methodology, all technologies are treated as being sourced from a supplier rather than being developed and produced in-house. As such, some portion of the total indirect costs of making a technology or system—those costs incurred by the supplier for research, development, transportation, marketing etc.—are contained in the sales price to the engine and/or vehicle/trailer manufacturer (i.e., the original equipment manufacturer (OEM)). That sale price paid by the OEM to the supplier is the DMC we estimate.

2.12.1.2 Indirect Costs

To produce a unit of output, engine and truck manufacturers incur direct and indirect costs. Direct costs include cost of materials and labor costs. Indirect costs are all the costs associated with producing the unit of output that are not direct costs – for example, they may be related to production (such as research and development [R&D]), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Indirect costs are generally recovered by allocating a share of the costs to each unit of good sold. Although it is possible to account for direct costs allocated to each unit of good sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To make a cost analysis process more feasible, markup factors, which relate total indirect costs to total direct costs, have been developed. These factors are often referred to as retail price equivalent (RPE) multipliers.

Cost analysts and regulatory agencies (including both EPA and NHTSA) have frequently used these multipliers to predict the resultant impact on costs associated with manufacturers' responses to regulatory requirements. The best approach, if it were possible, to determining the impact of changes in direct manufacturing costs on a manufacturer's indirect costs would be to actually estimate the cost impact on each indirect cost element. However, doing this within the constraints of an agency's time or budget is not always feasible, or the technical, financial, and accounting information to carry out such an analysis may simply be unavailable.

RPE multipliers provide, at an aggregate level, the relative shares of revenues (Revenue = Direct Costs + Indirect Costs + Net Income) to direct manufacturing costs. Using RPE multipliers implicitly assumes that incremental changes in direct manufacturing costs produce common incremental changes in all indirect cost contributors as well as net income. However, a concern in using the RPE multiplier in cost analysis for new technologies added in response to regulatory requirements is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel and the indirect costs attributable to those personnel. The use of RPEs, with their assumption that all technologies have the same proportion of indirect costs, is likely to overestimate the costs of less complex technologies and underestimate the costs of more complex technologies. Table 2-96 shows the RPE factors used in developing indirect costs in past, and this, agency analyses.

Table 2-96 Industry Retail Price Equivalent (RPE) Factors

INDUSTRY	RPE
Heavy engine manufacturers	1.28
Heavy truck manufacturers	1.36
Light-duty vehicle manufacturers	1.50

To address this concern, modified multipliers have been developed by EPA, working with a contractor, for use in rulemakings. These multipliers are referred to as indirect cost multipliers (or ICMs). In contrast to RPE multipliers, ICMs assign unique incremental changes to each indirect cost contributor as well as net income.

$$ICM = (\text{direct cost} + \text{adjusted indirect cost})/(\text{direct cost})$$

Developing the ICMs from the RPE multipliers requires developing adjustment factors based on the complexity of the technology and the time frame under consideration: the less complex a technology, the lower its ICM, and the longer the time frame for applying the technology, the lower the ICM. This methodology was used in the cost estimation for the recent light-duty MYs 2012-2016 and MYs 2017-2025 rulemaking and for the heavy-duty MYs 2014-2018 rulemaking. There was no serious disagreement with this approach in the public comments to any of these rulemakings. The ICMs for the light-duty context were developed in a peer-reviewed report from RTI International and were subsequently discussed in a peer-reviewed journal article.[166] Importantly, since publication of that peer-reviewed journal article, the agencies have revised the methodology to include a return on capital (i.e., profits) based on the assumption implicit in ICMs (and RPEs) that capital costs are proportional to direct costs, and businesses need to be able to earn returns on their investments.

For the heavy-duty pickup truck and van cost projections in this proposal, the agencies have used ICM adjustment factors developed for light-duty vehicles, inclusive of a return on capital, primarily because the manufacturers involved in this segment of the heavy-duty market are the same manufacturers that build light-duty trucks.

For the combination tractors, vocational vehicles, and heavy-duty engine cost projections in this proposal, the agencies are again using the ICMs used in the HD Phase 1 rules. Those ICMs were developed by RTI International under EPA contract to update EPA's methodology for accounting for indirect costs associated with changes in direct manufacturing costs for heavy-duty engine and truck manufacturers.[167] In addition to the indirect cost contributors varying by complexity and time frame, there is no reason to expect that the contributors would be the same for engine manufacturers as for truck manufacturers. The resulting report from RTI provides a description of the methodology, as well as calculations of the indirect cost multipliers that are being used as the basis for the markups used in this proposal. These indirect cost multipliers were used, along with calculations of direct manufacturing costs, to provide estimates of the full additional costs associated with new technologies.

As explained in the Phase 1 final rules, and entirely consistent with the analysis supporting that program, the agencies have made some changes to both the ICMs factors and to the method of applying those factors relative to the factors developed by RTI and presented in their reports. The first of these changes was done in response to continued thinking among the agencies about how past ICMs have been developed and what are the most appropriate data sources to rely upon in determining the appropriate ICMs. The second change was done in response to both staff concerns and public feedback suggesting that the agencies were inappropriately applying learning effects to indirect costs via the multiplicative approach to applying the ICMs.

Regarding the first change – to the ICM factors themselves – a little background must first be provided. In the original work done under contract to EPA by RTI International,[168] EPA experts had undergone a consensus approach to determining the impact of specific technology changes on the indirect costs of a company. Subsequent to that effort, EPA experts underwent a blind survey to make this determination on a different set of technology changes. This subsequent effort, referred to by EPA as a modified-Delphi approach, resulted in different ICM determinations. This effort is detailed in a memorandum contained in the docket for this rulemaking.[169] Upon completing this effort, EPA determined that the original RTI values should be averaged with the modified-Delphi values to arrive at the final ICMs for low and medium complexity technologies and that the original RTI values would be used for high complexity level 1 while the modified-Delphi values would be used for high complexity level 2. These final ICMs were used in the 2012-2016 light-duty GHG/CAFE rulemaking. Subsequent to that, EPA contracted RTI to update their light-duty report with an eye to the heavy-duty industry. In that effort, RTI determined the RPE of both the heavy-duty engine and heavy truck industries, then applied the light-duty indirect cost factors—those resulting from the averaging of the values from their original report with the modified-Delphi values—to the heavy-duty RPEs to arrive at heavy-duty specific ICMs. That effort is described in their final heavy-duty ICM report mentioned above.[170]

During development of the Phase 1 heavy-duty final rules, the agencies decided that the original light-duty RTI values, given the technologies considered for low and medium complexity, should no longer be used and that we should rely solely on the modified-Delphi values for these complexity levels. The original light-duty RTI study used low rolling resistance tires as a low complexity technology example and a dual clutch transmission as a medium complexity technology. Upon further thought, the technologies considered for the modified

Delphi values (passive aerodynamic improvements for low complexity and turbocharging with downsizing for medium complexity were considered to better represent the example technologies). As a result, the modified-Delphi values were to become the working ICMs for low and medium complexity rather than averaging those values with the original RTI report values. The agencies have also re-examined the technology complexity categories that were assigned to each light-duty technology and modified these assignments to better reflect the technologies that are now used as proxies for each category. This decision impacted the low and medium complexity heavy-duty ICMs too because the modified-Delphi values alone were to be applied to the heavy-duty RPEs to arrive at heavy-duty ICMs rather than using the averaged values developed for the light-duty 2012-2016 rulemaking.

A secondary-level change was also made as part of this ICM recalculation to the light-duty ICMs and, therefore, to the ICMs used in the Phase 1 HD final rules and again in this proposed analysis for HD pickups and vans. That change was to revise upward the RPE level reported in the original RTI report from an original value of 1.46 to 1.5 to reflect the long term average RPE. The original RTI study was based on 2008 data. However, an analysis of historical RPE data indicates that, although there is year to year variation, the average RPE has remained roughly 1.5. ICMs are applied to future year's data and therefore the agencies believed and continue to believe that it is most appropriate to base ICMs on the historical average rather than a single year's result. Therefore, ICMs were adjusted to reflect this average level. As a result, the High 1 and High 2 ICMs used for HD pickups and vans were changed for the Phase 1 final rules and we continue to use those changed values here.

Table 2-97 shows the ICM values used in this proposal. Near term values are used in early years, depending on the technology, and account for differences in the levels of R&D, tooling, and other indirect costs that would be incurred. Once the program has been fully implemented, some of the indirect costs would no longer be attributable to the standards and, as such, a lower ICM factor is applied to direct costs in later years.

Table 2-97 Indirect Cost Multipliers Used in this Analysis[a]

CLASS	COMPLEXITY	NEAR TERM	LONG TERM
HD Pickup Trucks and Vans	Low	1.24	1.19
	Medium	1.39	1.29
	High1	1.56	1.35
	High2	1.77	1.50
Loose diesel engines	Low	1.15	1.13
	Medium	1.24	1.18
	High1	1.28	1.19
	High2	1.44	1.29
Loose gasoline engines	Low	1.24	1.19
	Medium	1.39	1.29
	High1	1.56	1.35
	High2	1.77	1.50
Vocational Vehicles, Combination Tractors and Trailers	Low	1.18	1.14
	Medium	1.30	1.23
	High1	1.43	1.27

	High2	1.57	1.37

Note:
[a] Rogozhin, A., et. al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009); "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Helfand, G., and Sherwood, T., Memorandum dated August 2009; "Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers," Draft Report prepared by RTI International and Transportation Research Institute, University of Michigan, July 2010.

The second change made to the ICMs during development of the Phase 1 final rules had to do with the way in which the ICMs were applied. Until that time, we had applied the ICMs, as done in any analysis that relied on RPEs, as a pure multiplicative factor. This way, a direct manufacturing cost of, say, $100 would have been multiplied by an ICM of 1.24 to arrive at a marked up technology cost of $124. However, as learning effects (discussed below) are applied to the direct manufacturing cost, the indirect costs are also reduced accordingly. Therefore, in year 2 the $100 direct manufacturing cost might reduce to $97 and the marked up cost would become $120 ($97 x 1.24). As a result, indirect costs have been reduced from $24 to $23. Given that indirect costs cover many things such as facility-related costs, electricity, etc., it is perhaps not appropriate to apply the ICM to the learned direct costs, at least not for those indirect cost elements unlikely to change with learning. The agencies decided that it was more appropriate only to allow warranty costs to decrease with learning since warranty costs are tied to direct manufacturing costs (since warranty typically involves replacement of actual parts which should be less costly with learning).[Q] However, the remaining elements of the indirect costs should remain constant year-over-year, at least until some of those indirect costs are no longer attributable to the rulemaking effort that imposed them (such as R&D).

As a result, the ICM calculation became more complex with the analysis supporting the Phase 1 final rules, and we continue to use that more complex calculation here. We first establish the year in which the direct manufacturing costs are considered "valid." For example, a cost estimate might be considered valid today, or perhaps not until high volume production is reached in some future model year. That year is considered the base year for the estimated cost. That cost is the cost used to determine the "non-warranty" portion of the indirect costs. For example, the near term non-warranty portion of the loose diesel engine low complexity ICM is 0.149 (the warranty versus non-warranty portions of the ICMs are shown in Table 2-98). For the improved water pump technology we have estimated a direct manufacturing cost of $82.66 (2012$) in MY 2014. So the non-warranty portion of the indirect costs would be $12.32 ($82.66 x 0.149). This value would be added to the learned direct manufacturing cost for each year through 2022 since the near term markup is considered appropriate for that technology through 2022. Beginning in 2023, when long-term indirect costs begin, the additive factor would become $10.08 ($82.66 x 0.122). Additionally, the $82.66 cost in 2014 would become $80.18 in MY 2015 due to learning ($82.66 x (1-3 percent)). So, while the warranty portion of the indirect costs would be $0.49 ($82.66 x 0.006) in 2014, they would decrease to $0.48 ($80.18 x 0.006) in 2015 as warranty costs decrease with learning. The resultant indirect costs for the water pump

[Q] We note that the labor portion of warranty repairs does not decrease due to learning. However, we do not have data to separate this portion and so we apply learning to the entire warranty cost. Because warranty costs are a small portion of overall indirect costs, this has only a minor impact on the analysis.

would be $12.81 ($12.32+$0.49) in MY 2014 and $12.80 ($12.32+$0.48) in MY2015, and so on for subsequent years.

Importantly, since the bulk of the indirect costs calculated using this methodology are the non-warranty costs, and since those costs do not change over with learning, one cannot look at the ICMs shown in Table 2-97 and assume that our HD pickup and van total costs are, in general, 1.24 or 1.39 times the direct costs (since most technologies considered for application in HD pickups and vans are low and medium technologies). This can be illustrated by building on the example presented above for a water pump on a heavy diesel engine. We already calculated the MY 2014 total cost as $95.46 (2012$, $82.66+$12.32+$0.49). This is an effective markup of 1.155 ($95.46/$82.66). This is expected since the cost is based in 2014 and the near term ICM is 1.155. In MY2022, the final year of near term markups for this technology, the total cost would be $80.21 since the learned direct cost has reduced to $67.50, the non-warranty indirect costs (calculated above) remain $12.32, and the warranty indirect costs have become $0.39 ($67.50x0.006). So, in MY2022, we now have an effective markup of 1.19 ($80.21/$67.50).

Table 2-98 Warranty and Non-Warranty Portions of ICMs

		SHORT-TERM		LONG-TERM	
CLASS	COMPLEXITY	WARRANTY	NON-WARRANTY	WARRANTY	NON-WARRANTY
HD Pickup and Vans	Low	0.012	0.230	0.005	0.187
	Medium	0.045	0.343	0.031	0.259
	High1	0.065	0.499	0.032	0.314
	High2	0.074	0.696	0.049	0.448
Loose diesel engines	Low	0.006	0.149	0.003	0.122
	Medium	0.022	0.213	0.016	0.165
	High1	0.032	0.249	0.016	0.176
	High2	0.037	0.398	0.025	0.265
Loose gasoline engines	Low	0.012	0.230	0.005	0.187
	Medium	0.045	0.343	0.031	0.259
	High1	0.065	0.499	0.032	0.314
	High2	0.074	0.696	0.049	0.448
Vocational Vehicles, Combination Tractors and Trailers	Low	0.013	0.165	0.006	0.134
	Medium	0.051	0.252	0.035	0.190
	High1	0.073	0.352	0.037	0.233
	High2	0.084	0.486	0.056	0.312

The complexity levels and subsequent ICMs applied throughout this analysis for each technology are shown in Table 2-99.

Table 2-99 Indirect Cost Markups and Near Term/Long Term Cutoffs Used in this Analysis

TECHNOLOGY	APPLIED TO	ICM COMPLEXITY	NEAR TERM THRU
Cylinder head improvements 1	LH/MH/HH Engines	Low	2022
Cylinder head improvements 2	LH/MH/HH Engines	Low	2027
Turbo efficiency improvements 1	LH/MH/HH, HD Pickup & Van Engines	Low	2022
Turbo efficiency improvements 2	LH/MH/HH Engines	Low	2027
EGR cooler efficiency improvements 1	LH/MH/HH Engines	Low	2022

EGR cooler efficiency improvements 2	LH/MH/HH Engines	Low	2027
Water pump improvements 1	LH/MH/HH Engines	Low	2022
Water pump improvements 2	LH/MH/HH Engines	Low	2027
Oil pump improvements 1	LH/MH/HH Engines	Low	2022
Oil pump improvements 2	LH/MH/HH Engines	Low	2027
Fuel pump improvements 1	LH/MH/HH Engines	Low	2022
Fuel pump improvements 2	LH/MH/HH Engines	Low	2027
Fuel rail improvements 1	LH/MH/HH Engines	Low	2022
Fuel rail improvements 2	LH/MH/HH Engines	Low	2027
Fuel injector improvements 1	LH/MH/HH Engines	Low	2022
Fuel injector improvements 2	LH/MH/HH Engines	Low	2027
Piston improvements 1	LH/MH/HH Engines	Low	2022
Piston improvements 2	LH/MH/HH Engines	Low	2027
Valve train friction reductions 1	LH/MH/HH Engines	Low	2022
Valve train friction reductions 2	LH/MH/HH Engines	Low	2027
Turbo compounding 1	LH/MH/HH Engines	Low	2022
Turbo compounding 2	LH/MH/HH Engines	Low	2027
Aftertreatment improvements 1	LH/MH/HH Engines	Low	2022
Aftertreatment improvements 2	LH/MH/HH Engines	Low	2024
Model based control	LH/MH/HH Engines	Low	2022
Waste heat recovery	HH Engines	Medium	2025
Engine friction reduction 1	HD Pickup & Van Engines	Low	2018
Engine friction reduction 2	HD Pickup & Van Engines	Low	2024
Engine changes to accommodate low friction lubes	HD Pickup & Van Engines	Low	2018
Variable valve timing – coupled	HD Pickup & Van Engines	Low	2018
Variable valve timing – dual	HD Pickup & Van Engines	Medium	2018
Stoichiometric gasoline direct injection	HD Pickup & Van Engines	Medium	2018
Cylinder deactivation	HD Pickup & Van Engines	Medium	2018
Cooled EGR	HD Pickup & Van Engines	Medium	2024
Turbocharging & downsizing	HD Pickup & Van Engines	Medium	2018
"Right sized" diesel engine	HD Pickup & Van vehicles, Tractors	Low	2022
6 speed transmission	HD Pickup & Van vehicles	Medium	2018
8 speed transmission	HD Pickup & Van vehicles, Vocational	Medium	2018
Automated manual transmission (AMT)	Vocational, Tractors	Medium	2022
Auto transmission, power-shift	Tractors	Medium	2022
Conversion from manual to auto trans	Vocational	Medium	2018
Dual clutch transmission	Vocational, Tractors	Medium	2022
Improved transmission	Vocational	Low	2022
Lower RR tires 1	HD Pickup & Van vehicles	Low	2018
Lower RR tires 2	HD Pickup & Van vehicles	Low	2024
Low drag brakes	HD Pickup & Van vehicles	Low	2018
Electric power steering	HD Pickup & Van vehicles	Low	2018
High efficiency transmission	HD Pickup & Van vehicles	Low	2024
Driveline friction reduction	HD Pickup & Van vehicles	Low	2022
Improved accessories (electrification)	HD Pickup & Van vehicles	Low	2018
Improved accessories (electrification)	Tractors	Low	2022
Improved fan	Tractors	Low	2022
Lower RR tires 1	Vocational , Tractors, Trailers	Low	2022
Lower RR tires 2	Vocational , Tractors, Trailers	Low	2022
Lower RR tires 3	Vocational , Tractors, Trailers s	Medium	2025
Lower RR tires 4	Vocational , Tractors, Trailers	Medium	2028

Automated Tire Inflation System (ATIS)	Tractors, Trailers	Low	2022
Aero 1	HD Pickup & Van vehicles	Low	2018
Aero 2	HD Pickup & Van vehicles	Medium	2024
Aero Bins 1 thru 4	Tractors	Low	2022
Aero Bin 5 thru 7	Tractors	Medium	2025
Aero Bins 1 thru 8	Trailers	Low	2018
Weight reduction (via single wide tires and/or aluminum wheels)	Tractors	Low	2022
Weight reduction via material changes	HD Pickup & Van vehicles	Low	2018
Weight reduction via material changes – 200 lbs, 400 lbs	Vocational	Low	2022
Weight reduction via material changes – 1000 lbs	Vocational	Medium	2022
Weight reduction via material changes	Tractors	Low	2022
Auxiliary power unit	Tractors	Low	2022
Air conditioning leakage	Vocational, Tractors	Low	2022
Air conditioning efficiency	Tractors	Low	2022
Neutral idle	Vocational	Low	2022
Stop-start (no regeneration)	HD Pickup & Van vehicles	Medium	2018
Stop-start (no regeneration)	Vocational	Medium	2022
Mild hybrid	HD Pickup & Van vehicles	High1	2024
Mild hybrid	Tractors	High1	2025
Strong hybrid	HD Pickup & Van vehicles	High1	2024
Strong hybrid	Vocational	High1	2022
Full electric	Vocational, Tractors	High1	2028

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this proposal group all technologies into three broad categories and treat them as if individual technologies within each of the three categories (low, medium, and high complexity) would have the same ratio of indirect costs to direct costs. This simplification means it is likely that the direct cost for some technologies within a category will be higher and some lower than the estimate for the category in general. More importantly, the ICM estimates have not been validated through a direct accounting of actual indirect costs for individual technologies. RPEs themselves are inherently difficult to estimate because the accounting statements of manufacturers do not neatly categorize all cost elements as either direct or indirect costs. Hence, each researcher developing an RPE estimate must apply a certain amount of judgment to the allocation of the costs. Moreover, RPEs for heavy- and medium-duty trucks and for engine manufacturers are not as well studied as they are for the light-duty automobile industry. Since empirical estimates of ICMs are ultimately derived from the same data used to measure RPEs, this affects both measures. However, the value of RPE has not been measured for specific technologies, or for groups of specific technologies. Thus, even if we assume that the examined technology accurately represents the average impact on all technologies in its representative category, applying a single average RPE to any given technology by definition overstates costs for very simple technologies, or understates them for more advanced technologies in that group.

2.12.1.3 Learning Effects on Technology Costs

For some of the technologies considered in this analysis, manufacturer learning effects would be expected to play a role in the actual end costs. The “learning curve” or “experience curve” describes the reduction in unit production costs as a function of accumulated production volume. In theory, the cost behavior it describes applies to cumulative production volume measured at the level of an individual manufacturer, although it is often assumed—as both agencies have done in past regulatory analyses—to apply at the industry-wide level, particularly in industries that utilize many common technologies and component supply sources. Both agencies believe there are indeed many factors that cause costs to decrease over time. Research in the costs of manufacturing has consistently shown that, as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts. All of these factors allow manufacturers to lower the per-unit cost of production (*i.e.*, the manufacturing learning curve).[171]

The agencies have a detailed description of the learning effect in the light-duty 2012-2016 rulemaking. Most studies of the effect of experience or learning on production costs appear to assume that cost reductions begin only after some initial volume threshold has been reached, but not all of these studies specify this threshold volume. The rate at which costs decline beyond the initial threshold is usually expressed as the percent reduction in average unit cost that results from each successive doubling of cumulative production volume, sometimes referred to as the learning rate. Many estimates of experience curves do not specify a cumulative production volume beyond which cost reductions would no longer occur, instead depending on the asymptotic behavior of the effect for learning rates below 100 percent to establish a floor on costs.

In past rulemaking analyses, as noted above, both agencies have used a learning curve algorithm that applied a learning factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analyses, EPA has simplified the approach by using an "every two years" based learning progression rather than a pure production volume progression (*i.e.,* after two years of production it was assumed that production volumes would have doubled and, therefore, costs would be reduced by 20 percent).

In the light-duty 2012-2016 rulemaking, the agencies employed an additional learning algorithm to reflect the volume-based learning cost reductions that occur further along on the learning curve. This additional learning algorithm was termed "time-based" learning simply as a means of distinguishing this algorithm from the volume-based algorithm mentioned above, although both of the algorithms reflect the volume-based learning curve supported in the literature.[172] To avoid confusion, we now refer to this learning algorithm as the "flat-portion" of the learning curve. This way, we maintain the clarity that all learning is, in fact, volume-based learning, and the level of cost reductions depend only on where on the learning curve a technology's learning progression is. We distinguish the flat-portion of the curve from the steep-portion of the curve to indicate the level of learning taking place in the years following implementation of the technology. The agencies have applied the steep-portion learning algorithm for those technologies considered to be newer technologies likely to experience rapid cost reductions through manufacturer learning and the flat-portion learning algorithm for those technologies considered to be mature technologies likely to experience minor cost reductions through manufacturer learning. As noted above, the steep-portion learning algorithm results in 20 percent lower costs after two full years of implementation (*i.e.*, the 2016 MY costs are 20 percent lower than the 2014 and 2015 model year costs). Once the steep-portion learning steps have occurred (for technologies having the steep-portion learning algorithm applied), flat-portion learning at 3 percent per year becomes effective for 5 years. For technologies having the flat-portion learning algorithm applied), flat-portion learning at 3 percent per year begins in year 2 and remains effective for 5 years. Beyond 5 years of learning at 3 percent per year, 5 years of learning at 2 percent per year, then 5 at 1 percent per year become effective. There was no serious disagreement with this approach in the public comments to any of the GHG/fuel economy/consumption rulemakings.

Learning effects are applied to most but not all technologies because some of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. The steep-portion learning algorithm was applied for only a handful of technologies that are considered to be new or emerging technologies. Most technologies have been considered to be more established given their current use in the fleet and, hence, the lower flat-portion learning algorithm has been applied. The learning algorithms applied to each technology are summarized in Table 2-100.

Table 2-100 Learning Effect Algorithms Applied to Technologies Used in this Analysis

TECHNOLOGY	APPLIED TO	LEARNING ALGORITHM	LEARNING FACTOR "CURVE" [A]
Cylinder head improvements 1	LH/MH/HH Engines	Flat	2
Cylinder head improvements 2	LH/MH/HH Engines	Flat	13
Turbo efficiency improvements 1	LH/MH/HH, HD Pickup & Van Engines	Flat	2
Turbo efficiency improvements 2	LH/MH/HH Engines	Flat	13
EGR cooler efficiency improvements 1	LH/MH/HH Engines	Flat	2
EGR cooler efficiency improvements 2	LH/MH/HH Engines	Flat	13
Water pump improvements 1	LH/MH/HH Engines	Flat	2
Water pump improvements 2	LH/MH/HH Engines	Flat	13
Oil pump improvements 1	LH/MH/HH Engines	Flat	2
Oil pump improvements 2	LH/MH/HH Engines	Flat	13
Fuel pump improvements 1	LH/MH/HH Engines	Flat	2
Fuel pump improvements 2	LH/MH/HH Engines	Flat	13
Fuel rail improvements 1	LH/MH/HH Engines	Flat	2
Fuel rail improvements 2	LH/MH/HH Engines	Flat	13
Fuel injector improvements 1	LH/MH/HH Engines	Flat	2
Fuel injector improvements 2	LH/MH/HH Engines	Flat	13
Piston improvements 1	LH/MH/HH Engines	Flat	2
Piston improvements 2	LH/MH/HH Engines	Flat	13
Valve train friction reductions 1	LH/MH/HH Engines	Flat	2
Valve train friction reductions 2	LH/MH/HH Engines	Flat	13
Turbo compounding 1	LH/MH/HH Engines	Flat	2
Turbo compounding 2	LH/MH/HH Engines	Flat	13
Aftertreatment improvements 1 & 2	LH/MH/HH Engines	Flat	2
Model based control	LH/MH/HH Engines	Flat	13
Waste heat recovery	HH Engines	Flat	12
Engine friction reduction 1 & 2	HD Pickup & Van Engines	None	1
Engine changes to accommodate low friction lubes	HD Pickup & Van Engines	None	1
Variable valve timing	HD Pickup & Van	Flat	8

	Engines		
Stoichiometric gasoline direct injection	HD Pickup & Van Engines	Flat	7
Cylinder deactivation	HD Pickup & Van Engines	Flat	8
Cooled EGR	HD Pickup & Van Engines	Flat	7
Turbocharging & downsizing	HD Pickup & Van Engines	Flat	7
"Right sized" diesel engine	HD Pickup & Van vehicles, Tractors	None	1
6 speed transmission	HD Pickup & Van vehicles	Flat	7
8 speed transmission	HD Pickup & Van vehicles, Vocational	Flat	7
Automated manual transmission (AMT)	Vocational, Tractors	Flat	12
Auto transmission, power-shift	Tractors	Flat	12
Conversion from manual to auto trans	Vocational	Flat	7
Dual clutch transmission	Vocational, Tractors	Flat	12
Improved transmission	Vocational	Flat	13
Lower RR tires 1	HD Pickup & Van vehicles	None	1
Lower RR tires 2	HD Pickup & Van vehicles	Steep	11
Low drag brakes	HD Pickup & Van vehicles	None	1
Electric power steering	HD Pickup & Van vehicles	Flat	8
High efficiency transmission	HD Pickup & Van vehicles	Flat	6
Driveline friction reduction	HD Pickup & Van vehicles	Flat	3
Improved accessories (electrification)	HD Pickup & Van vehicles	Flat	8
Improved accessories	Tractors	Flat	12
Improved fan	Tractors	Flat	12
Lower RR tires 1	Vocational , Tractors, Trailers	Flat	2
Lower RR tires 2	Vocational , Tractors, Trailers	Flat	2
Lower RR tires 3	Vocational , Tractors, Trailers	Flat	12
Lower RR tires 4	Vocational , Tractors, Trailers	Flat	13
Automated Tire Inflation System (ATIS)	Tractors, Trailers	Flat	12
Aero 1 & 2	HD Pickup & Van vehicles	Flat	8
Aero Bins 1 & 2	Tractors	None	1
Aero Bin 3	Tractors	Flat	2
Aero Bins 4 thru 7	Tractors	Steep	4
Aero Bins 1 thru 8	Trailers	Flat	2
Weight reduction (via single wide tires and/or aluminum wheels)	Tractors	Flat	2

Weight reduction via material changes	HD Pickup & Van vehicles	Flat	6
Weight reduction via material changes	Vocational, Tractors	Flat	13
Auxiliary power unit	Tractors	Flat	2
Air conditioning leakage	Vocational, Tractors	Flat	2
Air conditioning efficiency	Tractors	Flat	12
Neutral idle	Vocational	None	1
Stop-start (no regeneration)	HD Pickup & Van vehicles	Steep	9
Stop-start (no regeneration)	Vocational	Flat	13
Mild hybrid	HD Pickup & Van vehicles	Flat	6
Mild hybrid	Tractors	Flat	12
Strong hybrid	HD Pickup & Van vehicles, Vocational	Steep	11
Full electric	Vocational, Tractors	Steep	4

Note:
[a] See table and figure below.

The actual year-by-year factors for the numbered curves shown in Table 2-100 are shown in Table 2-101 and are shown graphically in Figure 2-33.

Table 2-101 Year-by-year Learning Curve Factors for the Learning Curves Used in this Analysis

CURVE[A]	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	0.970	0.941	0.913	0.885	0.868	0.850	0.833	0.817	0.800	0.784	0.769
3	1.031	1.000	0.970	0.941	0.913	0.894	0.877	0.859	0.842	0.825	0.808	0.792
4	1.000	1.000	0.800	0.800	0.640	0.621	0.602	0.584	0.567	0.550	0.533	0.517
6	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.885	0.859	0.842	0.825	0.808
7	0.941	0.913	0.885	0.868	0.850	0.833	0.817	0.800	0.784	0.769	0.753	0.738
8	1.031	1.000	0.970	0.951	0.932	0.913	0.895	0.877	0.859	0.842	0.825	0.809
9	1.250	1.000	1.000	0.970	0.941	0.913	0.885	0.859	0.833	0.808	0.784	0.760
11	1.563	1.563	1.563	1.563	1.563	1.250	1.250	1.000	0.970	0.941	0.913	0.885
12	1.130	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.894	0.877	0.859	0.842
13	1.238	1.201	1.165	1.130	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.894

Note:
[a] Curves 5 and 10 were generated but subsequently not used so are not included in the table.

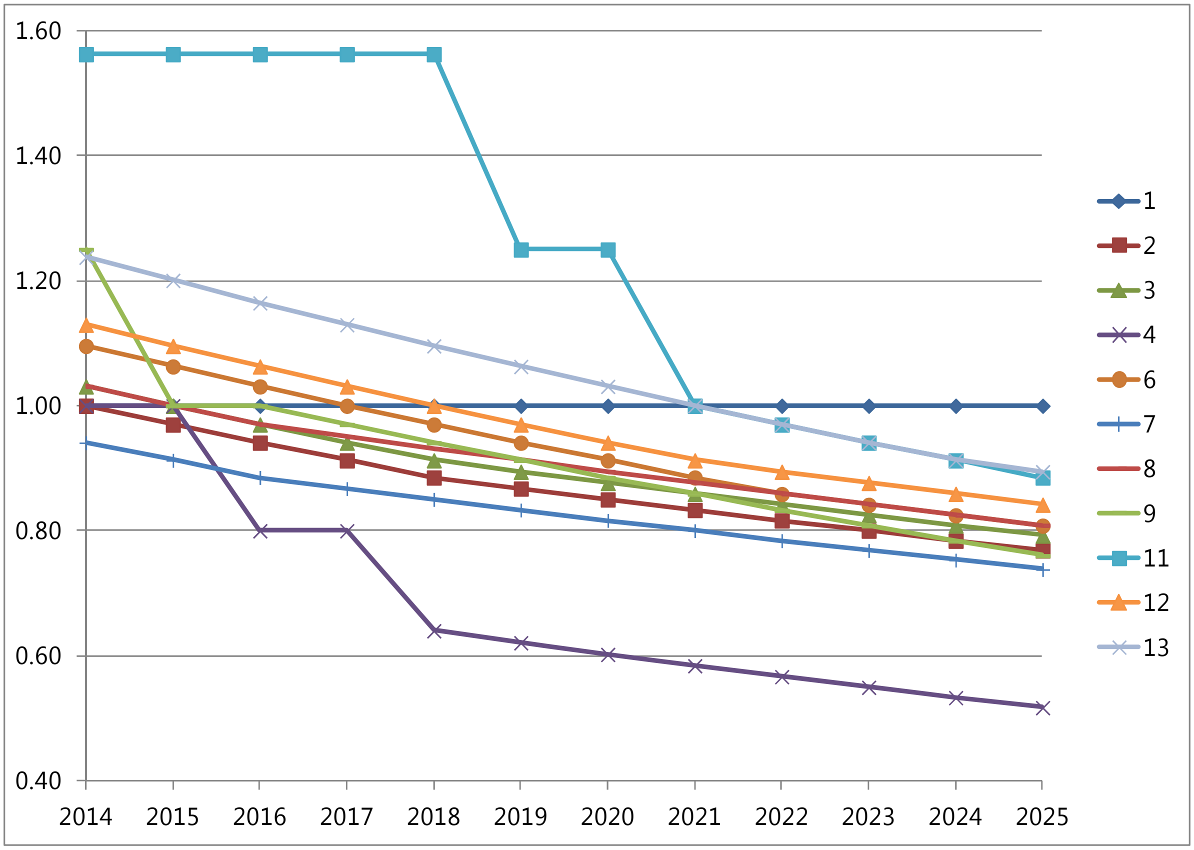


Figure 2-33 Year-by-year Learning Curve Factors for the Learning Curves used in this Analysis

Importantly, where the factors shown in Table 2-101 and, therefore, the curves shown in Figure 2-33 equal "1.00" represents the year for which any particular technology's cost is based. In other words, for example, the cost estimate that we have for cylinder head improvements 2 is "based" in 2021 (curve 13). Therefore, its learning factor equals 1.00 in 2021 and then decreases going forward to represent lower costs due to learning effects. Its learning factors are greater than 1.00 in years before 2021 to represent "reverse" learning, i.e., higher costs than our 2021 estimate since production volumes have, presumably, not yet reached the point where our cost estimate can be considered valid.

2.12.1.4 Technology Adoption Rates and Package Costs

Determining the stringency of the proposed standards involves a balancing of relevant factors – chiefly technology feasibility and effectiveness, costs, and lead time. For vocational vehicles, tractors and trailers, the agencies have projected a technology path to achieve the proposed standards reflecting an application rate of those technologies the agencies consider to be available at reasonable cost in the lead times provided. The agencies do not expect each of the technologies for which costs have been developed to be employed by all engines and vehicles across the board. Further, many of today's vehicles are already equipped with some of the technologies and/or are expected to adopt them by MY2018 to comply with the HD Phase 1 standards. Estimated adoption rates in both the reference and control cases are necessary for each vehicle/trailer category. The adoption rates for many technologies are zero in the reference case; however, for some technologies—notably aero and tire technologies—the adoption rate is not always zero in the reference case. These reference and control case adoption rates are then applied to the technology costs with the result being a package cost for each vehicle/trailer category. As such, package costs are rarely if ever a simple sum of all the technology costs since each technology would be expected to be adopted at different rates.

For HD pickups and vans, the CAFE model determines the technology adoption rates that most cost effectively meet the standards being proposed. Similar to vocational vehicles, tractors and trailers, package costs are rarely if ever a simple sum of all the technology costs since each technology would be expected to be adopted at different rates. The methods for estimating technology adoption rates and resultant costs (and other impacts) for HD pickups and vans are discussed in Chapter 10 of this draft RIA.

2.12.1.5 Conversion of Technology Costs to 2012 U.S. Dollars

As noted above in Section IX.C.1, the agencies are using technology costs from many different sources. These sources, having been published in different years, present costs in different year dollars (i.e., 2009 dollars or 2010 dollars). For this analysis, the agencies sought to have all costs in terms of 2012 dollars to be consistent with the dollars used by AEO in its 2014 Annual Energy Outlook.[173] While the factors used to convert from 2009 dollars (or other) to 2012 dollars are small, the agencies prefer to be overly diligent in this regard to ensure consistency across our benefit-cost analysis. The agencies have used the GDP Implicit Price Deflator for Gross Domestic Product as the converter, with the actual factors used as shown in Table 2-102.[174]

Table 2-102 Implicit Price Deflators and Conversion Factors for Conversion to 2012$

CALENDAR YEAR	2005	2006	2007	2008	2009	2010	2011	2012	2013
Price index for GDP	91.991	94.818	97.335	99.236	100	101.211	103.199	105.002	106.588
Factor applied for 2012$	1.141	1.107	1.079	1.058	1.050	1.037	1.017	1.000	0.985

The sections above describe the technologies expected to be used to enable compliance with the proposed standards and the adoption rates we estimate to be possible. Here we present the cost of each technology, the markups used for each, the learning effect applied, etc. The tables here present the direct manufacturing cost (DMC) we have estimated for each technology, the indirect costs (IC) associated with that technology, and the resultant total cost (TC) of each (where TC=DMC+IC). Each table also presents, where appropriate, the expected adoption rate of each technology in both the reference case (i.e., alternative 1a or the “no new controls” case) and the policy case (the proposed standards). For most technologies, the reference case adoption rate will be shown as 0 percent (or blanks in the tables) since the Phase 2 technologies are expected to be in limited or no use in the regulatory timeframe. However, for some technologies—notably tire and aero technologies—there is expected to considerably adoption of Phase 2 technologies in the reference case. The final row(s) of the tables shown here include the adoption rates applied to the technology costs to arrive at a total cost of each technology as it is applied to the ultimate package (noted as TCp). In Chapter 2.13 of this draft RIA, we sum these costs (the TCp costs) into total cost applied to the packages presented later in Chapter 7 of this draft RIA. We also describe how we moved from the total cost applied to the packages developed for the regulatory classes (i.e., Class 8 Sleeper cab, LH vocational medium-speed, etc.) to the MOVES sourcetypes (i.e., transit bus, refuse truck, combination long haul, etc.) in order to develop program costs. This final step—moving from regulatory classes to MOVES sourcetypes, was necessary because MOVES populations, sales, inventory calculations, etc., are based on sourcetypes, not regulatory classes, and to allow for a more granular look at payback as presented in Chapter 7.4 of this draft RIA.

Note that the text surrounding the tables presented here refer to low/medium/high complexity ICMs and to learning curves used. We discuss both the ICMs and the learning effects used in this analysis in Chapter 2.12.1.2 and 2.12.1.3 of this draft RIA, respectively.

2.12.2 **Costs of Engine Technologies**

2.12.2.1 Aftertreatment improvements

We have estimated the cost of aftertreatment improvements based on the aftertreatment improvements technology discussed in the Phase 1 rules. That technology was estimated at $25 (DMC, 2008$, in 2014) for each percentage improvement in fuel consumption, or $100 (DMC, 2008$, in 2014) for the 4 percent improvement expected as a result of that program. In Phase 2, we are expecting only a 0.6 percent improvement in fuel consumption resulting from aftertreatment improvements. Therefore, the cost in Phase 2 including updates to 2012$ is $16 (DMC, 2012$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2024. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-103 for vocational engines and in Table 2-104 for tractor engines.

Table 2-103 Costs of Aftertreatment Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aftertreatment improvements – level 2	DMC	$14	$14	$13	$13	$13	$13	$12	$12	$12	$12
Aftertreatment improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Aftertreatment improvements – level 2	TC	$17	$16	$16	$16	$15	$15	$15	$14	$14	$14
Aftertreatment improvements – level 2	Alt 1a										
Aftertreatment improvements – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Aftertreatment improvements – level 2	TCp	$0	$0	$0	$8	$8	$8	$13	$13	$13	$14

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-104 Costs of Aftertreatment Improvements – Level 2 HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aftertreatment improvements – level 2	DMC	$14	$14	$13	$13	$13	$13	$12	$12	$12	$12
Aftertreatment improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Aftertreatment improvements – level 2	TC	$17	$16	$16	$16	$15	$15	$15	$14	$14	$14
Aftertreatment improvements – level 2	Alt 1a										
Aftertreatment improvements – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Aftertreatment improvements – level 2	TCp	$0	$0	$0	$7	$7	$7	$14	$13	$13	$14

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.2 Cylinder head improvements

We have estimated the cost of cylinder head improvements based on the cylinder head improvements technology discussed in the Phase 1 rules. That technology was estimated at $9 (DMC, 2008$, in 2014) for light HDD engines and at $5 (DMC, 2008$, in 2014) for medium and heavy HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of cylinder head improvements. With updates to 2012$, we estimate the costs at $10 (DMC, 2012$, in 2021) for light HDD engines and at $6 (DMC, 2012$, in 2021) for medium and heavy HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-105 through Table 2-107.

Table 2-105 Costs for Cylinder Head Improvements – Level 2 Light HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$11	$11	$10	$10	$10	$9	$9	$9	$9	$9
Cylinder head improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Cylinder head improvements – level 2	TC	$12	$12	$12	$11	$11	$11	$11	$10	$10	$10
Cylinder head improvements – level 2	Alt 1a										
Cylinder head improvements – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$6	$6	$5	$10	$9	$10	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-106 Costs for Cylinder Head Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$6	$6	$6	$6	$6	$5	$5	$5	$5	$5
Cylinder head improvements – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Cylinder head improvements – level 2	TC	$7	$7	$7	$7	$7	$6	$6	$6	$6	$6
Cylinder head improvements – level 2	Alt 1a										
Cylinder head improvements – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$3	$3	$3	$6	$5	$5	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-107 Costs for Cylinder Head Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$6	$6	$6	$6	$6	$5	$5	$5	$5	$5
Cylinder head improvements – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Cylinder head improvements – level 2	TC	$7	$7	$7	$7	$7	$6	$6	$6	$6	$6
Cylinder head improvements – level 2	Alt 1a										
Cylinder head improvements – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$3	$3	$3	$6	$6	$6	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.3 Turbocharger efficiency improvements

We have estimated the cost of turbo efficiency improvements based on the turbo efficiency improvements technology discussed in the Phase 1 rules. That technology was estimated at $16 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of turbo efficiency improvements. With updates to 2012$, we estimate the costs at $17 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-108 and Table 2-109 for vocational and tractor engines.

Table 2-108 Costs for Turbocharger Efficiency Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 2	DMC	$18	$18	$17	$17	$16	$16	$15	$15	$14	$14
Turbo efficiency improvements – level 2	IC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Turbo efficiency improvements – level 2	TC	$21	$20	$20	$19	$19	$18	$18	$17	$17	$17
Turbo efficiency improvements – level 2	Alt 1a										
Turbo efficiency improvements – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Turbo efficiency improvements – level 2	TCp	$0	$0	$0	$10	$9	$9	$16	$16	$15	$17

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-109 Costs for Turbocharger Efficiency Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 2	DMC	$18	$18	$17	$17	$16	$16	$15	$15	$14	$14
Turbo efficiency improvements – level 2	IC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Turbo efficiency improvements – level 2	TC	$21	$20	$20	$19	$19	$18	$18	$17	$17	$17
Turbo efficiency improvements – level 2	Alt 1a										
Turbo efficiency improvements – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Turbo efficiency improvements – level 2	TCp	$0	$0	$0	$9	$8	$8	$17	$16	$16	$17

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For HD diesel pickups and vans, we are estimating use of the Phase 1 level of turbo efficiency improvements, or $17 (DMC, 2012$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs are shown in Table 2-110.

Table 2-110 Costs for Turbocharger Efficiency Improvements – Level 1
HD Pickups & Vans (2012$)

TECHNOLOGY		2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 1	DMC	$14	$14	$13	$13	$13	$13	$13
Turbo efficiency improvements – level 1	IC	$3	$3	$2	$2	$2	$2	$2
Turbo efficiency improvements – level 1	TC	$16	$16	$15	$15	$15	$15	$15

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.2.4 Turbo compounding

We have estimated the cost of turbo compounding based on the turbo compounding technology discussed in the Phase 1 rules. That technology was estimated at $813 (DMC, 2008$, in 2014) for all HDD tractor engines. In Phase 2, we are estimating equivalent costs for an additional level of turbo compounding improvements. With updates to 2012$, we estimate the costs at $860 (DMC, 2012$, in 2021) for all HDD tractor engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-111.

Table 2-111 Costs for Turbocharger Compounding – Level 2 HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo compounding – level 2	DMC	$942	$914	$886	$860	$834	$809	$785	$769	$754	$738
Turbo compounding – level 2	IC	$134	$133	$133	$133	$133	$133	$133	$133	$132	$132
Turbo compounding – level 2	TC	$1,076	$1,047	$1,020	$993	$967	$942	$917	$902	$886	$871
Turbo compounding – level 2	Alt 1a										
Turbo compounding – level 2	Alt 3				5%	5%	5%	10%	10%	10%	10%
Turbo compounding – level 2	TCp	$0	$0	$0	$50	$48	$47	$92	$90	$89	$87

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.5 Valve actuation

We have estimated the cost of valve actuation based on the dual cam phasing cost estimate used in the 2017-2025 light-duty rule. In that analysis, we estimated costs at $151 (DMC, 2010$, in 2015) for a large V8 engine. In this HD Phase 2 program, we are estimating equivalent costs for this technology. With updates to 2012$, we estimate the costs at $157 (DMC, 2012$, in 2015) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied a medium complexity ICM with short term markups through 2018. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-112 for vocational engines and in Table 2-113 for tractor engines.

Table 2-112 Costs for Valve Actuation
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valve actuation	DMC	$146	$143	$141	$138	$135	$132	$130	$127	$126	$125
Valve actuation	IC	$60	$45	$45	$45	$45	$45	$45	$45	$45	$44
Valve actuation	TC	$207	$188	$186	$183	$180	$177	$174	$172	$170	$169
Valve actuation	Alt 1a										
Valve actuation	Alt 3				50%	50%	50%	90%	90%	90%	100%
Valve actuation	All	$0	$0	$0	$91	$90	$89	$157	$154	$153	$169

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-113 Costs for Valve Actuation
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valve actuation	DMC	$146	$143	$141	$138	$135	$132	$130	$127	$126	$125
Valve actuation	IC	$60	$45	$45	$45	$45	$45	$45	$45	$45	$44
Valve actuation	TC	$207	$188	$186	$183	$180	$177	$174	$172	$170	$169
Valve actuation	Alt 1a										
Valve actuation	Alt 3				45%	45%	45%	95%	95%	95%	100%
Valve actuation	All	$0	$0	$0	$82	$81	$80	$166	$163	$162	$169

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For HD pickups and vans, we have estimated the costs of dual cam phasing based on the DMC, IC and TC presented above in Table 2-112.

For discrete variable valve lift (DVVL), we have again used the 2017-2025 light-duty FRM values updated to 2012$ to arrive at a cost of $259 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied medium complexity markups with short term markups through 2024. The resultant costs are presented in Table 2-114.

Table 2-114 Costs for Discrete Variable Valve Lift (DVVL)
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Discrete variable valve lift (DVVL)	DMC	$227	$223	$218	$214	$210	$207	$205
Discrete variable valve lift (DVVL)	IC	$74	$74	$74	$74	$74	$73	$73
Discrete variable valve lift (DVVL)	TC	$301	$297	$292	$288	$283	$281	$279

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.2.6 EGR

We have estimated the cost of EGR cooler improvements based on the EGR cooler improvements technology discussed in the Phase 1 rules. That technology was estimated at $3

(DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of EGR cooler improvements. With updates to 2012$, we estimate the costs at $3 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-115 for vocational engines and in Table 2-116 for tractor engines.

Table 2-115 Costs for EGR Cooler Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
EGR cooler – level 2	DMC	$4	$4	$3	$3	$3	$3	$3	$3	$3	$3
EGR cooler – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
EGR cooler – level 2	TC	$4	$4	$4	$4	$4	$4	$4	$3	$3	$3
EGR cooler – level 2	Alt 1a										
EGR cooler – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
EGR cooler – level 2	TCp	$0	$0	$0	$2	$2	$2	$3	$3	$3	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-116 Costs for EGR Cooler Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
EGR cooler – level 2	DMC	$4	$4	$3	$3	$3	$3	$3	$3	$3	$3
EGR cooler – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
EGR cooler – level 2	TC	$4	$4	$4	$4	$4	$4	$4	$3	$3	$3
EGR cooler – level 2	Alt 1a										
EGR cooler – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
EGR cooler – level 2	TCp	$0	$0	$0	$2	$2	$2	$3	$3	$3	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For HD pickups and vans, we have estimated the costs of adding cooled EGR to a gasoline engine based on the values used in the 2017-2025 light-duty FRM. We have scaled upward the light-duty value by 25 percent and converted to 2012$ to arrive at a cost of $317 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2024. The resultant costs are presented in Table 2-117.

Table 2-117 Costs for Cooled EGR
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Cooled EGR	DMC	$253	$248	$243	$239	$234	$231	$229
Cooled EGR	IC	$120	$120	$119	$119	$89	$89	$89
Cooled EGR	TC	$373	$368	$363	$358	$323	$321	$318

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.2.7 Water pump improvements

We have estimated the cost of water pump improvements based on the water pump improvements technology discussed in the Phase 1 rules. That technology was estimated at $78 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of water pump improvements. With updates to 2012$, we estimate the costs at $83 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-118 for vocational engines and in Table 2-119 for tractor engines.

Table 2-118 Costs for Water Pump Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Water pump – level 2	DMC	$91	$88	$85	$83	$80	$78	$75	$74	$72	$71
Water pump – level 2	IC	$13	$13	$13	$13	$13	$13	$13	$13	$13	$13
Water pump – level 2	TC	$103	$101	$98	$95	$93	$91	$88	$87	$85	$84
Water pump – level 2	Alt 1a										
Water pump – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Water pump – level 2	TCp	$0	$0	$0	$57	$56	$54	$79	$78	$77	$84

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-119 Costs for Water Pump Improvements – Level 2 HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Water pump – level 2	DMC	$91	$88	$85	$83	$80	$78	$75	$74	$72	$71
Water pump – level 2	IC	$13	$13	$13	$13	$13	$13	$13	$13	$13	$13
Water pump – level 2	TC	$103	$101	$98	$95	$93	$91	$88	$87	$85	$84
Water pump – level 2	Alt 1a										
Water pump – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Water pump – level 2	TCp	$0	$0	$0	$43	$42	$41	$84	$82	$81	$84

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.8 Oil pump improvements

We have estimated the cost of oil pump improvements based on the oil pump improvements technology discussed in the Phase 1 rules. That technology was estimated at just under $4 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of oil pump improvements. With updates to 2012$, we estimate the costs at just over $4 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-120 for vocational engines and in Table 2-121 for tractor engines.

Table 2-120 Costs for Oil Pump Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Oil pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Oil pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Oil pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Oil pump – level 2	Alt 1a										
Oil pump – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Oil pump – level 2	TCp	$0	$0	$0	$3	$3	$3	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-121 Costs for Oil Pump Improvements – Level 2 HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Oil pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Oil pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Oil pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Oil pump – level 2	Alt 1a										
Oil pump – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Oil pump – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.9 Fuel pump improvements

We have estimated the cost of fuel pump improvements based on the fuel pump improvements technology discussed in the Phase 1 rules. That technology was estimated at just under $4 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel pump improvements. With updates to 2012$, we estimate the costs at just over $4 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-122 for vocational engines and in Table 2-123 for tractor engines.

Table 2-122 Costs for Fuel Pump Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Fuel pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Fuel pump – level 2	Alt 1a										
Fuel pump – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Fuel pump – level 2	TCp	$0	$0	$0	$3	$3	$3	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-123 Costs for Fuel Pump Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Fuel pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Fuel pump – level 2	Alt 1a										
Fuel pump – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Fuel pump – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.10 Fuel rail improvements

We have estimated the cost of fuel rail improvements based on the fuel rail improvements technology discussed in the Phase 1 rules. That technology was estimated at $10 (DMC, 2008$, in 2014) for LHDD engines and just under $9 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel rail improvements. With updates to 2012$, we estimate the costs at $11 (DMC, 2012$, in 2021) for LHDD and at just over $9 (DMC, 2012$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-124 through Table 2-126.

Table 2-124 Costs for Fuel Rail Improvements – Level 2
Light HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$12	$11	$11	$11	$10	$10	$10	$10	$9	$9
Fuel rail – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel rail – level 2	TC	$13	$13	$13	$12	$12	$12	$11	$11	$11	$11
Fuel rail – level 2	Alt 1a										
Fuel rail – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$7	$7	$7	$10	$10	$10	$11

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-125 Costs for Fuel Rail Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$10	$10	$9	$9	$9	$9	$8	$8	$8	$8
Fuel rail – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel rail – level 2	TC	$11	$11	$11	$11	$10	$10	$10	$10	$9	$9
Fuel rail – level 2	Alt 1a										
Fuel rail – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$6	$6	$6	$9	$9	$8	$9

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-126 Costs for Fuel Rail Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$10	$10	$9	$9	$9	$9	$8	$8	$8	$8
Fuel rail – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel rail – level 2	TC	$11	$11	$11	$11	$10	$10	$10	$10	$9	$9
Fuel rail – level 2	Alt 1a										
Fuel rail – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$5	$5	$4	$9	$9	$9	$9

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.11 Fuel injector improvements

We have estimated the cost of fuel injector improvements based on the fuel injector improvements technology discussed in the Phase 1 rules. That technology was estimated at $13 (DMC, 2008$, in 2014) for LHDD engines and $9 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel injector improvements. With updates to 2012$, we estimate the costs at $13 (DMC, 2012$, in 2021) for LHDD and at $10 (DMC, 2012$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-127 through Table 2-129.

Table 2-127 Costs for Fuel Injector Improvements – Level 2
Light HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$14	$14	$14	$13	$13	$12	$12	$12	$12	$11
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$17	$16	$16	$15	$15	$14	$14	$14	$14	$13
Fuel injectors – level 2	Alt 1a										
Fuel injectors – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$8	$7	$7	$13	$12	$12	$13

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-128 Costs for Fuel Injector Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$11	$11	$10	$10	$10	$9	$9	$9	$9	$9
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$12	$12	$12	$11	$11	$11	$11	$10	$10	$10
Fuel injectors – level 2	Alt 1a										
Fuel injectors – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$6	$6	$5	$10	$9	$9	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-129 Costs for Fuel Injector Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$11	$11	$10	$10	$10	$9	$9	$9	$9	$9
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$12	$12	$12	$11	$11	$11	$11	$10	$10	$10
Fuel injectors – level 2	Alt 1a										
Fuel injectors – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$5	$5	$5	$10	$10	$10	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.12 Piston improvements

We have estimated the cost of piston improvements based on the piston improvements technology discussed in the Phase 1 rules. That technology was estimated at just over $2 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel pump improvements. With updates to 2012$, we estimate the costs at over $2 (DMC, 2012$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-130 for vocational engines and in Table 2-131 for tractor engines.

Table 2-130 Costs for Fuel Pump Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Piston improvements – level 2	DMC	$3	$3	$3	$2	$2	$2	$2	$2	$2	$2
Piston improvements – level 2	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Piston improvements – level 2	TC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Piston improvements – level 2	Alt 1a										
Piston improvements – level 2	Alt 3				50%	50%	50%	90%	90%	90%	100%
Piston improvements – level 2	TCp	$0	$0	$0	$1	$1	$1	$2	$2	$2	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-131 Costs for Fuel Pump Improvements – Level 2
HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Piston improvements – level 2	DMC	$3	$3	$3	$2	$2	$2	$2	$2	$2	$2
Piston improvements – level 2	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Piston improvements – level 2	TC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Piston improvements – level 2	Alt 1a										
Piston improvements – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Piston improvements – level 2	TCp	$0	$0	$0	$1	$1	$1	$3	$2	$2	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.13 Valvetrain friction reduction

We have estimated the cost of valvetrain friction reduction based on the valvetrain friction reduction technology discussed in the Phase 1 rules. That technology was estimated at $94 (DMC, 2008$, in 2014) for LHDD engines and $70 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel injector improvements. With updates to 2012$, we estimate the costs at $99 (DMC, 2012$, in 2021) for LHDD and at $74 (DMC, 2012$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-132 and Table 2-133 for vocational engines and in Table 2-134 for tractor engines.

Table 2-132 Costs for Valvetrain Friction Improvements – Level 2 Light HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$109	$105	$102	$99	$96	$93	$91	$89	$87	$85
Valvetrain friction reduction – level 2	IC	$15	$15	$15	$15	$15	$15	$15	$15	$15	$15
Valvetrain friction reduction – level 2	TC	$124	$121	$118	$115	$112	$109	$106	$104	$102	$100
Valvetrain friction reduction – level 2	Alt 1a										
Valvetrain friction reduction – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$69	$67	$65	$95	$94	$92	$100

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-133 Costs for Valvetrain Friction Improvements – Level 2 Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$82	$79	$77	$74	$72	$70	$68	$67	$65	$64
Valvetrain friction reduction – level 2	IC	$12	$12	$12	$12	$12	$11	$11	$11	$11	$11
Valvetrain friction reduction – level 2	TC	$93	$91	$88	$86	$84	$81	$79	$78	$77	$75
Valvetrain friction reduction – level 2	Alt 1a										
Valvetrain friction reduction – level 2	Alt 3				60%	60%	60%	90%	90%	90%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$52	$50	$49	$71	$70	$69	$75

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

**Table 2-134 Costs for Valvetrain Friction Improvements – Level 2
HDD Tractor Engines (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$82	$79	$77	$74	$72	$70	$68	$67	$65	$64
Valvetrain friction reduction – level 2	IC	$12	$12	$12	$12	$12	$11	$11	$11	$11	$11
Valvetrain friction reduction – level 2	TC	$93	$91	$88	$86	$84	$81	$79	$78	$77	$75
Valvetrain friction reduction – level 2	Alt 1a										
Valvetrain friction reduction – level 2	Alt 3				45%	45%	45%	95%	95%	95%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$39	$38	$37	$75	$74	$73	$75

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.14 "Right-sized" diesel engine

We have estimated the cost of a slightly smaller diesel engine at a $500 savings (DMC, 2013$, in any year) for all HDD tractor engines. We believe this represents an opportunity for lower costs because smaller diesel engines contain less materials and are, generally, less costly to produce than a larger diesel engine. In 2012$, we estimate the costs at $493 (DMC, 2012$, in any year) for all HDD tractor engines. As this cost is considered applicable in any year, we have applied not learning effects (curve 1). We have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-135 for tractor engines. For HD pickups and vans, we estimated the right-sized diesel engine cost as cost neutral to any reference case diesel engine and limited the technology to diesel vans. We have not included any costs associated with lost utility of the smaller diesel engine. We believe that the smaller engine would be attractive to some buyers, but not all, and that those buyers would not be concerned by any possible lost utility. For that reason, we have used a limited application rate for this technology since, as noted, not all buyers would be interested in this option due to the potential for lost utility. Note that, for HD pickups and vans, we have considered this technology to be cost neutral.

Table 2-135 Costs for "Right-sized" HDD Tractor Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Right-sized diesel engine	DMC	-$493	-$493	-$493	-$493	-$493	-$493	-$493	-$493	-$493	-$493
Right-sized diesel engine	IC	$88	$88	$88	$88	$88	$69	$69	$69	$69	$69
Right-sized diesel engine	TC	-$405	-$405	-$405	-$405	-$405	-$424	-$424	-$424	-$424	-$424
Right-sized diesel engine	Alt 1a										
Right-sized diesel engine	Alt 3				10%	10%	10%	20%	20%	20%	30%
Right-sized diesel engine	TCp	$0	$0	$0	-$40	-$40	-$42	-$85	-$85	-$85	-$127

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.15 Waste heat recovery

We have estimated the cost of waste heat recovery based on the estimate from Tetra Tech showing it at $12,000 (retail, 2013$). Using that $12,000 estimate and dividing by a 1.36 RPE (see Chapter 2.12.1.2 of this draft RIA) and converting to 2012$, we arrive at our estimated DMC of $8,692 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) because although waste heat recovery is a new technology and in the 2015 to 2017 timeframe remains, perhaps, on the steeper portion of the learning curve, applying such rapid learning effects to the cost estimate we have would result in costs too low in the MY2024 to 2027 timeframe. We have applied a medium complexity ICM with short term markups through 2025. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-136 for tractor engines.

Table 2-136 Costs for Waste Heat Recovery
HDD Tractor Engines (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Waste heat recovery	DMC	$8,692	$8,431	$8,179	$7,933	$7,775	$7,619	$7,467	$7,317	$7,171	$7,028
Waste heat recovery	IC	$2,628	$2,615	$2,602	$2,589	$2,581	$2,574	$2,566	$2,558	$1,908	$1,903
Waste heat recovery	TC	$11,320	$11,046	$10,780	$10,523	$10,356	$10,193	$10,032	$9,876	$9,079	$8,931
Waste heat recovery	Alt 1a										
Waste heat recovery	Alt 3				1%	1%	1%	5%	5%	5%	15%
Waste heat recovery	TCp	$0	$0	$0	$105	$104	$102	$502	$494	$454	$1,340

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.16 Model-based control

We have estimated the cost of model-based controls at $100 (DMC, 2013$). Using that estimate and converting to 2012$, we arrive at our estimated DMC of $99 (DMC, 2012$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-137 for vocational engines.

Table 2-137 Costs for Model Based Controls
Light/Medium/Heavy HDD Vocational Engines (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Model-based control	DMC	$108	$105	$102	$99	$96	$93	$90	$88	$86	$85
Model-based control	IC	$15	$15	$15	$15	$15	$12	$12	$12	$12	$12
Model-based control	TC	$123	$120	$117	$114	$111	$105	$102	$100	$99	$97
Model-based control	Alt 1a										
Model-based control	Alt 3				25%	25%	25%	30%	30%	30%	40%
Model-based control	TCp	$0	$0	$0	$28	$28	$26	$31	$30	$30	$39

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.2.17 Engine friction reduction and accommodating low friction lubes

We have based the costs for accommodating low friction lubes (LUB) on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD engines. Using that cost ($3 DMC, 2006$, in any year) and converting to 2012$

results in a cost of $5 (DMC, 2012$, in any year). We consider this technology to be beyond learning (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown in Table 2-138.

Table 2-138 Costs for Accommodating Low Friction Lubes
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 1	DMC	$5	$5	$5	$5	$5	$5	$5
Engine friction reduction - level 1	IC	$1	$1	$1	$1	$1	$1	$1
Engine friction reduction - level 1	TC	$6	$6	$6	$6	$6	$6	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

We have based the costs for engine friction reduction level 1 (EFR1) on the costs used in the light-duty 2017-2025 FRM. That cost is based on an original estimate of $11/cylinder (DMC, 2006$, in any year). Using that cost for an 8 cylinder engine and converting to 2012$ results in a cost of $97 (DMC, 2012$, in any year). We consider this technology to be beyond learning (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown in Table 2-139.

Table 2-139 Costs for Engine Friction Reduction – Level 1
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 1	DMC	$97	$97	$97	$97	$97	$97	$97
Engine friction reduction - level 1	IC	$19	$19	$19	$19	$19	$19	$19
Engine friction reduction - level 1	TC	$116	$116	$116	$116	$116	$116	$116

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For engine friction reduction level 2 (EFR2, which includes costs for accommodating low friction lubes) we have used the same approach as used in the light-duty 2017-2025 rule in that we have doubled the DMC associated with LUB and EFR1. As with those technologies, we consider EFR2 to be beyond learning (curve 1) and have applied low complexity markups but have applied near term markups through 2024. The resultant costs for gasoline HD pickups and vans are shown in Table 2-140.

Table 2-140 Costs for Engine Friction Reduction – Level 2
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 2	DMC	$205	$205	$205	$205	$205	$205	$205
Engine friction reduction - level 2	IC	$50	$50	$50	$50	$39	$39	$39
Engine friction reduction - level 2	TC	$254	$254	$254	$254	$244	$244	$244

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For diesel HD pickups and vans, we have used the above costs for EFR level 2 and added to that costs associated with improvements to other parasitic loads on the engine. For that latter portion of the cost, we have used the light HDD engine DMCs for improved water pump level 1, improved oil pump level 1, improved fuel pump level 1, improved fuel injectors level 1 and valvetrain friction reduction level 1, which together result in a cost of $193 (DMC, 2012$, in and year). We consider this combined set of technologies to be beyond the effects of learning (curve 1) and have applied low complexity markups with near term markups through 2022. The resultant costs for diesel HD pickups and vans are shown in Table 2-141.

Table 2-141 Costs for Engine Friction Reduction & Improvements to Other Parasitics
Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - diesel	DMC	$397	$397	$397	$397	$397	$397	$397
Engine friction reduction - diesel	IC	$96	$96	$87	$87	$77	$77	$77
Engine friction reduction - diesel	TC	$494	$494	$484	$484	$474	$474	$474

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.2.18 Cylinder deactivation

For cylinder deactivation on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$ to arrive at a cost of $169 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied medium complexity markups with near term markups through 2018. The resultant costs are presented in Table 2-142.

Table 2-142 Costs for Cylinder Deactivation
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Cylinder deactivation	DMC	$148	$145	$142	$139	$137	$135	$134
Cylinder deactivation	IC	$48	$48	$48	$48	$48	$48	$48
Cylinder deactivation	TC	$196	$193	$190	$187	$185	$183	$182

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.2.19 Stoichiometric gasoline direct injection (SGDI)

For gasoline direct injection on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$ to arrive at a cost of $417 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. The resultant costs are presented in Table 2-143.

Table 2-143 Costs for Direct Injection Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Gasoline direct injection	DMC	$333	$327	$320	$314	$307	$304	$301
Gasoline direct injection	IC	$118	$118	$118	$117	$117	$117	$117
Gasoline direct injection	TC	$451	$445	$438	$431	$425	$422	$418

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost.

2.12.2.20 Turbocharging & downsizing

For turbocharging and downsizing (TDS) on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$. For the twin turbo configuration expected on a V6 engine (downsized from a V8), we estimate the cost at $735 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. For downsizing from an overhead valve (OHV) V8 to an overhead cam (OHC) V6 valvetrain, we have estimated the cost at $340 (DMC, 2012$, in 2017). We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied medium complexity markups with near term markups through 2018. For downsizing from an OHC V8 to an OHC V6, we have estimated the cost at -$295 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve to arrive at a cost of $417 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2024. The resultant costs for the turbocharging system are shown in Table 2-144, for downsizing from an OHV V8 to an OHC V6 in Table 2-145, and downsizing from an OHC V8 to an OHC V6 in Table 2-146.

Table 2-144 Costs for Adding Twin Turbos Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Adding twin turbos	DMC	$588	$576	$565	$553	$542	$537	$531
Adding twin turbos	IC	$208	$208	$208	$207	$207	$207	$207
Adding twin turbos	TC	$796	$784	$772	$761	$749	$744	$738

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-145 Costs for Downsizing from an OHV V8 to an OHC V6 Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Downsizing from OHV V8 to OHC V6	DMC	$301	$292	$286	$280	$275	$269	$264
Downsizing from OHV V8 to OHC V6	IC	$97	$97	$97	$97	$96	$96	$96
Downsizing from OHV V8 to OHC V6	TC	$398	$389	$383	$377	$371	$365	$360

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-146 Costs for Downsizing from an OHC V8 to an OHC V6 Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Downsizing from OHC V8 to OHC V6	DMC	-$236	-$232	-$227	-$223	-$218	-$216	-$214
Downsizing from OHC V8 to OHC V6	IC	$112	$112	$111	$111	$83	$83	$83
Downsizing from OHC V8 to OHC V6	TC	-$125	-$120	-$116	-$111	-$135	-$133	-$131

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.3 **Transmissions**

2.12.3.1 Adding additional gears (vocational)

We have estimated the cost of adding 2 additional gears for vocational vehicles (light/medium HD, heavy HD urban/multipurpose) based on the light-duty cost for an 8 speed automatic transmission relative to a 6 speed automatic of $78 (DMC, 2010$, in 2012).[R] We have scaled that value by typical torque values of 2000 foot-pounds for vocational and 332 for a light-duty truck. With updates to 2012$, this DMC for vocational vehicles becomes $486 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied a medium complexity ICM with short term markups through 2018. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-147 and Table 2-148 for vocational vehicles.

[R] This cost was updated by FEV in early 2013. We are using the updated cost here, not the value used in the light-duty 2017-2025 final rule.

Table 2-147 Costs for Adding 2 Gears to an Automatic Transmission Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Adding additional gears	DMC	$413	$405	$397	$389	$381	$374	$366	$359	$355	$352
Adding additional gears	IC	$143	$107	$107	$106	$106	$106	$105	$105	$105	$105
Adding additional gears	TC	$557	$512	$504	$495	$487	$479	$472	$464	$460	$457
Adding additional gears	Alt 1a										
Adding additional gears	Alt 3				5%	5%	5%	5%	5%	5%	5%
Adding additional gears	TCp	$0	$0	$0	$25	$24	$24	$24	$23	$23	$23

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-148 Costs for Adding 2 Gears to an Automatic Transmission Vocational Light/Medium HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Adding additional gears	DMC	$413	$405	$397	$389	$381	$374	$366	$359	$355	$352
Adding additional gears	IC	$143	$107	$107	$106	$106	$106	$105	$105	$105	$105
Adding additional gears	TC	$557	$512	$504	$495	$487	$479	$472	$464	$460	$457
Adding additional gears	Alt 1a										
Adding additional gears	Alt 3				5%	5%	5%	5%	5%	5%	10%
Adding additional gears	TCp	$0	$0	$0	$25	$24	$24	$24	$23	$23	$46

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.2 Automated manual transmissions (AMT)

We have estimated the cost of an AMT transmission, relative to a manual transmission, based on an estimate by Tetra Tech of $5,100 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 and converted to 2012$ to arrive at an estimated cost of $3694 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-149 for vocational vehicles and in Table 2-150 for tractors.

Table 2-149 Costs for an AMT Transmission
Vocational Heavy HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AMT	DMC	$3,694	$3,583	$3,476	$3,372	$3,304	$3,238	$3,173	$3,110	$3,048	$2,987
Manual to AMT	IC	$1,117	$1,111	$1,106	$1,101	$1,097	$818	$815	$813	$811	$809
Manual to AMT	TC	$4,811	$4,695	$4,582	$4,472	$4,401	$4,056	$3,989	$3,923	$3,859	$3,795
Manual to AMT	Alt 1a										
Manual to AMT	Alt 3				22%	22%	22%	33%	33%	33%	25%
Manual to AMT	TCp	$0	$0	$0	$984	$968	$892	$1,316	$1,295	$1,273	$949

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-150 Costs for an AMT Transmission
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AMT	DMC	$3,694	$3,583	$3,476	$3,372	$3,304	$3,238	$3,173	$3,110	$3,048	$2,987
Manual to AMT	IC	$1,117	$1,111	$1,106	$1,101	$1,097	$818	$815	$813	$811	$809
Manual to AMT	TC	$4,811	$4,695	$4,582	$4,472	$4,401	$4,056	$3,989	$3,923	$3,859	$3,795
Manual to AMT	Alt 1a										
Manual to AMT	Alt 3				40%	40%	40%	50%	50%	50%	50%
Manual to AMT	TCp	$0	$0	$0	$1,789	$1,761	$1,622	$1,994	$1,961	$1,929	$1,898

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.3 Automatic Transmission Powershift

We have estimated the cost of a powershift automatic transmission, relative to a manual transmission, based on an estimate by Tetra Tech of $15000 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 and converted to 2012$ to arrive at an estimated cost of $11670 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-151 for tractors.

Table 2-151 Costs for a Powershift Automatic Transmission Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AT powershift	DMC	$11,670	$11,320	$10,981	$10,651	$10,438	$10,229	$10,025	$9,824	$9,628	$9,435
Manual to AT powershift	IC	$3,528	$3,511	$3,493	$3,477	$3,466	$2,583	$2,576	$2,569	$2,562	$2,555
Manual to AT powershift	TC	$15,199	$14,831	$14,474	$14,128	$13,904	$12,812	$12,601	$12,393	$12,190	$11,990
Manual to AT powershift	Alt 1a										
Manual to AT powershift	Alt 3				10%	10%	10%	20%	20%	20%	30%
Manual to AT powershift	TCp	$0	$0	$0	$1,413	$1,390	$1,281	$2,520	$2,479	$2,438	$3,597

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.4 Dual-clutch transmissions (DCT)

For vocational light/medium HD vehicles and for heavy HD urban and multipurpose vehicles, we estimate the cost of a move to a DCT from an automatic transmission to be cost neutral. For vocational heavy HD regional vehicles, we have estimated the cost of a DCT, relative to a manual transmission, as being equal to the move from a manual transmission to an AMT or $3694 (DMC, 2012$, in 2018, see 2.12.3.2 above). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-154.

Table 2-152 Costs for a Dual Clutch Transmission (DCT) Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Auto trans to DCT	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	Alt 1a										
Auto trans to DCT	Alt 3				5%	5%	5%	15%	15%	15%	5%
Auto trans to DCT	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-153 Costs for a Dual Clutch Transmission (DCT) Vocational Light/Medium HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Auto trans to DCT	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Auto trans to DCT	Alt 1a										
Auto trans to DCT	Alt 3				5%	5%	5%	15%	15%	15%	10%
Auto trans to DCT	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-154 Costs for a Dual Clutch Transmission (DCT) Vocational Heavy HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to DCT	DMC	$3,694	$3,583	$3,476	$3,372	$3,304	$3,238	$3,173	$3,110	$3,048	$2,987
Manual to DCT	IC	$1,117	$1,111	$1,106	$1,101	$1,097	$818	$815	$813	$811	$809
Manual to DCT	TC	$4,811	$4,695	$4,582	$4,472	$4,401	$4,056	$3,989	$3,923	$3,859	$3,795
Manual to DCT	Alt 1a										
Manual to DCT	Alt 3				22%	22%	22%	33%	33%	33%	25%
Manual to DCT	TCp	$0	$0	$0	$984	$968	$892	$1,316	$1,295	$1,273	$949

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For tractors, we have based our estimated cost of a DCT relative to a manual transmission on a Tetra Tech estimate of $17,500 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 and converted to 2012$ to arrive at an estimated cost of $12676 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-155 for tractors.

Table 2-155 Costs for a Dual Clutch Transmission (DCT) Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to DCT	DMC	$12,676	$12,296	$11,927	$11,569	$11,338	$11,111	$10,889	$10,671	$10,458	$10,248
Manual to DCT	IC	$3,832	$3,813	$3,794	$3,776	$3,765	$2,806	$2,798	$2,790	$2,783	$2,775
Manual to DCT	TC	$16,509	$16,109	$15,721	$15,346	$15,102	$13,917	$13,687	$13,461	$13,240	$13,024
Manual to DCT	Alt 1a										
Manual to DCT	Alt 3				5%	5%	5%	10%	10%	10%	10%
Manual to DCT	TCp	$0	$0	$0	$767	$755	$696	$1,369	$1,346	$1,324	$1,302

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.5 Improved transmissions – vocational vehicles

For this technology, we have relied on our light-duty technologies referred to as high efficiency gearbox (HEG), aggressive shift logic (ASL1) and early torque converter lockup (TORQ). Each of those technologies was estimated at $202, $27 and $25 (all are DMC, in 2010$, in 2015 or 2017 (HEG)). For this analysis, we have used those estimates for ASL1 and TORQ, but have scaled upward the cost of HEG by 25 percent to account for differences between light-duty and HD. Converting to 2012$ results in costs for this technology of $316 (DMC, 2012$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-156 for vocational vehicles.

Table 2-156 Costs of Improved Transmissions All Vocational HD Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved trans	DMC	$346	$336	$326	$316	$307	$297	$288	$283	$277	$271
Improved trans	IC	$57	$57	$57	$56	$56	$44	$44	$44	$44	$44
Improved trans	TC	$403	$393	$382	$372	$363	$342	$333	$327	$321	$315
Improved trans	Alt 1a										
Improved trans	Alt 3				15%	15%	15%	30%	30%	30%	70%
Improved trans	TCp	$0	$0	$0	$56	$54	$51	$100	$98	$96	$221

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.6 Manual to automatic transmission, vocational heavy HD regional vehicles

For this technology, we have estimated the cost as equal to the cost for moving from a manual transmission to an AMT, as presented above, but have considered that cost to be applicable to MY2012, or $3694 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied a medium complexity ICM with short term markups through 2018. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-157.

Table 2-157 Cost for an Automatic Transmission
Vocational Heavy HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to auto trans	DMC	$3,141	$3,078	$3,017	$2,956	$2,897	$2,839	$2,782	$2,727	$2,699	$2,672
Manual to auto trans	IC	$1,089	$812	$810	$808	$806	$804	$802	$800	$799	$798
Manual to auto trans	TC	$4,230	$3,890	$3,826	$3,764	$3,703	$3,643	$3,584	$3,526	$3,498	$3,470
Manual to auto trans	Alt 1a										
Manual to auto trans	Alt 3				22%	22%	22%	33%	33%	33%	25%
Manual to auto trans	TCp	$0	$0	$0	$828	$815	$801	$1,183	$1,164	$1,154	$868

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.3.7 8 speed transmission relative to a 6 speed, HD pickups & vans

We have based the cost of this technology on several values used in the light-duty 2017-2025 final rule. In that rule, we presented costs for 6 to 8 speed automatic transmission, high efficiency gearbox (HEG) and aggressive shift logic (ASL1) as separate technologies. Here we are treating these technologies as separate for costing (since some metrics differ for each) but considering them as being applied together as a complete group. As such, the cost for moving to an 8 speed transmission from the base 6 would always be the summation within any given year of the total costs shown in the tables that follow. For adding 2 gears, we have estimated the cost at $121 (DMC, 2012$, in 2012). We consider that technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. For HEG, we have estimated the cost at $263 (DMC, 2012$, in 2017). We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied low complexity markups with near term markups through 2024. For shift logic, we have estimated the cost at $28 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant costs for adding 2 gears are shown in Table 2-158, for HEG in Table 2-159 and for ASL1 in Table 2-160.

Table 2-158 Costs to Add 2 Transmission Gears
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Move from 6 to 8 gears	DMC	$97	$95	$93	$91	$89	$88	$88
Move from 6 to 8 gears	IC	$34	$34	$34	$34	$34	$34	$34
Move from 6 to 8 gears	TC	$131	$129	$127	$125	$123	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-159 Costs for High Efficiency Gearbox (HEG)
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
High efficiency gearbox	DMC	$232	$225	$221	$217	$212	$208	$204
High efficiency gearbox	IC	$63	$63	$63	$63	$50	$50	$50
High efficiency gearbox	TC	$296	$288	$284	$279	$262	$258	$254

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-160 Costs for Aggressive Shift Logic Level 1
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aggressive shift logic 1	DMC	$25	$24	$24	$23	$23	$22	$22
Aggressive shift logic 1	IC	$5	$5	$5	$5	$5	$5	$5
Aggressive shift logic 1	TC	$30	$30	$29	$29	$28	$28	$28

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-161 Complete Cost of Moving from the Base 6 Speed to 8 Speed Transmission
2 Gears+HEG+ASL1
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Move from 6speed to 8speed Transmission	TC	$457	$447	$440	$433	$414	$409	$403
Notes: TC=total cost.								

2.12.4 **Air Conditioning**

2.12.4.1 Direct AC controls – vocational (all)

We have estimated the cost of this technology based on an estimate from TetraTech of $30 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $22 (DMC, 2012$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-162.

Table 2-162 Costs for Direct Air Conditioning Controls
All Vocational HD Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
A/C direct	DMC	$19	$19	$18	$18	$18	$17	$17	$17	$17	$16
A/C direct	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
A/C direct	TC	$23	$23	$22	$22	$22	$20	$20	$20	$20	$19
A/C direct	Alt 1a										
A/C direct	Alt 3				100%	100%	100%	100%	100%	100%	100%
A/C direct	TCp	$0	$0	$0	$22	$22	$20	$20	$20	$20	$19

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.4.2 Indirect AC controls – tractors (all)

We have estimated the cost of this technology based on an estimate from TetraTech of $218 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $158 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-163.

Table 2-163 Costs for Indirect AC Controls
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
A/C indirect	DMC	$158	$153	$148	$144	$141	$138	$135	$133	$130	$127
A/C indirect	IC	$28	$28	$28	$28	$28	$22	$22	$22	$22	$22
A/C indirect	TC	$186	$181	$176	$172	$169	$160	$157	$155	$152	$149
A/C indirect	Alt 1a										
A/C indirect	Alt 3				10%	10%	10%	20%	20%	20%	30%
A/C indirect	TCp	$0	$0	$0	$17	$17	$16	$31	$31	$30	$45

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.5 **Axles**

2.12.5.1 6x2 Axle

We have estimated the cost of this technology based on an estimate from TetraTech of $250 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $181 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-164 for vocational heavy HD regional vehicles, in Table 2-165 for Class 8 tractors (day and sleeper cab) with low and mid roofs, and in Table 2-166 for Class 8 tractors (day and sleeper cab) with high roofs.

Table 2-164 Costs for 6x2 Axles
Vocational Heavy HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle 6x2	DMC	$181	$176	$170	$165	$162	$159	$156	$152	$149	$146
Axle 6x2	IC	$32	$32	$32	$32	$32	$25	$25	$25	$25	$25
Axle 6x2	TC	$213	$208	$203	$197	$194	$184	$181	$178	$175	$172
Axle 6x2	Alt 1a										
Axle 6x2	Alt 3				23%	23%	23%	30%	30%	30%	30%
Axle 6x2	TCp	$0	$0	$0	$44	$44	$41	$54	$53	$52	$51

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-165 Costs for 6x2 Axles
Class 8 Day Cab Low and Sleeper Cab Low/Mid Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle 6x2	DMC	$181	$176	$170	$165	$162	$159	$156	$152	$149	$146
Axle 6x2	IC	$32	$32	$32	$32	$32	$25	$25	$25	$25	$25
Axle 6x2	TC	$213	$208	$203	$197	$194	$184	$181	$178	$175	$172
Axle 6x2	Alt 1a										
Axle 6x2	Alt 3				10%	10%	10%	20%	20%	20%	20%
Axle 6x2	TCp	$0	$0	$0	$20	$19	$18	$36	$36	$35	$34

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-166 Costs for 6x2 Axles
Class 8 Day Cab and Sleeper Cab High Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle 6x2	DMC	$181	$176	$170	$165	$162	$159	$156	$152	$149	$146
Axle 6x2	IC	$32	$32	$32	$32	$32	$25	$25	$25	$25	$25
Axle 6x2	TC	$213	$208	$203	$197	$194	$184	$181	$178	$175	$172
Axle 6x2	Alt 1a										
Axle 6x2	Alt 3				20%	20%	20%	60%	60%	60%	60%
Axle 6x2	TCp	$0	$0	$0	$39	$39	$37	$108	$107	$105	$103

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.5.2 Axle disconnect

We have estimated the cost of this technology based on an estimate from TetraTech of $140 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $101 (DMC, 2012$, in all years). We consider this technology to be on the flat portion of the learning curve with no additional learning to occur (curve 1) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-167.

**Table 2-167 Costs for Axle Disconnect
Vocational Heavy HD Regional Vehicles (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle disconnect	DMC	$101	$101	$101	$101	$101	$101	$101	$101	$101	$101
Axle disconnect	IC	$18	$18	$18	$18	$18	$14	$14	$14	$14	$14
Axle disconnect	TC	$120	$120	$120	$120	$120	$116	$116	$116	$116	$116
Axle disconnect	Alt 1a										
Axle disconnect	Alt 3				46%	46%	46%	61%	30%	30%	30%
Axle disconnect	TCp	$0	$0	$0	$55	$55	$53	$71	$35	$35	$35

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.5.3 Axle downspeed

We have estimated the cost of this technology based on engineering judgment at $50 (DMC, 2013$, in 2018). This DMC is expected to cover development and some testing and integration work since there is no real hardware required for this technology. Converting this DMC to 2012$ results in a $49 cost (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-168.

**Table 2-168 Costs for Axle Downspeeding
Tractors (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle downspeed	DMC	$49	$48	$46	$45	$44	$43	$42	$41	$41	$40
Axle downspeed	IC	$9	$9	$9	$9	$9	$7	$7	$7	$7	$7
Axle downspeed	TC	$58	$57	$55	$54	$53	$50	$49	$48	$47	$47
Axle downspeed	Alt 1a										
Axle downspeed	Alt 3				20%	20%	20%	40%	40%	40%	60%
Axle downspeed	TCp	$0	$0	$0	$11	$11	$10	$20	$19	$19	$28

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.5.4 Low friction axle lubes

We have estimated the cost of this technology based on an estimate from TetraTech of $250 (retail, 2013$), an estimate applicable to tractors having 3 axles. Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $181 (DMC, 2012$, in 2018). We consider this estimate to be applicable also to vocational HH vehicles since these generally have 3 axles. For vocational light/medium HD vehicles, which generally have 2 axles, we have estimated the DMC at 2/3 the vocational heavy HD/tractor cost, or $121 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-169 for vocational light and medium HD vehicles and in Table 2-170 for vocational heavy HD vehicles, and in Table 2-171 for tractors.

Table 2-169 Costs for Low Friction Axle Lubes
Vocational Light/Medium HD Urban/Multipurpose/Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$121	$117	$114	$110	$108	$106	$104	$102	$100	$98
Axle low friction lubes	IC	$22	$22	$21	$21	$21	$17	$17	$17	$17	$17
Axle low friction lubes	TC	$142	$139	$135	$132	$129	$123	$121	$118	$116	$114
Axle low friction lubes	Alt 1a										
Axle low friction lubes	Alt 3				75%	75%	75%	75%	75%	75%	75%
Axle low friction lubes	TCp	$0	$0	$0	$99	$97	$92	$90	$89	$87	$86

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-170 Costs for Low Friction Axle Lubes
Vocational Heavy HD Urban/Multipurpose/Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$181	$176	$170	$165	$162	$159	$156	$152	$149	$146
Axle low friction lubes	IC	$32	$32	$32	$32	$32	$25	$25	$25	$25	$25
Axle low friction lubes	TC	$213	$208	$203	$197	$194	$184	$181	$178	$175	$172
Axle low friction lubes	Alt 1a										
Axle low friction lubes	Alt 3				75%	75%	75%	75%	75%	75%	75%
Axle low friction lubes	TCp	$0	$0	$0	$148	$146	$138	$136	$133	$131	$129

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-171 Costs for Low Friction Axle Lubes
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$181	$176	$170	$165	$162	$159	$156	$152	$149	$146
Axle low friction lubes	IC	$32	$32	$32	$32	$32	$25	$25	$25	$25	$25
Axle low friction lubes	TC	$213	$208	$203	$197	$194	$184	$181	$178	$175	$172
Axle low friction lubes	Alt 1a										
Axle low friction lubes	Alt 3				20%	20%	20%	40%	40%	40%	40%
Axle low friction lubes	TCp	$0	$0	$0	$39	$39	$37	$72	$71	$70	$69

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.6 Idle Reduction

2.12.6.1 Auxiliary power units (APU)

We have estimated the cost of this technology based on the APU costs discussed in the Phase 1 rule. That technology was estimated at $4586 (DMC, 2008$, in 2014). With updates, that cost becomes $4853 (DMC, 2012$, in 2014) for Phase 2. We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-172.

**Table 2-172 Costs for Auxiliary Power Units (APU)
Sleeper Cab Tractors (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
APU	DMC	$4,296	$4,210	$4,126	$4,043	$3,962	$3,883	$3,805	$3,729	$3,692	$3,655
APU	IC	$859	$857	$856	$855	$854	$674	$673	$673	$673	$672
APU	TC	$5,154	$5,067	$4,982	$4,899	$4,817	$4,557	$4,479	$4,402	$4,365	$4,327
APU	Alt 1a	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
APU	Alt 3	30%	30%	30%	70%	70%	70%	80%	90%	90%	90%
APU	TCp	$0	$0	$0	$1,959	$1,927	$1,823	$2,239	$2,641	$2,619	$2,596

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.12.6.2 Neutral idle

We have estimated the cost of this technology based on engineering judgment at $10 (retail, 2013$). Using that estimate, we have divided by a 1.36 RPE and converted to 2012$ to arrive at a $7 cost (DMC, 2012$, in all years). This DMC is expected to cover development and some testing and integration work since there is no real hardware required for this technology. We consider this technology to be on the flat portion of the learning curve with no additional learning to occur (curve 1) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-173 and Table 2-174 for vocational vehicles.

**Table 2-173 Costs for Neutral Idle Technology
Vocational Light/Medium HD Urban Vehicles (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Neutral idle	DMC	$7	$7	$7	$7	$7	$7	$7	$7	$7	$7
Neutral idle	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Neutral idle	TC	$9	$9	$9	$9	$9	$8	$8	$8	$8	$8
Neutral idle	Alt 1a										
Neutral idle	Alt 3				70%	70%	70%	85%	85%	85%	25%
Neutral idle	TCp	$0	$0	$0	$6	$6	$6	$7	$7	$7	$2

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

**Table 2-174 Costs for Neutral Idle Technology
Vocational Light/Medium/Heavy HD Multipurpose Vehicles and
Vocational Light/Medium HD Regional Vehicles
And Vocational Heavy HD Urban Vehicles (2012$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Neutral idle	DMC	$7	$7	$7	$7	$7	$7	$7	$7	$7	$7
Neutral idle	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Neutral idle	TC	$9	$9	$9	$9	$9	$8	$8	$8	$8	$8
Neutral idle	Alt 1a										
Neutral idle	Alt 3				70%	70%	70%	85%	85%	85%	30%
Neutral idle	TCp	$0	$0	$0	$6	$6	$6	$7	$7	$7	$2

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.6.3 Stop-start

We have estimated the cost of this technology based on several cost estimates. First, an estimate from TetraTech of $700 (retail, 2013$) for gasoline HD pickups and vans and $1500 (retail, 2013$) for diesel HD pickups and vans. Using these values, we divided by a 1.36 RPE and converted to 2012$ to arrive at $507 (DMC, 2012$, in 2021) and $1087 (DMC, 2012$, in 2021) which were considered appropriate for vocational MH and HH vehicles, respectively. To these estimates, we have added the costs for improved accessories used for HD pickups and vans of $124 (DMC, 2012$, in 2015) which is based on values from the 2017-2025 light-duty FRM. However, to account for the heavier vocational vehicles relative to the HD pickup and vans, we have scaled upward the improved accessory value by 50 percent to arrive at a cost of $186 (DMC, 2012$, in 2015). We have then added these values to arrive at costs of $693 (DMC, 2012$, in 2021) and $1272 (DMC, 2012$, in 2021) and have applied the lower cost to vocational medium HD vehicles and the higher cost to vocational heavy HD vehicles. For vocational light HD, we have used the stop-start cost for the 2017-2025 rule for LD pickups ($377 DMC, 2012$, in 2015) but have scaled upward that value by 25 percent to account for the weight difference between the LD and vocational light HD vehicles. Doing this results in a cost of $471 (DMC, 2012$, in 2021). Adding to that the $186 value for improved accessories mentioned earlier gives the resultant vocational light HD cost of $656 (DMC, 2012$, in 2021). We consider all of these technologies to be on the flat portion of the learning curve (curve 13) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-175 for vocational light HD, Table 2-176 for vocational medium HD, and in Table 2-177 for vocational heavy HD vehicles.

Table 2-175 Costs for Stop-start
Vocational Light HD Urban/Multipurpose/Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start	DMC	$719	$698	$677	$656	$637	$618	$599	$587	$575	$564
Stop-start	IC	$202	$201	$200	$198	$197	$147	$146	$146	$145	$145
Stop-start	TC	$921	$898	$876	$855	$834	$764	$745	$733	$721	$709
Stop-start	Alt 1a										
Stop-start	Alt 3				5%	5%	5%	15%	15%	15%	70%
Stop-start	TCp	$0	$0	$0	$43	$42	$38	$112	$110	$108	$496

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-176 Costs for Stop-start
Vocational Medium HD Urban/Multipurpose/Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start	DMC	$759	$736	$714	$693	$672	$652	$632	$620	$607	$595
Stop-start	IC	$213	$212	$211	$209	$208	$155	$154	$154	$153	$153
Stop-start	TC	$972	$948	$925	$902	$880	$807	$786	$773	$761	$748
Stop-start	Alt 1a										
Stop-start	Alt 3				5%	5%	5%	15%	15%	15%	70%
Stop-start	TCp	$0	$0	$0	$45	$44	$40	$118	$116	$114	$524

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-177 Costs for Stop-start
Vocational Heavy HD Urban/Multipurpose/Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start	DMC	$1,394	$1,352	$1,312	$1,272	$1,234	$1,197	$1,161	$1,138	$1,115	$1,093
Stop-start	IC	$391	$389	$387	$385	$383	$284	$283	$282	$282	$281
Stop-start	TC	$1,785	$1,741	$1,698	$1,657	$1,617	$1,482	$1,444	$1,420	$1,397	$1,374
Stop-start	Alt 1a										
Stop-start	Alt 3							15%	15%	15%	70%
Stop-start	TCp	$0	$0	$0	$0	$0	$0	$217	$213	$210	$962

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For HD pickups and vans, we have based our costs for stop-start systems on the values used in the light-duty 2017-2025 final rule, but have scaled upward those costs by 25 percent to account for the larger and harder starting HD engines. Using this approach and converting to 2012$ results in a cost of $471 (DMC, 2012$, in 2015). We consider this technology to be on the steep portion of the learning curve (curve 9, note the different year of cost-applicability relative to the vocational cost discussed above) and have applied medium complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in Table 2-178.

Table 2-178 Costs of Stop-start
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Stop-start	DMC	$404	$392	$380	$369	$358	$351	$344
Stop-start	IC	$134	$134	$134	$133	$133	$133	$132
Stop-start	TC	$539	$526	$514	$502	$491	$483	$476

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.7 **Electrification (strong/mild HEV, full EV)**

2.12.7.1 Strong hybrid electric vehicle (strong HEV)

We have estimated the cost of this technology using the costs estimated in the 2017-2025 light-duty rule for a light-duty pickup strong HEV. There we estimated the cost at $2729 (DMC, 2010$, in 2021) for a LD truck with a 5200 pound curb weight. We have then scaled upward that value using the ratio of test weights for HD pickups in our MY2014 market file (8739 pounds) to the test weight of the 5200 pound LD truck (5500 pounds). The resultant strong hybrid costs become $4335 (DMC, 2012$, in 2021) for HD pickups and vans. We consider this technology to be on the steep portion of the learning curve today but on the flat portion by 2021 (curve 11) and have applied high complexity level 1 with short term markups through 2024. The resultant technology costs are shown in Table 2-179 for HD pickups and vans.

Table 2-179 Costs of Strong Hybrid HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Strong HEV	DMC	$4,335	$4,205	$4,079	$3,957	$3,838	$3,723	$3,648
Strong HEV	IC	$2,443	$2,435	$2,427	$2,419	$1,482	$1,478	$1,476
Strong HEV	TC	$6,779	$6,640	$6,506	$6,376	$5,320	$5,201	$5,124

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For vocational vehicle strong hybrids, we have scaled upward from the HD pickup and van values using best estimates of curb weights. For vocational vehicles, we have used curb weights of 16,000 for light HD, 25,150 for medium HD and 42,000 for heavy HD relative to a 6500 pound value for HD pickups. Scaling based on curb weight here should provide an acceptable scaling of costs with battery and motor sizes since those are generally directly correlated with the weight of the vehicle itself. Using these scaling factors results in costs for complete hybrid systems for light, medium and heavy HD, respectively, of $10,672, $16,774 and $28,013 (DMC, 2012$, in 2021). We consider this technology to be on the steep portion of the learning curve today but on the flat portion by 2021 (curve 11) and have applied high complexity level 1 with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown are shown in Table 2-180 for light HD, in Table 2-181 for medium HD and in Table 2-182 for heavy HD vocational vehicles.

Table 2-180 Costs for Strong Hybrid Vocational Light HD Urban/Multipurpose Vehicles (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Strong HEV	DMC	$16,674	$13,340	$13,340	$10,672	$10,351	$10,041	$9,740	$9,448	$9,164	$8,981
Strong HEV	IC	$4,975	$4,731	$4,731	$4,536	$4,512	$2,849	$2,838	$2,827	$2,817	$2,810
Strong HEV	TC	$21,649	$18,070	$18,070	$15,207	$14,864	$12,890	$12,578	$12,275	$11,981	$11,791
Strong HEV	Alt 1a										
Strong HEV	Alt 3				4%	4%	4%	7%	7%	7%	18%
Strong HEV	TCp	$0	$0	$0	$547	$535	$464	$906	$884	$863	$2,122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-181 Costs for Strong Hybrid
Vocational Medium HD Urban/Multipurpose Vehicles (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Strong HEV	DMC	$26,210	$20,968	$20,968	$16,774	$16,271	$15,783	$15,310	$14,850	$14,405	$14,117
Strong HEV	IC	$7,820	$7,436	$7,436	$7,129	$7,093	$4,478	$4,461	$4,444	$4,428	$4,418
Strong HEV	TC	$34,030	$28,404	$28,404	$23,904	$23,364	$20,262	$19,771	$19,295	$18,833	$18,534
Strong HEV	Alt 1a										
Strong HEV	Alt 3				4%	4%	4%	7%	7%	7%	18%
Strong HEV	TCp	$0	$0	$0	$861	$841	$729	$1,424	$1,389	$1,356	$3,336

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-182 Costs for Strong Hybrid
Vocational Heavy HD Urban/Multipurpose Vehicles (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Strong HEV	DMC	$43,770	$35,016	$35,016	$28,013	$27,173	$26,357	$25,567	$24,800	$24,056	$23,575
Strong HEV	IC	$13,059	$12,418	$12,418	$11,906	$11,844	$7,479	$7,450	$7,422	$7,395	$7,377
Strong HEV	TC	$56,829	$47,435	$47,435	$39,919	$39,017	$33,836	$33,017	$32,222	$31,451	$30,952
Strong HEV	Alt 1a										
Strong HEV	Alt 3				4%	4%	4%	7%	7%	7%	18%
Strong HEV	TCp	$0	$0	$0	$1,437	$1,405	$1,218	$2,377	$2,320	$2,264	$5,571

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.7.2 Mild hybrid electric vehicle (mild HEV)

We have estimated the cost of this technology using the costs estimated in the 2017-2025 light-duty rule for a light-duty pickup mild HEV. There we estimated the cost at $983 (DMC, 2010$, in 2021) for a LD truck with a 3500 pound curb weight. We have then scaled upward that value using the ratio of curb weights for HD pickups of 6500 pounds to the 3500 pound curb weight. The resultant mild hybrid costs become $1894 (DMC, 2012$, in 2017) for HD pickups and vans. We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied high complexity level 1 with short term markups through 2024. The resultant technology costs are shown in Table 2-183 for HD pickups and vans.

Table 2-183 Costs of Mild Hybrid
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$1,677	$1,626	$1,594	$1,562	$1,531	$1,500	$1,470
Mild HEV	IC	$1,053	$1,050	$1,048	$1,046	$643	$642	$641
Mild HEV	TC	$2,730	$2,677	$2,642	$2,608	$2,173	$2,142	$2,111

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For tractors, we have estimated the cost of this technology based on an estimate from TetraTech of $20,000 (retail, 2013$). Using that value, we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $14,487 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a high complexity level 1 markup with short term markups through 2025. The resultant technology costs are shown in Table 2-184 (note that this technology is not expected to be used so the application rate is 0%).

Table 2-184 Costs for Mild Hybrid
Tractors (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$14,487	$14,052	$13,631	$13,222	$12,958	$12,698	$12,444	$12,196	$11,952	$11,713
Mild HEV	IC	$6,157	$6,125	$6,094	$6,065	$6,045	$6,026	$6,008	$5,989	$3,806	$3,798
Mild HEV	TC	$20,644	$20,178	$19,725	$19,287	$19,003	$18,725	$18,452	$18,185	$15,758	$15,510

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.12.7.3 Full electric vehicle (Full EV)

For vocational vehicle full EVs, we have used an estimate of $77888 (retail, 2013$) based on an estimate from The West Coast Collaborative.[175] Using that value, we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $56,418 (DMC, 2012$, in 2014). We consider this technology to be on the steep portion of the learning curve (curve 4) and have applied a high complexity level 1 markup with short term markups through 2028. The resultant technology costs are shown in Table 2-185.

Table 2-185 Costs of Full Electric Vehicle
Vocational Light/Medium HD (Urban/Multipurpose/Regional) Vehicles (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Full EV	DMC	$36,108	$35,025	$33,974	$32,955	$31,966	$31,007	$30,077	$29,174	$28,591	$28,019
Full EV	IC	$22,492	$22,413	$22,336	$22,262	$22,189	$22,119	$22,051	$21,985	$21,942	$21,900
Full EV	TC	$58,600	$57,438	$56,310	$55,216	$54,155	$53,126	$52,128	$51,159	$50,533	$49,920

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For day cab tractor full EVs, we have used an estimate of $203,000 (retail, 2012$) based on an estimate from the California Energy Commission. Using that value, we divided by a 1.36

RPE to arrive at a cost of $149,265 (DMC, 2012$, in 2014). We consider this technology to be on the steep portion of the learning curve (curve 4) and have applied a high complexity level 1 markup with short term markups through 2028. The resultant technology costs are shown in Table 2-186.

Table 2-186 Costs for Full Electric Vehicle Day Cab Tractors (2012$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Full EV	DMC	$95,529	$92,664	$89,884	$87,187	$84,572	$82,034	$79,573	$77,186	$75,642	$74,130
Full EV	IC	$59,507	$59,297	$59,094	$58,897	$58,705	$58,520	$58,340	$58,165	$58,052	$57,941
Full EV	TC	$155,036	$151,961	$148,978	$146,084	$143,277	$140,554	$137,913	$135,351	$133,694	$132,071

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.8 Tires

2.12.8.1 Lower rolling resistance tires ($/tire)

We have estimated the cost of lower rolling resistance tires based on an estimate from TetraTech of $30 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $22 (DMC, 2012$) but consider that cost valid in different years depending on the level of rolling resistance. For LRR tires level 1 and 2, we consider that $22 value valid in 2014, level 3 in 2018, and level 4 in 2021. We consider this technology to be on the flat portion of the curve with LRR tires level 1 and 2 on curve 4, LRR tires level 3 on curve 12 and LRR tires level 4 on curve 13. We have applied a low complexity markup to LRR tires levels 1 and 3 with short term markups through 2022. For LRR tires level 3, we have applied a medium complexity markup with short term markups through 2025 and, for LRR tires level 4, we have applied a medium complexity markup with short term markups through 2028. As a result, despite using the same DMC for each level of rolling resistance, our tire costs can vary considerably year-over-year for each of the 4 levels of rolling resistance considered. The resultant costs on a per-tire basis are shown in Table 2-187. Table 2-188 through Table 2-202 show the costs per vehicle depending on the number of tires present on the vehicle.

Table 2-187 Costs for Lower Rolling Resistance Tires at each LRR level (2012$/tire)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	DMC	$19	$19	$18	$18	$18	$17	$17	$17	$17	$16
LRR – level 2	DMC	$19	$19	$18	$18	$18	$17	$17	$17	$17	$16
LRR – level 3	DMC	$22	$21	$20	$20	$19	$19	$19	$18	$18	$18
LRR – level 4	DMC	$24	$23	$22	$22	$21	$20	$20	$19	$19	$19
LRR – level 1	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
LRR – level 2	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
LRR – level 3	IC	$7	$7	$7	$6	$6	$6	$6	$6	$5	$5
LRR – level 4	IC	$7	$7	$7	$7	$7	$7	$6	$6	$6	$6
LRR – level 1	TC	$23	$23	$22	$22	$22	$20	$20	$20	$20	$19
LRR – level 2	TC	$23	$23	$22	$22	$22	$20	$20	$20	$20	$19
LRR – level 3	TC	$28	$28	$27	$26	$26	$25	$25	$25	$23	$22
LRR – level 4	TC	$30	$30	$29	$28	$28	$27	$26	$26	$25	$25

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.8.2 Lower RR steer tires, All Vocational Vehicles

Table 2-188 Costs for Lower Rolling Resistance Steer Tires All Vocational Vehicles (2012$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 2	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 3	TC	$57	$55	$54	$53	$52	$51	$50	$49	$45	$45
LRR – level 4	TC	$61	$59	$58	$57	$55	$54	$53	$52	$51	$50
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a										
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR –	Alt 3	100%	100%	100%	20%	20%	20%	10%	10%	10%	0%

level 1											
LRR – level 2	Alt 3										
LRR – level 3	Alt 3				80%	80%	80%	30%	30%	30%	20%
LRR – level 4	Alt 3							60%	60%	60%	80%
LRR – level 1	TCp	$0	$0	$0	-$35	-$35	-$33	-$36	-$35	-$35	-$39
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$42	$41	$41	$15	$15	$14	$9
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$32	$31	$31	$40

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.3 Lower RR drive tires, All Vocational Light/Medium HD Vehicles

Table 2-189 Costs for Lower Rolling Resistance Drive Tires Vocational Light/Medium HD Vehicles (2012$/vehicle @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 2	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 3	TC	$113	$110	$108	$105	$104	$102	$100	$99	$91	$89
LRR – level 4	TC	$122	$119	$116	$113	$110	$108	$105	$104	$102	$100
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a										
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	100%	100%	100%	50%	50%	50%	20%	20%	20%	10%
LRR – level 2	Alt 3				50%	50%	50%	50%	50%	50%	25%
LRR – level 3	Alt 3							30%	30%	30%	50%
LRR – level 4	Alt 3										15%
LRR – level 1	TCp	$0	$0	$0	-$44	-$43	-$41	-$64	-$63	-$63	-$70
LRR – level 2	TCp	$0	$0	$0	$44	$43	$41	$40	$39	$39	$19
LRR –	TCp	$0	$0	$0	$0	$0	$0	$30	$30	$27	$45

level 3											
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$15

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.4 Lower RR drive tires, Vocational Heavy HD Vehicles

Table 2-190 Costs for Lower Rolling Resistance Drive Tires Vocational Heavy HD Vehicles (2012$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 3	TC	$226	$221	$216	$210	$207	$204	$201	$198	$182	$179
LRR – level 4	TC	$244	$238	$232	$226	$221	$216	$210	$207	$204	$201
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a										
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	100%	100%	100%	50%	50%	50%	20%	20%	20%	10%
LRR – level 2	Alt 3				50%	50%	50%	50%	50%	50%	25%
LRR – level 3	Alt 3							30%	30%	30%	50%
LRR – level 4	Alt 3										15%
LRR – level 1	TCp	$0	$0	$0	-$88	-$86	-$82	-$128	-$126	-$125	-$140
LRR – level 2	TCp	$0	$0	$0	$88	$86	$82	$80	$79	$78	$39
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$60	$59	$54	$89
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$30

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.5 Lower RR steer tires, Day cab low roof tractors

Table 2-191 Costs for Lower Rolling Resistance Steer Tires
Day Cab Low Roof Tractors
(2012$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 2	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 3	TC	$57	$55	$54	$53	$52	$51	$50	$49	$45	$45
LRR – level 4	TC	$61	$59	$58	$57	$55	$54	$53	$52	$51	$50
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	50%	50%	50%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	10%	10%	10%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	$4	$4	$4	$0	$0	$0	-$12
LRR – level 2	TCp	$0	$0	$0	$7	$6	$6	$8	$8	$8	$16
LRR – level 3	TCp	$0	$0	$0	$5	$5	$5	$8	$7	$7	$11
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.6 Lower RR steer tires, Day cab high roof tractors

Table 2-192 Costs for Lower Rolling Resistance Steer Tires
Day Cab High Roof Tractors
(2012$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 2	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR –	TC	$57	$55	$54	$53	$52	$51	$50	$49	$45	$45

level 3											
LRR – level 4	TC	$61	$59	$58	$57	$55	$54	$53	$52	$51	$50
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	70%	70%	70%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	20%	20%	20%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	-$4	-$4	-$4	-$8	-$8	-$8	-$19
LRR – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$12
LRR – level 3	TCp	$0	$0	$0	$5	$5	$5	$8	$7	$7	$11
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.7 Lower RR steer tires, Sleeper cab low/mid roof tractors

Table 2-193 Costs for Lower Rolling Resistance Steer Tires
Sleeper Cab Low/Mid Roof Tractors
(2012$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 2	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 3	TC	$57	$55	$54	$53	$52	$51	$50	$49	$45	$45
LRR – level 4	TC	$61	$59	$58	$57	$55	$54	$53	$52	$51	$50
LRR – level 1	Alt 1a	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR –	Alt 3	60%	60%	60%	60%	60%	60%	50%	50%	50%	20%

level 1											
LRR – level 2	Alt 3	10%	10%	10%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	-$4	-$4	-$4	-$16
LRR – level 2	TCp	$0	$0	$0	$7	$6	$6	$8	$8	$8	$16
LRR – level 3	TCp	$0	$0	$0	$5	$5	$5	$8	$7	$7	$11
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.8 Lower RR steer tires, Sleeper cab high roof tractors

Table 2-194 Costs for Lower Rolling Resistance Steer Tires Sleeper Cab High Roof Tractors (2012$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 2	TC	$46	$45	$45	$44	$43	$41	$40	$39	$39	$39
LRR – level 3	TC	$57	$55	$54	$53	$52	$51	$50	$49	$45	$45
LRR – level 4	TC	$61	$59	$58	$57	$55	$54	$53	$52	$51	$50
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	70%	70%	70%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	20%	20%	20%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	-$4	-$4	-$4	-$8	-$8	-$8	-$19
LRR – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$12
LRR –	TCp	$0	$0	$0	$5	$5	$5	$8	$7	$7	$11

level 3											
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.9 Lower RR drive tires, Class 7 Day cab low roof tractors

Table 2-195 Costs for Lower Rolling Resistance Drive Tires Class 7 Day Cab Low Roof Tractors (2012$/vehicle @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 2	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 3	TC	$113	$110	$108	$105	$104	$102	$100	$99	$91	$89
LRR – level 4	TC	$122	$119	$116	$113	$110	$108	$105	$104	$102	$100
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	50%	50%	50%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	10%	10%	10%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	$9	$9	$8	$0	$0	$0	-$23
LRR – level 2	TCp	$0	$0	$0	$13	$13	$12	$16	$16	$16	$31
LRR – level 3	TCp	$0	$0	$0	$11	$10	$10	$15	$15	$14	$22
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.10 Lower RR drive tires, Class 8 Day cab low roof tractors

Table 2-196 Costs for Lower Rolling Resistance Drive Tires
Class 8 Day Cab Low Roof Tractors
(2012$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 3	TC	$226	$221	$216	$210	$207	$204	$201	$198	$182	$179
LRR – level 4	TC	$244	$238	$232	$226	$221	$216	$210	$207	$204	$201
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	50%	50%	50%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	10%	10%	10%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	$18	$17	$16	$0	$0	$0	-$47
LRR – level 2	TCp	$0	$0	$0	$26	$26	$24	$32	$32	$31	$62
LRR – level 3	TCp	$0	$0	$0	$21	$21	$20	$30	$30	$27	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.11 Lower RR drive tires, Class 7 Day cab high roof tractors

Table 2-197 Costs for Lower Rolling Resistance Drive Tires Class 7 Day Cab High Roof Tractors (2012$/vehicle @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 2	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR – level 3	TC	$113	$110	$108	$105	$104	$102	$100	$99	$91	$89
LRR – level 4	TC	$122	$119	$116	$113	$110	$108	$105	$104	$102	$100
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	70%	70%	70%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	20%	20%	20%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	-$9	-$9	-$8	-$16	-$16	-$16	-$39
LRR – level 2	TCp	$0	$0	$0	$4	$4	$4	$8	$8	$8	$23
LRR – level 3	TCp	$0	$0	$0	$11	$10	$10	$15	$15	$14	$22
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.12 Lower RR drive tires, Class 8 Day cab high roof tractors

Table 2-198 Costs for Lower Rolling Resistance Drive Tires
Class 8 Day Cab High Roof Tractors
(2012$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 3	TC	$226	$221	$216	$210	$207	$204	$201	$198	$182	$179
LRR – level 4	TC	$244	$238	$232	$226	$221	$216	$210	$207	$204	$201
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	70%	70%	70%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	20%	20%	20%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	-$18	-$17	-$16	-$32	-$32	-$31	-$78
LRR – level 2	TCp	$0	$0	$0	$9	$9	$8	$16	$16	$16	$47
LRR – level 3	TCp	$0	$0	$0	$21	$21	$20	$30	$30	$27	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.13 Lower RR drive tires, Class 8 Sleeper cab low/mid roof tractors

Table 2-199 Costs for Lower Rolling Resistance Drive Tires Class 8 Sleeper Cab Low/Mid Roof Tractors (2012$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 3	TC	$226	$221	$216	$210	$207	$204	$201	$198	$182	$179
LRR – level 4	TC	$244	$238	$232	$226	$221	$216	$210	$207	$204	$201
LRR – level 1	Alt 1a	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	60%	60%	60%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	10%	10%	10%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	-$16	-$16	-$16	-$62
LRR – level 2	TCp	$0	$0	$0	$26	$26	$24	$32	$32	$31	$62
LRR – level 3	TCp	$0	$0	$0	$21	$21	$20	$30	$30	$27	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.14 Lower RR drive tires, Class 8 Sleeper cab high roof tractors

Table 2-200 Costs for Lower Rolling Resistance Drive Tires
Class 8 Sleeper Cab High Roof Tractors
(2012$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR – level 3	TC	$226	$221	$216	$210	$207	$204	$201	$198	$182	$179
LRR – level 4	TC	$244	$238	$232	$226	$221	$216	$210	$207	$204	$201
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a										
LRR – level 4	Alt 1a										
LRR – level 1	Alt 3	70%	70%	70%	60%	60%	60%	50%	50%	50%	20%
LRR – level 2	Alt 3	20%	20%	20%	25%	25%	25%	30%	30%	30%	50%
LRR – level 3	Alt 3				10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3										
LRR – level 1	TCp	$0	$0	$0	-$18	-$17	-$16	-$32	-$32	-$31	-$78
LRR – level 2	TCp	$0	$0	$0	$9	$9	$8	$16	$16	$16	$47
LRR – level 3	TCp	$0	$0	$0	$21	$21	$20	$30	$30	$27	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.15 Lower RR tires, 53-foot dry van & reefer

Table 2-201 Costs for Lower Rolling Resistance Tires
53-foot Dry Van & Reefer Highway Trailers
(2012$/trailer @ 8 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR–level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR–level 1	Alt 1a	50%	51%	52%	53%	54%	56%	57%	58%	59%	60%
LRR–level 2	Alt 1a										
LRR–level 1	Alt 3	85%	85%	85%	90%	90%	90%				
LRR–level 2	Alt 3							95%	95%	95%	95%
LRR–level 1	TCp	$65	$62	$59	$65	$62	$56	-$91	-$91	-$92	-$93
LRR–level 2	TCp	$0	$0	$0	$0	$0	$0	$152	$150	$149	$147

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.16 Lower RR tires, 28-foot dry van

Table 2-202 Costs for Lower Rolling Resistance Tires
28-foot Dry Van Trailers
(2012$/trailer @ 4 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR–level 2	TC	$92	$91	$89	$88	$86	$82	$80	$79	$78	$78
LRR–level 1	Alt 1a										
LRR–level 2	Alt 1a										
LRR–level 1	Alt 3	85%	85%	85%	90%	90%	90%				
LRR–level 2	Alt 3							95%	95%	95%	95%
LRR–level 1	TCp	$78	$77	$76	$79	$78	$73	$0	$0	$0	$0
LRR–level 2	TCp	$0	$0	$0	$0	$0	$0	$76	$75	$74	$74

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.17 Lower RR tires, Non-box highway trailers

Table 2-203 Costs for Lower Rolling Resistance Tires
Other Non-Box Highway Trailers
(2012$/trailer @ 4 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR–level 2	TC	$185	$182	$178	$175	$173	$163	$160	$158	$156	$155
LRR–level 1	Alt 1a										
LRR–level 2	Alt 1a										
LRR–level 1	Alt 3	100%	100%	100%	100%	100%	100%				
LRR–level 2	Alt 3							100%	100%	100%	100%
LRR–level 1	TCp	$185	$182	$178	$175	$173	$163	$0	$0	$0	$0
LRR–level 2	TCp	$0	$0	$0	$0	$0	$0	$160	$158	$156	$155

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.8.18 Lower RR tires, HD pickup & van ($/tire)

We have estimated the costs of lower rolling resistance tires for HD pickups and vans using the costs used in the 2017-2025 light-duty FRM. In that rule, we estimated the costs of lower rolling resistance tires level 1 at $5/vehicle including a spare (DMC, 2010$, in all years) and level 2 at $40/vehicle assuming no spare (DMC, 2010$, in 2021). For HD pickups and vans, we have scaled upward both of those costs by 50 percent to account for the heavier and larger HD tires. We consider the level 1 tires to be learned out (curve 1) and the level 2 tires to be on the steep portion of the curve until 2021 after which it is on the flatter portion of the curve (curve 11). We have applied a low complexity markup to both with short term markups through 2018 for level 1 and through 2024 for level 2. With the exception of the 50 percent scaling factor, all LRR tire costs for HD pickups and vans are identical to the 2017-2025 light-duty FRM. The resultant costs are presented in Table 2-204.

Table 2-204 Costs for Lower Rolling Resistance Tires
HD Pickups & Vans
(2012$ @ 4 tires/vehicle)

ITEM		2021	2022	2023	2024	2025	2026	2027
LRR – level 1	DMC	$8	$8	$8	$8	$8	$8	$8
LRR – level 2	DMC	$63	$61	$59	$58	$56	$54	$53
LRR – level 1	IC	$2	$2	$2	$2	$2	$2	$2
LRR – level 2	IC	$15	$15	$15	$15	$12	$12	$12
LRR – level 1	TC	$10	$10	$10	$10	$10	$10	$10
LRR – level 2	TC	$78	$76	$74	$73	$68	$66	$65

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.8.19 Automatic Tire Inflation Systems (ATIS)

For tractors, we have estimated the cost of this technology based on an estimate from TetraTech of $1143 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $828 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-205 for tractors.

Table 2-205 Costs for Automatic Tire Inflation Systems
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$828	$803	$779	$755	$740	$725	$711	$697	$683	$669
ATIS	IC	$148	$147	$147	$147	$147	$115	$115	$115	$115	$115
ATIS	TC	$975	$950	$926	$902	$887	$841	$826	$812	$798	$784
ATIS	Alt 1a										
ATIS	Alt 3				20%	20%	20%	40%	40%	40%	40%
ATIS	TCp	$0	$0	$0	$180	$177	$168	$330	$325	$319	$314

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For trailers, we have estimated the cost of this technology based on an estimate from TetraTech of $800 (retail, 2013$). We consider this estimate to be valid for all trailers except tandems. For tandems, we have used an estimate of $600 (retail, 2013$) since they have just one axle. Using these estimates we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $579 (DMC, 2012$, in 2018) for all but tandems and $435 (DMC, 2012$, in 2018) for tandems. We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-206 for 53-foot dry and reefer vans, in Table 2-207 for 28-foot dry vans and in Table 2-208 for non-box highway trailers.

Table 2-206 Costs for Automatic Tire Inflation Systems
53-foot Dry and Reefer Van Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$579	$562	$545	$529	$518	$508	$498	$488	$478	$469
ATIS	IC	$103	$103	$103	$103	$103	$81	$81	$81	$81	$80
ATIS	TC	$683	$665	$648	$632	$621	$589	$578	$568	$559	$549
ATIS	Alt 1a	50%	51%	52%	53%	54%	56%	57%	58%	59%	60%
ATIS	Alt 3	85%	85%	85%	90%	90%	90%	95%	95%	95%	95%
ATIS	TCp	$239	$226	$214	$234	$224	$200	$220	$210	$201	$192

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-207 Costs for Automatic Tire Inflation Systems
28-foot Dry Van Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$435	$422	$409	$397	$389	$381	$373	$366	$359	$351
ATIS	IC	$78	$77	$77	$77	$77	$61	$60	$60	$60	$60
ATIS	TC	$512	$499	$486	$474	$466	$441	$434	$426	$419	$412
ATIS	Alt 1a										
ATIS	Alt 3	85%	85%	85%	90%	90%	90%	95%	95%	95%	95%
ATIS	TCp	$435	$424	$413	$426	$419	$397	$412	$405	$398	$391

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-208 Costs for Automatic Tire Inflation Systems
Non-box Highway Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$579	$562	$545	$529	$518	$508	$498	$488	$478	$469
ATIS	IC	$103	$103	$103	$103	$103	$81	$81	$81	$81	$80
ATIS	TC	$683	$665	$648	$632	$621	$589	$578	$568	$559	$549
ATIS	Alt 1a										
ATIS	Alt 3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
ATIS	TCp	$683	$665	$648	$632	$621	$589	$578	$568	$559	$549

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9 **Aerodynamic Improvements (aero)**

The agencies' estimates for cost of tractor aero features are based the work done by ICF in support of the Phase 1 HD rules. For trailers, we have based our estimates on the work presented in the ICCT trailer technology report.[176]

2.12.9.1 Aero improvements, Day cab low roof tractors

For low roof day cab tractors, Aero Bin 2 costs are estimated at $1001, Bin 3 at $2022 and Bin 4 at $2578 (all are DMC, in 2012$, and applicable in 2014). We consider Bin 2 technologies to be beyond the effects of learning (curve 1), Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to each with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-209.

Table 2-209 Costs of Aero Technologies
Day Cab Low Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$1,001	$1,001	$1,001	$1,001	$1,001	$1,001	$1,001	$1,001	$1,001	$1,001
Aero Bin3	DMC	$1,790	$1,755	$1,719	$1,685	$1,651	$1,618	$1,586	$1,554	$1,539	$1,523
Aero Bin4	DMC	$1,650	$1,601	$1,553	$1,506	$1,461	$1,417	$1,375	$1,333	$1,307	$1,281
Aero Bin2	IC	$179	$179	$179	$179	$179	$140	$140	$140	$140	$140
Aero Bin3	IC	$358	$357	$357	$356	$356	$281	$281	$280	$280	$280
Aero Bin4	IC	$448	$447	$447	$446	$445	$354	$354	$353	$353	$353
Aero Bin2	TC	$1,180	$1,180	$1,180	$1,180	$1,180	$1,141	$1,141	$1,141	$1,141	$1,141
Aero Bin3	TC	$2,148	$2,112	$2,076	$2,041	$2,007	$1,899	$1,867	$1,835	$1,819	$1,803
Aero Bin4	TC	$2,098	$2,048	$1,999	$1,952	$1,906	$1,771	$1,728	$1,687	$1,660	$1,634
Aero Bin2	Alt 1a	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
Aero Bin3	Alt 1a										
Aero Bin4	Alt 1a										
Aero Bin2	Alt 3	60%	60%	60%	75%	75%	75%	60%	60%	60%	50%
Aero Bin3	Alt 3				25%	25%	25%	38%	38%	38%	40%
Aero Bin4	Alt 3							2%	2%	2%	10%
Aero Bin2	TCp	$0	$0	$0	$177	$177	$171	$0	$0	$0	-$114
Aero Bin3	TCp	$0	$0	$0	$510	$502	$475	$709	$697	$691	$721
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$35	$34	$33	$163

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9.2 Aero improvements, Day cab high roof tractors

For high roof day cab tractors, Aero Bin 3 costs are estimated at $1028, Bin 4 at $2049, Bin 5 at $2612, Bin 6 at $3176 and Bin 7 at $3739 (all are DMC, in 2012$, and applicable in 2014). We consider Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 through 7 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to Bins 3 and 4 with short term markups through 2022. We have applied medium complexity ICMs to Bins 5 through 7 with short term markups through 2025. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-210.

Table 2-210 Costs of Aero Technologies
Day Cab High Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$910	$892	$874	$856	$839	$822	$806	$790	$782	$774
Aero Bin4	DMC	$1,311	$1,272	$1,234	$1,197	$1,161	$1,126	$1,092	$1,059	$1,038	$1,017
Aero Bin5	DMC	$1,672	$1,622	$1,573	$1,526	$1,480	$1,436	$1,393	$1,351	$1,324	$1,297
Aero Bin6	DMC	$2,032	$1,971	$1,912	$1,855	$1,799	$1,745	$1,693	$1,642	$1,609	$1,577
Aero Bin7	DMC	$2,393	$2,321	$2,252	$2,184	$2,118	$2,055	$1,993	$1,933	$1,895	$1,857
Aero Bin3	IC	$182	$182	$181	$181	$181	$143	$143	$142	$142	$142
Aero Bin4	IC	$356	$355	$355	$354	$354	$281	$281	$281	$281	$281
Aero Bin5	IC	$742	$740	$737	$735	$732	$730	$728	$726	$544	$543
Aero Bin6	IC	$902	$899	$896	$893	$890	$888	$885	$882	$661	$660
Aero Bin7	IC	$1,062	$1,059	$1,055	$1,052	$1,048	$1,045	$1,042	$1,039	$779	$777
Aero Bin3	TC	$1,092	$1,073	$1,055	$1,037	$1,020	$965	$949	$932	$924	$916
Aero Bin4	TC	$1,667	$1,627	$1,589	$1,551	$1,515	$1,407	$1,373	$1,340	$1,319	$1,298
Aero Bin5	TC	$2,414	$2,361	$2,310	$2,260	$2,212	$2,166	$2,120	$2,077	$1,868	$1,840
Aero Bin6	TC	$2,934	$2,870	$2,808	$2,748	$2,690	$2,633	$2,578	$2,524	$2,271	$2,237
Aero Bin7	TC	$3,455	$3,380	$3,307	$3,236	$3,167	$3,100	$3,035	$2,972	$2,674	$2,634
Aero Bin3	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Aero Bin4	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Aero Bin5	Alt 1a										
Aero Bin6	Alt 1a										
Aero Bin7	Alt 1a										
Aero Bin3	Alt 3	70%	70%	70%	40%	40%	40%	30%	30%	30%	20%
Aero Bin4	Alt 3	20%	20%	20%	35%	35%	35%	30%	30%	30%	20%
Aero Bin5	Alt 3				20%	20%	20%	25%	25%	25%	35%
Aero Bin6	Alt 3				5%	5%	5%	13%	13%	13%	20%
Aero Bin7	Alt 3							2%	2%	2%	5%
Aero Bin3	TCp	$0	$0	$0	-$311	-$306	-$290	-$379	-$373	-$370	-$458
Aero Bin4	TCp	$0	$0	$0	$233	$227	$211	$137	$134	$132	$0
Aero Bin5	TCp	$0	$0	$0	$452	$442	$433	$530	$519	$467	$644
Aero Bin6	TCp	$0	$0	$0	$137	$134	$132	$335	$328	$295	$447
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$61	$59	$53	$132

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9.3 Aero improvements, Sleeper cab low/mid roof tractors

For low and mid roof sleeper cab tractors, Aero Bin 2 costs are estimated at $1222, Bin 3 at $2313 and Bin 4 at $2949 (all are DMC, in 2012$, and applicable in 2014). We consider Bin 2 technologies to be beyond the effects of learning (curve 1), Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to each with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-211.

Table 2-211 Costs of Aero Technologies
Sleeper Cab Low/Mid Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$1,222	$1,222	$1,222	$1,222	$1,222	$1,222	$1,222	$1,222	$1,222	$1,222
Aero Bin3	DMC	$2,048	$2,007	$1,967	$1,928	$1,889	$1,851	$1,814	$1,778	$1,760	$1,742
Aero Bin4	DMC	$1,888	$1,831	$1,776	$1,723	$1,671	$1,621	$1,572	$1,525	$1,495	$1,465
Aero Bin2	IC	$218	$218	$218	$218	$218	$171	$171	$171	$171	$171
Aero Bin3	IC	$409	$409	$408	$408	$407	$321	$321	$321	$321	$320
Aero Bin4	IC	$512	$512	$511	$510	$509	$405	$405	$404	$404	$404
Aero Bin2	TC	$1,440	$1,440	$1,440	$1,440	$1,440	$1,393	$1,393	$1,393	$1,393	$1,393
Aero Bin3	TC	$2,457	$2,416	$2,375	$2,335	$2,296	$2,172	$2,135	$2,099	$2,081	$2,063
Aero Bin4	TC	$2,400	$2,343	$2,287	$2,233	$2,181	$2,026	$1,977	$1,930	$1,899	$1,869
Aero Bin2	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Aero Bin3	Alt 1a										
Aero Bin4	Alt 1a										
Aero Bin2	Alt 3	70%	70%	70%	75%	75%	75%	60%	60%	60%	50%
Aero Bin3	Alt 3				25%	25%	25%	38%	38%	38%	40%
Aero Bin4	Alt 3							2%	2%	2%	10%
Aero Bin2	TCp	$0	$0	$0	$72	$72	$70	-$139	-$139	-$139	-$279
Aero Bin3	TCp	$0	$0	$0	$584	$574	$543	$811	$797	$791	$825
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$40	$39	$38	$187

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9.4 Aero improvements, Sleeper cab high roof tractors

For high roof sleeper cab tractors, Aero Bin 3 costs are estimated at $1387, Bin 4 at $2379, Bin 5 at $3034, Bin 6 at $3688 and Bin 7 at $4342 (all are DMC, in 2012$, and applicable in 2014). We consider Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 through 7 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to Bins 3 and 4 with short term markups through 2022. We have applied medium complexity ICMs to Bins 5 through 7 with short term markups through 2025. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-212.

Table 2-212 Costs of Aero Technologies
Sleeper Cab High Roof Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$1,228	$1,204	$1,180	$1,156	$1,133	$1,110	$1,088	$1,066	$1,056	$1,045
Aero Bin4	DMC	$1,523	$1,477	$1,433	$1,390	$1,348	$1,308	$1,268	$1,230	$1,206	$1,182
Aero Bin5	DMC	$1,942	$1,883	$1,827	$1,772	$1,719	$1,667	$1,617	$1,569	$1,537	$1,507
Aero Bin6	DMC	$2,360	$2,290	$2,221	$2,154	$2,090	$2,027	$1,966	$1,907	$1,869	$1,832
Aero Bin7	DMC	$2,779	$2,696	$2,615	$2,536	$2,460	$2,387	$2,315	$2,246	$2,201	$2,157
Aero Bin3	IC	$245	$245	$245	$245	$244	$193	$192	$192	$192	$192
Aero Bin4	IC	$413	$413	$412	$412	$411	$327	$326	$326	$326	$326
Aero Bin5	IC	$862	$859	$856	$853	$851	$848	$845	$843	$632	$631
Aero Bin6	IC	$1,048	$1,044	$1,041	$1,037	$1,034	$1,031	$1,028	$1,025	$768	$767
Aero Bin7	IC	$1,234	$1,229	$1,225	$1,221	$1,217	$1,214	$1,210	$1,207	$904	$903
Aero Bin3	TC	$1,474	$1,449	$1,425	$1,401	$1,377	$1,303	$1,281	$1,259	$1,248	$1,237
Aero Bin4	TC	$1,936	$1,890	$1,845	$1,801	$1,759	$1,634	$1,595	$1,557	$1,532	$1,508
Aero Bin5	TC	$2,803	$2,742	$2,683	$2,625	$2,569	$2,515	$2,463	$2,412	$2,169	$2,137
Aero Bin6	TC	$3,408	$3,334	$3,262	$3,192	$3,124	$3,058	$2,994	$2,932	$2,637	$2,598
Aero Bin7	TC	$4,013	$3,925	$3,840	$3,758	$3,678	$3,600	$3,525	$3,452	$3,105	$3,060
Aero Bin3	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Aero Bin4	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Aero Bin5	Alt 1a										
Aero Bin6	Alt 1a										
Aero Bin7	Alt 1a										
Aero Bin3	Alt 3	70%	70%	70%	40%	40%	40%	30%	30%	30%	20%
Aero Bin4	Alt 3	20%	20%	20%	35%	35%	35%	30%	30%	30%	20%
Aero Bin5	Alt 3				20%	20%	20%	25%	25%	25%	35%
Aero Bin6	Alt 3				5%	5%	5%	13%	13%	13%	20%
Aero Bin7	Alt 3							2%	2%	2%	5%
Aero Bin3	TCp	$0	$0	$0	-$420	-$413	-$391	-$512	-$503	-$499	-$619
Aero Bin4	TCp	$0	$0	$0	$270	$264	$245	$159	$156	$153	$0
Aero Bin5	TCp	$0	$0	$0	$525	$514	$503	$616	$603	$542	$748
Aero Bin6	TCp	$0	$0	$0	$160	$156	$153	$389	$381	$343	$520
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$71	$69	$62	$153

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9.5 Aero improvements, trailers

For dry and reefer van trailers, Aero Bin 3 costs are based on and ICCT estimate of $700 (retail, 2013$), Bin 4 costs are based on an ICCT estimate of $1000 (retail, 2013$), Bin 5 costs are based on an ICCT estimate of $1600 (retail, 2013$), Bin 6 costs are based on an ICCT estimate of $1900 (retail, 2013$), and Bin 7 costs are based on an ICCT estimate of $2200 (retail, 2013$). We have used these costs and divided by a 1.36 RPE and converted to 2012$ to arrive at direct manufacturing costs of $507, $724, $1159, $1376 and $1594 for Bins 3 through 7, respectively (all are DMC, in 2012$, applicable in 2014). We consider each of these technologies to be on the flat portion of the learning curve (curve 2) and have applied low complexity ICMs with short term markups through 2018. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-213 and Table 2-214 for 53-foot dry and reefer van trailers, respectively, and in Table 2-215 for 28-foot dry van trailers.

Table 2-213 Costs of Aero Technologies
53-foot Dry Van Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$449	$440	$431	$422	$414	$406	$398	$390	$386	$382
Aero Bin4	DMC	$641	$628	$616	$604	$591	$580	$568	$557	$551	$546
Aero Bin5	DMC	$1,026	$1,006	$985	$966	$946	$927	$909	$891	$882	$873
Aero Bin6	DMC	$1,218	$1,194	$1,170	$1,147	$1,124	$1,101	$1,079	$1,058	$1,047	$1,037
Aero Bin7	DMC	$1,411	$1,383	$1,355	$1,328	$1,301	$1,275	$1,250	$1,225	$1,212	$1,200
Aero Bin8	DMC	$1,860	$1,822	$1,786	$1,750	$1,715	$1,681	$1,647	$1,614	$1,598	$1,582
Aero Bin3	IC	$90	$71	$71	$71	$70	$70	$70	$70	$70	$70
Aero Bin4	IC	$128	$101	$101	$101	$101	$101	$100	$100	$100	$100
Aero Bin5	IC	$205	$161	$161	$161	$161	$161	$161	$161	$161	$161
Aero Bin6	IC	$244	$192	$191	$191	$191	$191	$191	$191	$191	$191
Aero Bin7	IC	$282	$222	$222	$222	$221	$221	$221	$221	$221	$221
Aero Bin8	IC	$372	$293	$292	$292	$292	$292	$291	$291	$291	$291
Aero Bin3	TC	$539	$511	$502	$493	$484	$476	$468	$460	$456	$452
Aero Bin4	TC	$769	$729	$717	$704	$692	$680	$669	$657	$652	$646
Aero Bin5	TC	$1,231	$1,167	$1,147	$1,127	$1,107	$1,088	$1,070	$1,051	$1,042	$1,034
Aero Bin6	TC	$1,462	$1,386	$1,362	$1,338	$1,315	$1,292	$1,270	$1,249	$1,238	$1,227
Aero Bin7	TC	$1,693	$1,604	$1,577	$1,549	$1,523	$1,496	$1,471	$1,446	$1,433	$1,421
Aero Bin8	TC	$2,231	$2,115	$2,078	$2,042	$2,007	$1,973	$1,939	$1,906	$1,889	$1,873
Aero Bin3	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Aero Bin4	Alt 1a	30%	31%	32%	33%	34%	36%	37%	38%	39%	40%
Aero Bin5	Alt 1a	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Aero Bin6	Alt 1a										
Aero Bin7	Alt 1a										
Aero Bin8	Alt 1a										
Aero Bin3	Alt 3	30%	30%	30%	5%	5%	5%				
Aero Bin4	Alt 3	60%	60%	60%	55%	55%	55%	25%	25%	25%	
Aero Bin5	Alt 3	5%	5%	5%	10%	10%	10%	10%	10%	10%	10%
Aero Bin6	Alt 3										
Aero Bin7	Alt 3				30%	30%	30%	65%	65%	65%	50%
Aero Bin8	Alt 3										40%
Aero Bin3	TCp	$54	$51	$50	-$74	-$73	-$71	-$94	-$92	-$91	-$90
Aero Bin4	TCp	$231	$212	$201	$155	$145	$129	-$80	-$85	-$91	-$258
Aero Bin5	TCp	$0	$0	$0	$56	$55	$54	$53	$53	$52	$52
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$465	$457	$449	$956	$940	$932	$711
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$749

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-214 Costs of Aero Technologies
Reefer Van Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$449	$440	$431	$422	$414	$406	$398	$390	$386	$382
Aero Bin4	DMC	$641	$628	$616	$604	$591	$580	$568	$557	$551	$546
Aero Bin5	DMC	$1,026	$1,006	$985	$966	$946	$927	$909	$891	$882	$873
Aero Bin6	DMC	$1,218	$1,194	$1,170	$1,147	$1,124	$1,101	$1,079	$1,058	$1,047	$1,037
Aero Bin7	DMC	$1,411	$1,383	$1,355	$1,328	$1,301	$1,275	$1,250	$1,225	$1,212	$1,200
Aero Bin8	DMC	$1,860	$1,822	$1,786	$1,750	$1,715	$1,681	$1,647	$1,614	$1,598	$1,582
Aero Bin3	IC	$90	$71	$71	$71	$70	$70	$70	$70	$70	$70
Aero Bin4	IC	$128	$101	$101	$101	$101	$101	$100	$100	$100	$100
Aero Bin5	IC	$205	$161	$161	$161	$161	$161	$161	$161	$161	$161
Aero Bin6	IC	$244	$192	$191	$191	$191	$191	$191	$191	$191	$191
Aero Bin7	IC	$282	$222	$222	$222	$221	$221	$221	$221	$221	$221
Aero Bin8	IC	$372	$293	$292	$292	$292	$292	$291	$291	$291	$291
Aero Bin3	TC	$539	$511	$502	$493	$484	$476	$468	$460	$456	$452
Aero Bin4	TC	$769	$729	$717	$704	$692	$680	$669	$657	$652	$646
Aero Bin5	TC	$1,231	$1,167	$1,147	$1,127	$1,107	$1,088	$1,070	$1,051	$1,042	$1,034
Aero Bin6	TC	$1,462	$1,386	$1,362	$1,338	$1,315	$1,292	$1,270	$1,249	$1,238	$1,227
Aero Bin7	TC	$1,693	$1,604	$1,577	$1,549	$1,523	$1,496	$1,471	$1,446	$1,433	$1,421
Aero Bin8	TC	$2,231	$2,115	$2,078	$2,042	$2,007	$1,973	$1,939	$1,906	$1,889	$1,873
Aero Bin3	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Aero Bin4	Alt 1a	30%	31%	32%	33%	34%	36%	37%	38%	39%	40%
Aero Bin5	Alt 1a	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Aero Bin6	Alt 1a										
Aero Bin7	Alt 1a										
Aero Bin8	Alt 1a										
Aero Bin3	Alt 3	30%	30%	30%	5%	5%	5%				
Aero Bin4	Alt 3	60%	60%	60%	55%	55%	55%	25%	25%	25%	
Aero Bin5	Alt 3	5%	5%	5%	10%	10%	10%	10%	10%	10%	20%
Aero Bin6	Alt 3										
Aero Bin7	Alt 3				30%	30%	30%	65%	65%	65%	60%
Aero Bin8	Alt 3										20%
Aero Bin3	TCp	$54	$51	$50	-$74	-$73	-$71	-$94	-$92	-$91	-$90
Aero Bin4	TCp	$231	$212	$201	$155	$145	$129	-$80	-$85	-$91	-$258
Aero Bin5	TCp	$0	$0	$0	$56	$55	$54	$53	$53	$52	$155
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$465	$457	$449	$956	$940	$932	$853
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$375

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-215 Costs of Aero Technologies
28-foot Dry Van Trailers (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$449	$440	$431	$422	$414	$406	$398	$390	$386	$382
Aero Bin4	DMC	$641	$628	$616	$604	$591	$580	$568	$557	$551	$546
Aero Bin5	DMC	$1,090	$1,068	$1,047	$1,026	$1,006	$985	$966	$946	$937	$928
Aero Bin3	IC	$90	$71	$71	$71	$70	$70	$70	$70	$70	$70
Aero Bin4	IC	$128	$101	$101	$101	$101	$101	$100	$100	$100	$100
Aero Bin5	IC	$218	$171	$171	$171	$171	$171	$171	$171	$171	$171
Aero Bin3	TC	$539	$511	$502	$493	$484	$476	$468	$460	$456	$452
Aero Bin4	TC	$769	$729	$717	$704	$692	$680	$669	$657	$652	$646
Aero Bin5	TC	$1,308	$1,240	$1,218	$1,197	$1,177	$1,156	$1,137	$1,117	$1,108	$1,098
Aero Bin3	Alt 1a										
Aero Bin4	Alt 1a										
Aero Bin5	Alt 1a										
Aero Bin3	Alt 3				95%	95%	95%	70%	70%	70%	30%
Aero Bin4	Alt 3							30%	30%	30%	60%
Aero Bin5	Alt 3										10%
Aero Bin3	TCp	$0	$0	$0	$468	$460	$452	$328	$322	$319	$136
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$281	$276	$274	$543
Aero Bin5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$110

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.9.6 Aero improvements, HD pickups and vans

For HD pickups and vans, we have based our aero improvement costs on values used in our light-duty 2017-2025 final rule. Using those values updated to 2012$ results in costs for aero 1 (passive aero treatments) and active aero treatments of $47 and $142 (both are DMC, in 2012$, in 2015). Note that the aero 2 costs are the passive aero 1 plus the active aero costs. We consider both of these technologies to be on the flat portion of the learning curve (curve 8) and, to aero 1, have applied low complexity markups with near term markups through 2018 and, to active aero, have applied medium complexity markups with near term markups through 2024. The resultant costs for HD pickups and vans are shown in Table 2-216 (aero 1) and in Table 2-217 (active aero) and in Table 2-218 (aero 2, passive+active aero).

Table 2-216 Costs for Passive Aero Treatments – Aero 1
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 1 – passive aero	DMC	$42	$41	$40	$39	$38	$38	$38
Aero 1 – passive aero	IC	$9	$9	$9	$9	$9	$9	$9
Aero 1 – passive aero	TC	$51	$50	$49	$48	$47	$47	$47

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-217 Costs for Active Aero Treatments
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 2 – active aero	DMC	$125	$122	$120	$118	$115	$114	$113
Aero 2 – active aero	IC	$54	$54	$54	$54	$40	$40	$40
Aero 2 – active aero	TC	$179	$177	$174	$172	$156	$154	$153

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-218 Costs for Aero 2 (passive plus active aero)
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 2 – active aero	DMC	$166	$163	$160	$157	$154	$152	$151
Aero 2 – active aero	IC	$63	$63	$63	$63	$50	$49	$49
Aero 2 – active aero	TC	$230	$227	$223	$220	$203	$201	$200

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.10 **Other Technologies**

2.12.10.1 Advanced cruise controls, tractors

We have estimated the cost of this technology based on an estimate from TetraTech of $1100 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $797 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-219 for tractors.

Table 2-219 Costs for Advanced Cruise Controls
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Advanced cruise control	DMC	$797	$773	$750	$727	$713	$698	$684	$671	$657	$644
Advanced cruise control	IC	$142	$142	$142	$141	$141	$111	$111	$111	$111	$111
Advanced cruise control	TC	$939	$915	$891	$868	$854	$809	$795	$782	$768	$755
Advanced cruise control	Alt 1a										
Advanced cruise control	Alt 3				20%	20%	20%	40%	40%	40%	40%
Advanced cruise control	TCp	$0	$0	$0	$174	$171	$162	$318	$313	$307	$302

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

2.12.10.2 Improved accessories

We have estimated the cost of this technology based on an estimate from TetraTech of $350 (retail, 2013$). Using that estimate we divided by a 1.36 RPE and converted to 2012$ to arrive at a cost of $254 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-220 for tractors.

Table 2-220 Costs for Improved Accessories
Tractors (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved accessories	DMC	$254	$246	$239	$231	$227	$222	$218	$213	$209	$205
Improved accessories	IC	$45	$45	$45	$45	$45	$35	$35	$35	$35	$35
Improved accessories	TC	$299	$291	$284	$276	$272	$258	$253	$249	$244	$240
Improved accessories	Alt 1a										
Improved accessories	Alt 3				10%	10%	10%	20%	20%	20%	30%
Improved accessories	TCp	$0	$0	$0	$28	$27	$26	$51	$50	$49	$72

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

For HD pickups and vans, we have estimated the costs for two levels of improved accessories based on estimates presented in the light-duty 2017-2025 final rule. In that rule, we estimated the costs of IACC1 and IACC2 at $73 and $118, respectively (both are DMC, 2009$, in 2015). With updates to 2012$, these costs become $77 and $124, respectively (both are DMC, 2012$, in 2015). Note that IACC2 includes IACC1. We consider these technologies to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant cost for both are shown in Table 2-221.

Table 2-221 Costs for Improved Accessories
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Improved accessories 1 (IACC1)	DMC	$67	$66	$64	$63	$62	$61	$61
Improved accessories 1 (IACC2)	DMC	$109	$106	$104	$102	$100	$99	$98
Improved accessories 1 (IACC1)	IC	$15	$15	$15	$15	$15	$15	$15
Improved accessories 1 (IACC2)	IC	$24	$24	$24	$24	$24	$24	$24
Improved accessories 1 (IACC1)	TC	$82	$80	$79	$78	$77	$76	$75
Improved accessories 1 (IACC2)	TC	$132	$130	$128	$126	$124	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.10.3 Weight reduction, vocational vehicles

We have estimated the cost of a 200, 400 and 1000 pound weight reduction on vocational vehicles at $4/pound, $6/pound and $8/pound, respectively (all are retail, 2013$). Using those costs we have divided by a 1.36 RPE and converted to 2012$ to arrive at costs of $579, $1738 and $5795 for 200, 400 and 1000 pound reductions, respectively (all are DMC, in 2012$, applicable in 2021). We consider each of these weight reduction levels to be on the flat portion of the learning curve (curve 13) and have applied low complexity ICMs with short term markups through 2022 for 200 and 400 pound reductions, and medium complexity ICMs with short term markups through 2022 for a 1000 pound reduction. The resultant technology costs, adoption rates and total cost applied to the package are shown in Table 2-222 though Table 2-227.

Table 2-222 Costs for a 200 Pound Weight Reduction
Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 200 lbs	DMC	$635	$616	$597	$579	$562	$545	$529	$518	$508	$498
Weight reduction, 200 lbs	IC	$104	$104	$104	$103	$103	$81	$81	$81	$81	$81
Weight reduction, 200 lbs	TC	$739	$720	$701	$683	$665	$626	$610	$599	$589	$578
Weight reduction, 200 lbs	Alt 1a										
Weight reduction, 200 lbs	Alt 3				4%	4%	4%	4%	4%	4%	5%
Weight reduction, 200 lbs	TCp	$0	$0	$0	$27	$27	$25	$24	$24	$24	$29

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-223 Costs for a 200 Pound Weight Reduction
Vocational Light HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 200 lbs	DMC	$635	$616	$597	$579	$562	$545	$529	$518	$508	$498
Weight reduction, 200 lbs	IC	$104	$104	$104	$103	$103	$81	$81	$81	$81	$81
Weight reduction, 200 lbs	TC	$739	$720	$701	$683	$665	$626	$610	$599	$589	$578
Weight reduction, 200 lbs	Alt 1a										
Weight reduction, 200 lbs	Alt 3				7%	7%	7%	7%	7%	7%	8%
Weight reduction, 200 lbs	TCp	$0	$0	$0	$48	$47	$44	$43	$42	$41	$46

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-224 Costs for a 200 Pound Weight Reduction
Vocational Medium HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 200 lbs	DMC	$635	$616	$597	$579	$562	$545	$529	$518	$508	$498
Weight reduction, 200 lbs	IC	$104	$104	$104	$103	$103	$81	$81	$81	$81	$81
Weight reduction, 200 lbs	TC	$739	$720	$701	$683	$665	$626	$610	$599	$589	$578
Weight reduction, 200 lbs	Alt 1a										
Weight reduction, 200 lbs	Alt 3				6%	6%	6%	6%	6%	6%	7%
Weight reduction, 200 lbs	TCp	$0	$0	$0	$41	$40	$38	$37	$36	$35	$40

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-225 Costs for a 200 Pound Weight Reduction
Vocational Heavy HD Regional Vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 200 lbs	DMC	$635	$616	$597	$579	$562	$545	$529	$518	$508	$498
Weight reduction, 200 lbs	IC	$104	$104	$104	$103	$103	$81	$81	$81	$81	$81
Weight reduction, 200 lbs	TC	$739	$720	$701	$683	$665	$626	$610	$599	$589	$578
Weight reduction, 200 lbs	Alt 1a										
Weight reduction, 200 lbs	Alt 3				5%	5%	5%	5%	5%	5%	6%
Weight reduction, 200 lbs	TCp	$0	$0	$0	$34	$33	$31	$30	$30	$29	$35

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative; empty cells for adoption rates denote 0% adoption

Table 2-226 Costs for a 400 Pound Weight Reduction Vocational vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 400 lbs	DMC	$1,905	$1,848	$1,792	$1,738	$1,686	$1,636	$1,587	$1,555	$1,524	$1,493
Weight reduction, 400 lbs	IC	$312	$312	$311	$310	$310	$243	$243	$242	$242	$242
Weight reduction, 400 lbs	TC	$2,217	$2,159	$2,103	$2,049	$1,996	$1,879	$1,829	$1,797	$1,766	$1,735

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-227 Costs for a 1000 Pound Weight Reduction Vocational vehicles (2012$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 1000 lbs	DMC	$6,349	$6,159	$5,974	$5,795	$5,621	$5,452	$5,289	$5,183	$5,079	$4,978
Weight reduction, 1000 lbs	IC	$1,780	$1,770	$1,761	$1,752	$1,743	$1,296	$1,290	$1,286	$1,283	$1,279
Weight reduction, 1000 lbs	TC	$8,129	$7,929	$7,735	$7,547	$7,364	$6,748	$6,579	$6,469	$6,362	$6,257

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.10.4 Weight reduction in HD pickups and vans

For this proposal, we are estimating weight reduction costs for HD pickups and vans using the same cost curve used in support of the 2017-2025 light-duty GHG/CAFE FRM. That curve can be expressed as:

Mass Reduction Direct Manufacturing Cost (DMC) ($/lb) = 4.55 x Percentage of Mass Reduction (2012$)

For example, this results in an estimated $80 (2012$) DMC increase for a 5 percent mass reduction of a 7,000 pound vehicle and $318 (2012$) DMC increase for a 10 percent mass reduction of a 7,000 pound vehicle, or $0.227 $/lb and $0.455/lb, respectively (both in 2012$).

Consistent with the 2017-2025 light-duty FRM, the agencies consider this DMC to be applicable to MY2017 and consider mass reduction technology to be on the flat portion of the learning curve in the 2017-2025MY timeframe. To estimate indirect costs for applied mass reduction of up to 10 percent, the agencies have applied a low complexity ICM with near term markups through 2018.

2.12.10.5 Electric power steering, HD pickups and vans

We have based the costs for electric power steering on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD vehicles. Using that cost and converting to 2012$ results in a cost of $141 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown in Table 2-228.

Table 2-228 Costs for Electric Power Steering
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Electric power steering (EPS)	DMC	$124	$121	$119	$117	$114	$113	$112
Electric power steering (EPS)	IC	$27	$27	$27	$27	$27	$27	$27
Electric power steering (EPS)	TC	$151	$148	$146	$144	$141	$140	$139

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.10.6 Low drag brakes, HD pickups and vans

We have based the costs for low drag brakes on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD vehicles. Using that cost and converting to 2012$ results in a cost of $91 (DMC, 2012$, in any year). We consider this technology to be beyond the learning curve (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown in Table 2-229.

Table 2-229 Costs for Low Drag Brakes
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Low drag brakes	DMC	$91	$91	$91	$91	$91	$91	$91
Low drag brakes	IC	$18	$18	$18	$18	$18	$18	$18
Low drag brakes	TC	$109	$109	$109	$109	$109	$109	$109

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12.10.7 Driveline friction reduction, diesel HD pickups & vans

We have estimated the cost of driveline friction reduction based on the cost of secondary axle disconnect in the light-duty 2017-2025 final rule. Using that cost of $80 (DMC, 2009$, in 2015), we have scaled upward by 50 percent to account for the larger HD componentry to arrive at a cost of $126 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 3) and have applied low complexity markups with near term markups through 2022. The resultant costs for driveline friction reduction (applied only to diesel HD pickups & vans) are shown in Table 2-230.

Table 2-230 Costs for Driveline Friction Reduction
Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Driveline friction reduction	DMC	$108	$106	$104	$102	$100	$99	$98
Driveline friction reduction	IC	$30	$30	$24	$24	$24	$24	$24
Driveline friction reduction	TC	$139	$136	$128	$126	$124	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.13 Package Costs

Section 0presents detailed technology costs along with adoption rates to illustrate how each technology is accounted for in the package costs. Here we present package costs by regulated sector (i.e., vocational heavy HD, urban vehicles) and package costs by MOVES sourcetype (i.e., diesel refuse trucks). We determine package costs by MOVES sourcetype so that we can calculate total program costs (i.e., package costs multiplied by vehicle sales) since sourcetypes are the sales figures that we can glean from MOVES. As a result, the sourcetype package costs presented here are the costs used in our program cost estimations.

2.13.1 Package Costs by Regulated Sector

2.13.1.1 Vocational vehicles

We have estimated costs for 9 vocational segments and 2 fuels. We present package costs in Table 2-231 through Table 2-238 for these for alternatives 3 and 4, both relative to alternatives 1a and 1b and separately for diesel and gasoline vehicles.

Table 2-231 Package Costs for Regulated Vocational Segment
Alternative 3 Incremental to Alternative 1a
Diesel (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$1,125	$1,100	$1,008	$1,737	$1,701	$1,664	$3,489	$3,427
Light HD	Multipurpose	$1,125	$1,100	$1,008	$1,737	$1,701	$1,664	$3,490	$3,427
Light HD	Regional	$598	$585	$563	$849	$835	$819	$1,407	$1,378
Medium HD	Urban	$1,418	$1,386	$1,254	$2,228	$2,180	$2,132	$4,696	$4,616
Medium HD	Multipurpose	$1,418	$1,386	$1,254	$2,228	$2,180	$2,132	$4,696	$4,616
Medium HD	Regional	$571	$559	$537	$817	$803	$788	$1,395	$1,367
Heavy HD	Urban	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
Heavy HD	Multipurpose	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
Heavy HD	Regional	$3,404	$3,348	$3,160	$4,834	$4,755	$4,683	$4,682	$4,607

Table 2-232 Package Costs for Regulated Vocational Segment
Alternative 3 Incremental to Alternative 1a
Gasoline (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$832	$814	$729	$1,299	$1,271	$1,240	$3,086	$3,037
Light HD	Multipurpose	$832	$814	$729	$1,299	$1,271	$1,240	$3,087	$3,038
Light HD	Regional	$305	$299	$284	$412	$405	$395	$1,004	$989
Medium HD	Urban	$1,147	$1,122	$996	$1,823	$1,782	$1,740	$4,327	$4,259
Medium HD	Multipurpose	$1,147	$1,122	$996	$1,823	$1,782	$1,740	$4,328	$4,259
Medium HD	Regional	$300	$294	$279	$412	$405	$395	$1,026	$1,010
Heavy HD	Urban	$1,728	$1,690	$1,491	$2,927	$2,860	$2,791	$7,053	$6,941
Heavy HD	Multipurpose	$1,728	$1,690	$1,491	$2,927	$2,860	$2,791	$7,053	$6,941
Heavy HD	Regional	$3,134	$3,083	$2,902	$4,429	$4,357	$4,290	$4,314	$4,251

Table 2-233 Package Costs for Regulated Vocational Segment
Alternative 4 Incremental to Alternative 1a
Diesel (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$2,169	$2,120	$1,911	$3,741	$3,661	$3,582	$3,525	$3,462
Light HD	Multipurpose	$2,169	$2,120	$1,911	$3,704	$3,625	$3,546	$3,490	$3,427
Light HD	Regional	$805	$788	$756	$1,482	$1,457	$1,430	$1,407	$1,378
Medium HD	Urban	$2,938	$2,873	$2,560	$5,030	$4,920	$4,810	$4,733	$4,652
Medium HD	Multipurpose	$2,938	$2,873	$2,560	$4,992	$4,882	$4,772	$4,696	$4,616
Medium HD	Regional	$777	$760	$729	$1,469	$1,444	$1,417	$1,395	$1,367
Heavy HD	Urban	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
Heavy HD	Multipurpose	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
Heavy HD	Regional	$2,693	$2,647	$2,504	$4,912	$4,831	$4,752	$4,682	$4,607

Table 2-234 Package Costs for Regulated Vocational Segment
Alternative 4 Incremental to Alternative 1a
Gasoline (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$1,796	$1,757	$1,556	$3,322	$3,245	$3,172	$3,122	$3,072
Light HD	Multipurpose	$1,796	$1,757	$1,556	$3,285	$3,209	$3,136	$3,087	$3,038
Light HD	Regional	$433	$424	$401	$1,063	$1,041	$1,020	$1,004	$989
Medium HD	Urban	$2,594	$2,536	$2,232	$4,648	$4,539	$4,435	$4,365	$4,296
Medium HD	Multipurpose	$2,594	$2,536	$2,232	$4,609	$4,501	$4,398	$4,328	$4,259
Medium HD	Regional	$432	$423	$400	$1,086	$1,063	$1,042	$1,026	$1,010
Heavy HD	Urban	$3,992	$3,903	$3,416	$7,512	$7,339	$7,168	$7,053	$6,941
Heavy HD	Multipurpose	$3,992	$3,903	$3,416	$7,512	$7,339	$7,168	$7,053	$6,941
Heavy HD	Regional	$2,348	$2,310	$2,175	$4,529	$4,450	$4,378	$4,314	$4,251

Table 2-235 Package Costs for Regulated Vocational Segment Alternative 3 Incremental to Alternative 1b Diesel (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$1,125	$1,100	$1,008	$1,737	$1,701	$1,664	$3,489	$3,427
Light HD	Multipurpose	$1,125	$1,100	$1,008	$1,737	$1,701	$1,664	$3,490	$3,427
Light HD	Regional	$598	$585	$563	$849	$835	$819	$1,407	$1,378
Medium HD	Urban	$1,418	$1,386	$1,254	$2,228	$2,180	$2,132	$4,696	$4,616
Medium HD	Multipurpose	$1,418	$1,386	$1,254	$2,228	$2,180	$2,132	$4,696	$4,616
Medium HD	Regional	$571	$559	$537	$817	$803	$788	$1,395	$1,367
Heavy HD	Urban	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
Heavy HD	Multipurpose	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
Heavy HD	Regional	$3,404	$3,348	$3,160	$4,834	$4,755	$4,683	$4,682	$4,607

Table 2-236 Package Costs for Regulated Vocational Segment Alternative 3 Incremental to Alternative 1b Gasoline (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$843	$825	$740	$1,311	$1,282	$1,251	$3,097	$3,048
Light HD	Multipurpose	$843	$825	$740	$1,311	$1,282	$1,251	$3,097	$3,049
Light HD	Regional	$316	$310	$295	$423	$416	$406	$1,015	$999
Medium HD	Urban	$1,159	$1,134	$1,008	$1,835	$1,793	$1,750	$4,338	$4,270
Medium HD	Multipurpose	$1,159	$1,134	$1,008	$1,835	$1,793	$1,750	$4,339	$4,270
Medium HD	Regional	$312	$306	$291	$424	$416	$406	$1,037	$1,021
Heavy HD	Urban	$1,740	$1,702	$1,502	$2,938	$2,871	$2,802	$7,064	$6,952
Heavy HD	Multipurpose	$1,740	$1,702	$1,502	$2,938	$2,871	$2,802	$7,064	$6,952
Heavy HD	Regional	$3,146	$3,095	$2,914	$4,441	$4,368	$4,301	$4,324	$4,262

Table 2-237 Package Costs for Regulated Vocational Segment Alternative 4 Incremental to Alternative 1b

Diesel (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$2,169	$2,120	$1,911	$3,741	$3,661	$3,582	$3,525	$3,462
Light HD	Multipurpose	$2,169	$2,120	$1,911	$3,704	$3,625	$3,546	$3,490	$3,427
Light HD	Regional	$805	$788	$756	$1,482	$1,457	$1,430	$1,407	$1,378
Medium HD	Urban	$2,938	$2,873	$2,560	$5,030	$4,920	$4,810	$4,733	$4,652
Medium HD	Multipurpose	$2,938	$2,873	$2,560	$4,992	$4,882	$4,772	$4,696	$4,616
Medium HD	Regional	$777	$760	$729	$1,469	$1,444	$1,417	$1,395	$1,367
Heavy HD	Urban	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
Heavy HD	Multipurpose	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
Heavy HD	Regional	$2,693	$2,647	$2,504	$4,912	$4,831	$4,752	$4,682	$4,607

Table 2-238 Package Costs for Regulated Vocational Segment Alternative 4 Incremental to Alternative 1b

Gasoline (2012$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027	2028
Light HD	Urban	$1,808	$1,768	$1,567	$3,334	$3,256	$3,183	$3,132	$3,083
Light HD	Multipurpose	$1,808	$1,768	$1,567	$3,297	$3,220	$3,147	$3,097	$3,049
Light HD	Regional	$445	$436	$413	$1,075	$1,052	$1,031	$1,015	$999
Medium HD	Urban	$2,605	$2,547	$2,243	$4,659	$4,550	$4,446	$4,375	$4,306
Medium HD	Multipurpose	$2,605	$2,547	$2,243	$4,620	$4,512	$4,408	$4,339	$4,270
Medium HD	Regional	$444	$435	$412	$1,097	$1,074	$1,053	$1,037	$1,021
Heavy HD	Urban	$4,004	$3,915	$3,428	$7,524	$7,350	$7,178	$7,064	$6,952
Heavy HD	Multipurpose	$4,004	$3,915	$3,428	$7,524	$7,350	$7,178	$7,064	$6,952
Heavy HD	Regional	$2,360	$2,321	$2,187	$4,540	$4,461	$4,389	$4,324	$4,262

2.13.1.2 Tractors

We have estimated costs for 7 tractor segments and 1 fuel. We present package costs in Table 2-239 through Table 2-242 for these for alternatives 3 and 4, both relative to alternatives 1a and 1b.

Table 2-239 Package Costs for Regulated Tractor Segment Alternative 3 Incremental to Alternative 1a Diesel (2012$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027	2028
7	Day cab, low roof	$5,468	$5,381	$5,008	$8,400	$8,259	$8,095	$10,140	$9,968
7	Day cab, high roof	$5,252	$5,161	$4,811	$8,304	$8,160	$7,913	$10,099	$9,923
8	Day cab, low roof	$5,520	$5,432	$5,057	$8,467	$8,325	$8,159	$10,204	$10,031
8	Day cab, high roof	$5,298	$5,206	$4,854	$8,419	$8,274	$8,024	$10,209	$10,030
8	Sleeper cab, low roof	$7,916	$7,786	$7,281	$11,102	$10,912	$10,723	$12,744	$12,548
8	Sleeper cab, mid roof	$7,916	$7,786	$7,281	$11,102	$10,912	$10,723	$12,744	$12,548
8	Sleeper cab, high roof	$7,771	$7,637	$7,156	$11,145	$10,952	$10,666	$12,842	$12,640

Table 2-240 Package Costs for Regulated Tractor Segment Alternative 4 Incremental to Alternative 1a Diesel (2012$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027	2028
7	Day cab, low roof	$8,946	$8,799	$8,180	$10,757	$10,574	$10,306	$10,140	$9,968
7	Day cab, high roof	$8,769	$8,621	$8,035	$10,851	$10,664	$10,270	$10,099	$9,923
8	Day cab, low roof	$8,999	$8,852	$8,230	$10,826	$10,642	$10,371	$10,204	$10,031
8	Day cab, high roof	$8,816	$8,666	$8,079	$10,968	$10,780	$10,382	$10,209	$10,030
8	Sleeper cab, low roof	$11,397	$11,208	$10,456	$13,461	$13,229	$12,934	$12,744	$12,548
8	Sleeper cab, mid roof	$11,397	$11,208	$10,456	$13,461	$13,229	$12,934	$12,744	$12,548
8	Sleeper cab, high roof	$11,318	$11,126	$10,411	$13,717	$13,481	$13,039	$12,842	$12,640

Table 2-241 Package Costs for Regulated Tractor Segment Alternative 3 Incremental to Alternative 1b Diesel (2012$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027	2028
7	Day cab, low roof	$5,244	$5,086	$4,642	$7,966	$7,765	$7,564	$9,504	$9,337
7	Day cab, high roof	$5,159	$5,040	$4,681	$8,156	$7,995	$7,726	$9,885	$9,710
8	Day cab, low roof	$5,296	$5,137	$4,691	$8,033	$7,831	$7,628	$9,569	$9,400
8	Day cab, high roof	$5,205	$5,085	$4,724	$8,271	$8,108	$7,836	$9,995	$9,818
8	Sleeper cab, low roof	$7,642	$7,426	$6,863	$10,610	$10,381	$10,140	$12,078	$11,882
8	Sleeper cab, mid roof	$7,556	$7,332	$6,770	$10,528	$10,283	$10,044	$11,944	$11,758
8	Sleeper cab, high roof	$7,653	$7,497	$7,019	$10,996	$10,788	$10,497	$12,640	$12,443

Table 2-242 Package Costs for Regulated Tractor Segment Alternative 4 Incremental to Alternative 1b Diesel (2012$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027	2028
7	Day cab, low roof	$8,721	$8,505	$7,815	$10,323	$10,080	$9,774	$9,504	$9,337
7	Day cab, high roof	$8,676	$8,499	$7,905	$10,703	$10,499	$10,083	$9,885	$9,710
8	Day cab, low roof	$8,775	$8,557	$7,865	$10,392	$10,148	$9,840	$9,569	$9,400
8	Day cab, high roof	$8,722	$8,545	$7,949	$10,820	$10,614	$10,195	$9,995	$9,818
8	Sleeper cab, low roof	$11,124	$10,848	$10,038	$12,969	$12,698	$12,351	$12,078	$11,882
8	Sleeper cab, mid roof	$11,037	$10,753	$9,944	$12,887	$12,599	$12,255	$11,944	$11,758
8	Sleeper cab, high roof	$11,200	$10,985	$10,273	$13,567	$13,317	$12,870	$12,640	$12,443

2.13.1.3 Trailers

We have estimated costs for 7 trailer types. We present package costs in Table 2-243 and Table 2-244 for these for alternatives 3 and 4 relative to alternative 1a. We present package costs in Table 2-245 and Table 2-246 for alternative 3 and 4 relative to alternative 1b.

Table 2-243 Costs for Trailers
Alternative 3 Incremental to Alternative 1a (2012$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
53-foot dry van	$588	$550	$524	$901	$870	$817	$1,116	$1,083	$1,059	$1,409	$1,396
53-foot reefer van	$588	$550	$524	$901	$870	$817	$1,116	$1,083	$1,059	$1,280	$1,267
Container chassis	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28-foot dry van	$514	$501	$489	$974	$957	$923	$1,097	$1,078	$1,065	$1,253	$1,239
Platform	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other highway	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693

Table 2-244 Costs for Trailers
Alternative 4 Incremental to Alternative 1a (2012$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
53-foot dry van	$588	$550	$524	$1,207	$1,172	$1,113	$1,504	$1,465	$1,437	$1,409	$1,396
53-foot reefer van	$588	$550	$524	$1,207	$1,172	$1,113	$1,371	$1,333	$1,306	$1,280	$1,267
Container chassis	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28-foot dry van	$514	$501	$489	$1,146	$1,127	$1,090	$1,304	$1,282	$1,267	$1,253	$1,239
Platform	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other highway	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693

Table 2-245 Costs for Trailers
Alternative 3 Incremental to Alternative 1b (2012$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
53-foot dry van	$588	$550	$524	$901	$856	$817	$1,116	$1,083	$1,059	$1,409	$1,382
53-foot reefer van	$588	$550	$524	$901	$856	$817	$1,116	$1,083	$1,059	$1,280	$1,254
Container chassis	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28-foot dry van	$514	$501	$489	$974	$957	$923	$1,097	$1,078	$1,065	$1,253	$1,239
Platform	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other highway	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693

Table 2-246 Costs for Trailers
Alternative 4 Incremental to Alternative 1b (2012$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
53-foot dry van	$588	$550	$524	$1,207	$1,157	$1,113	$1,504	$1,465	$1,437	$1,409	$1,382
53-foot reefer van	$588	$550	$524	$1,207	$1,157	$1,113	$1,371	$1,333	$1,306	$1,280	$1,254
Container chassis	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28-foot dry van	$514	$501	$489	$1,146	$1,127	$1,090	$1,304	$1,282	$1,267	$1,253	$1,239
Platform	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other highway	$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693

2.13.1.4 HD Pickups and Vans

The costs presented in Table 2-247 are CAFE model outputs used in this analysis. We describe the CAFE model and how these costs were generated in Chapter 11 of this draft RIA. The costs presented here spread evenly over MYs 2021 through 2026 the costs estimated by the CAFE model for MYs 2017-2020.

Table 2-247 Package Costs for HD Pickups and Vans (2012$)

ALTERNATIVE	BASELINE CASE	2021	2022	2023	2024	2025	2026	2027
3	1a	$516	$508	$791	$948	$1,161	$1,224	$1,342
4	1a	$1,050	$1,033	$1,621	$1,734	$1,825	$1,808	$1,841
3	1b	$493	$485	$766	$896	$1,149	$1,248	$1,366
4	1b	$909	$894	$1,415	$1,532	$1,627	$1,649	$1,684

2.13.2 **Package Costs by MOVES Sourcetype**

The package costs by segment can then be used to calculate package costs by MOVES sourcetype. To do this, we need the percentage of the MOVES sourcetype fleet comprised of each regulated sector. Table 2-248 shows this breakout for the vocational sector and Table 2-249 shows it for tractors.

Table 2-248 Fleet Mix by MOVES Sourcetype and Regulated Sector -- Vocational[a]

ENGINE	FUEL	SPEED	INTERCITY BUS	TRANSIT BUS	SCHOOL BUS	REFUSE TRUCKS	SINGLE UNIT SHORT HAUL	SINGLE UNIT LONG HAUL	MOTOR HOMES
Light HD	Gasoline	Urban	0%	7%	0%	0%	4%	0%	0%
Light HD	Gasoline	Multipurpose	0%	20%	1%	0%	49%	0%	0%
Light HD	Gasoline	Regional	0%	0%	0%	0%	28%	0%	54%
Medium HD	Gasoline	Urban	0%	2%	0%	0%	1%	0%	0%
Medium HD	Gasoline	Multipurpose	0%	7%	95%	0%	11%	0%	0%
Medium HD	Gasoline	Regional	0%	0%	0%	0%	7%	0%	41%
Heavy HD	Gasoline	Urban	0%	16%	0%	0%	0%	0%	0%
Heavy HD	Gasoline	Multipurpose	0%	48%	4%	0%	0%	0%	0%
Heavy HD	Gasoline	Regional	0%	0%	0%	0%	0%	0%	5%
Light HD	Diesel	Urban	0%	0%	0%	0%	2%	0%	0%
Light HD	Diesel	Multipurpose	0%	0%	1%	0%	25%	0%	0%
Light HD	Diesel	Regional	2%	0%	0%	0%	14%	25%	54%
Medium HD	Diesel	Urban	0%	0%	0%	3%	2%	0%	0%
Medium HD	Diesel	Multipurpose	0%	0%	95%	0%	20%	0%	0%
Medium HD	Diesel	Regional	15%	0%	0%	0%	12%	37%	41%
Heavy HD	Diesel	Urban	0%	25%	0%	97%	1%	0%	0%
Heavy HD	Diesel	Multipurpose	0%	75%	5%	0%	15%	0%	0%
Heavy HD	Diesel	Regional	83%	0%	0%	0%	9%	37%	5%

Note:
[a] Columns add to 100% or 0% for gasoline rows and 100% for diesel rows.

Table 2-249 Fleet Mix by MOVES Sourcetype and Regulated Sector – Tractors[a]

ENGINE	MOVES SOURCETYPE	CLASS 7 DAY CAB LOW ROOF	CLASS 7 DAY CAB HIGH ROOF	CLASS 8 DAY CAB LOW ROOF	CLASS 8 DAY CAB HIGH ROOF	CLASS 8 SLEEPER CAB LOW ROOF	CLASS 8 SLEEPER CAB MID ROOF	CLASS 8 SLEEPER CAB HIGH ROOF
Medium HD	Combination Short haul	11%	11%					
Heavy HD	Combination Short haul			39%	39%			
Heavy HD	Combination Long haul					5%	15%	80%

Note:
[a] Combination short haul adds to 100% and long haul to 100%; empty cells denote 0%.

Using the fleet mix information shown in Table 2-248 and Table 2-249, along with the package costs shown in Table 2-231 through Table 2-246, we can generate the package costs by MOVES sourcetype (note that package costs by MOVES sourcetype differ from package costs by regulated sector only for vocational vehicles and tractors; trailer and HD pickup and van costs do not change). These costs are shown in Table 2-250 through Table 2-253.

Table 2-250 Package Costs by MOVES Sourcetype
Alternative 3 Incremental to Alternative 1a (2012$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Intercity Bus	Diesel	$0	$0	$0	$2,913	$2,864	$2,705	$4,138	$4,070	$4,008	$4,112	$4,045
Transit Bus	Diesel	$0	$0	$0	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
School Bus	Diesel	$0	$0	$0	$1,442	$1,410	$1,275	$2,275	$2,226	$2,177	$4,813	$4,730
Refuse Truck	Diesel	$0	$0	$0	$1,983	$1,939	$1,735	$3,302	$3,230	$3,156	$7,350	$7,226
SingleUnit ShortHaul	Diesel	$0	$0	$0	$1,400	$1,371	$1,261	$2,155	$2,112	$2,069	$3,975	$3,905
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,637	$1,608	$1,525	$2,327	$2,289	$2,252	$2,627	$2,581
MotorHome	Diesel	$0	$0	$0	$736	$721	$690	$1,047	$1,030	$1,011	$1,576	$1,545
Intercity Bus	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Transit Bus	Gasoline	$0	$0	$0	$1,434	$1,402	$1,240	$2,388	$2,334	$2,277	$5,736	$5,645
School Bus	Gasoline	$0	$0	$0	$1,170	$1,145	$1,016	$1,868	$1,826	$1,782	$4,439	$4,368
Refuse Truck	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
SingleUnit ShortHaul	Gasoline	$0	$0	$0	$686	$671	$606	$1,053	$1,031	$1,006	$2,512	$2,472
SingleUnit LongHaul	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MotorHome	Gasoline	$0	$0	$0	$453	$444	$421	$625	$615	$602	$1,189	$1,170
Comb ShortHaul	Diesel	$0	$0	$0	$5,398	$5,309	$4,945	$8,423	$8,279	$8,072	$10,187	$10,012
Comb LongHaul	Diesel	$0	$0	$0	$7,800	$7,667	$7,181	$11,137	$10,944	$10,677	$12,823	$12,622
53' dry van		$588	$550	$524	$901	$870	$817	$1,116	$1,083	$1,059	$1,409	$1,396
53' rfr van		$588	$550	$524	$901	$870	$817	$1,116	$1,083	$1,059	$1,280	$1,267
Container ch		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28' dry van		$514	$501	$489	$974	$957	$923	$1,097	$1,078	$1,065	$1,253	$1,239
Platform		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other trailer		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Vocational	Diesel	$0	$0	$0	$1,366	$1,337	$1,230	$2,102	$2,060	$2,018	$3,892	$3,824
Vocational	Gasoline	$0	$0	$0	$612	$599	$547	$916	$898	$877	$2,086	$2,053
Vocational	Weighted Avg	$0	$0	$0	$1,152	$1,128	$1,037	$1,766	$1,731	$1,695	$3,381	$3,323
Tractor	Weighted Avg	$0	$0	$0	$6,708	$6,605	$6,184	$9,935	$9,774	$9,542	$11,684	$11,503
Trailer	Weighted Avg	$639	$613	$592	$898	$877	$832	$1,012	$989	$971	$1,165	$1,152
Tractor/Trailer	Weighted Avg	$639	$613	$592	$7,606	$7,482	$7,016	$10,947	$10,763	$10,513	$12,849	$12,655

Table 2-251 Package Costs by MOVES Sourcetype Alternative 4 Incremental to Alternative 1a (2012$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Intercity Bus	Diesel	$0	$0	$0	$2,361	$2,320	$2,197	$4,314	$4,243	$4,174	$4,112	$4,045
Transit Bus	Diesel	$0	$0	$0	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
School Bus	Diesel	$0	$0	$0	$2,997	$2,930	$2,610	$5,115	$5,002	$4,890	$4,813	$4,730
Refuse Truck	Diesel	$0	$0	$0	$4,300	$4,204	$3,714	$7,819	$7,645	$7,470	$7,350	$7,227
SingleUnit ShortHaul	Diesel	$0	$0	$0	$2,388	$2,336	$2,109	$4,216	$4,128	$4,040	$3,976	$3,907
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,500	$1,473	$1,400	$2,760	$2,714	$2,668	$2,627	$2,581
MotorHome	Diesel	$0	$0	$0	$894	$875	$838	$1,658	$1,630	$1,601	$1,576	$1,545
Intercity Bus	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Transit Bus	Gasoline	$0	$0	$0	$3,273	$3,201	$2,807	$6,112	$5,971	$5,832	$5,739	$5,648
School Bus	Gasoline	$0	$0	$0	$2,649	$2,590	$2,279	$4,727	$4,616	$4,510	$4,439	$4,368
Refuse Truck	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
SingleUnit ShortHaul	Gasoline	$0	$0	$0	$1,417	$1,386	$1,235	$2,673	$2,612	$2,554	$2,513	$2,474
SingleUnit LongHaul	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MotorHome	Gasoline	$0	$0	$0	$534	$524	$495	$1,256	$1,231	$1,207	$1,189	$1,170
Comb ShortHaul	Diesel	$0	$0	$0	$8,896	$8,748	$8,144	$10,877	$10,691	$10,357	$10,187	$10,012
Comb LongHaul	Diesel	$0	$0	$0	$11,334	$11,142	$10,420	$13,666	$13,430	$13,018	$12,823	$12,622
53' dry van		$588	$550	$524	$1,207	$1,172	$1,113	$1,504	$1,465	$1,437	$1,409	$1,396
53' rfr van		$588	$550	$524	$1,207	$1,172	$1,113	$1,371	$1,333	$1,306	$1,280	$1,267
Container ch		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28' dry van		$514	$501	$489	$1,146	$1,127	$1,090	$1,304	$1,282	$1,267	$1,253	$1,239
Platform		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other trailer		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Vocational	Diesel	$0	$0	$0	$2,333	$2,282	$2,061	$4,126	$4,041	$3,955	$3,892	$3,825
Vocational	Gasoline	$0	$0	$0	$1,134	$1,109	$997	$2,218	$2,168	$2,121	$2,087	$2,054
Vocational	Weighted Avg	$0	$0	$0	$1,994	$1,950	$1,760	$3,586	$3,511	$3,436	$3,382	$3,324
Tractor	Weighted Avg	$0	$0	$0	$10,225	$10,065	$9,404	$12,431	$12,227	$11,859	$11,684	$11,503
Trailer	Weighted Avg	$639	$613	$592	$1,084	$1,059	$1,012	$1,231	$1,204	$1,184	$1,165	$1,152
Tractor/Trailer	Weighted Avg	$639	$613	$592	$11,310	$11,124	$10,416	$13,662	$13,431	$13,043	$12,849	$12,655

Table 2-252 Package Costs by MOVES Sourcetype
Alternative 3 Incremental to Alternative 1b (2012$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Intercity Bus	Diesel	$0	$0	$0	$2,913	$2,864	$2,705	$4,138	$4,070	$4,008	$4,112	$4,045
Transit Bus	Diesel	$0	$0	$0	$1,998	$1,954	$1,748	$3,332	$3,258	$3,183	$7,422	$7,298
School Bus	Diesel	$0	$0	$0	$1,442	$1,410	$1,275	$2,275	$2,226	$2,177	$4,813	$4,730
Refuse Truck	Diesel	$0	$0	$0	$1,983	$1,939	$1,735	$3,302	$3,230	$3,156	$7,350	$7,226
SingleUnit ShortHaul	Diesel	$0	$0	$0	$1,400	$1,371	$1,261	$2,155	$2,112	$2,069	$3,975	$3,905
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,637	$1,608	$1,525	$2,327	$2,289	$2,252	$2,627	$2,581
MotorHome	Diesel	$0	$0	$0	$736	$721	$690	$1,047	$1,030	$1,011	$1,576	$1,545
Intercity Bus	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Transit Bus	Gasoline	$11	$12	$12	$1,445	$1,414	$1,252	$2,399	$2,345	$2,288	$5,747	$5,655
School Bus	Gasoline	$11	$12	$12	$1,182	$1,156	$1,028	$1,880	$1,837	$1,793	$4,449	$4,379
Refuse Truck	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
SingleUnit ShortHaul	Gasoline	$11	$12	$12	$697	$683	$617	$1,065	$1,041	$1,017	$2,522	$2,483
SingleUnit LongHaul	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MotorHome	Gasoline	$11	$12	$12	$465	$456	$432	$636	$625	$613	$1,199	$1,181
Comb ShortHaul	Diesel	$0	-$59	-$114	$5,240	$5,101	$4,698	$8,132	$7,950	$7,713	$9,763	$9,590
Comb LongHaul	Diesel	$0	-$70	-$115	$7,638	$7,468	$6,974	$10,906	$10,692	$10,411	$12,508	$12,312
53' dry van		$588	$550	$524	$901	$856	$817	$1,116	$1,083	$1,059	$1,409	$1,382
53' rfr van		$588	$550	$524	$901	$856	$817	$1,116	$1,083	$1,059	$1,280	$1,254
Container ch		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28' dry van		$514	$501	$489	$974	$957	$923	$1,097	$1,078	$1,065	$1,253	$1,239
Platform		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other trailer		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Vocational	Diesel	$0	$0	$0	$1,366	$1,337	$1,230	$2,102	$2,060	$2,018	$3,892	$3,824
Vocational	Gasoline	$11	$12	$12	$624	$611	$558	$928	$909	$888	$2,096	$2,063
Vocational	Weighted Avg	$3	$3	$3	$1,156	$1,132	$1,040	$1,770	$1,734	$1,698	$3,384	$3,326
Tractor	Weighted Avg	$0	-$65	-$114	$6,547	$6,402	$5,958	$9,678	$9,488	$9,235	$11,321	$11,145
Trailer	Weighted Avg	$639	$613	$592	$898	$870	$832	$1,012	$989	$971	$1,165	$1,146
Tractor/Trailer	Weighted Avg	$639	$548	$478	$7,445	$7,273	$6,790	$10,690	$10,476	$10,206	$12,487	$12,292

Table 2-253 Package Costs by MOVES Sourcetype
Alternative 4 Incremental to Alternative 1b (2012$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Intercity Bus	Diesel	$0	$0	$0	$2,361	$2,320	$2,197	$4,314	$4,243	$4,174	$4,112	$4,045
Transit Bus	Diesel	$0	$0	$0	$4,337	$4,240	$3,745	$7,895	$7,719	$7,542	$7,422	$7,298
School Bus	Diesel	$0	$0	$0	$2,997	$2,930	$2,610	$5,115	$5,002	$4,890	$4,813	$4,730
Refuse Truck	Diesel	$0	$0	$0	$4,300	$4,204	$3,714	$7,819	$7,645	$7,470	$7,350	$7,227
SingleUnit ShortHaul	Diesel	$0	$0	$0	$2,388	$2,336	$2,109	$4,216	$4,128	$4,040	$3,976	$3,907
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,500	$1,473	$1,400	$2,760	$2,714	$2,668	$2,627	$2,581
MotorHome	Diesel	$0	$0	$0	$894	$875	$838	$1,658	$1,630	$1,601	$1,576	$1,545
Intercity Bus	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Transit Bus	Gasoline	$11	$12	$12	$3,285	$3,212	$2,819	$6,124	$5,981	$5,843	$5,750	$5,659
School Bus	Gasoline	$11	$12	$12	$2,661	$2,602	$2,290	$4,738	$4,627	$4,521	$4,449	$4,379
Refuse Truck	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
SingleUnit ShortHaul	Gasoline	$11	$12	$12	$1,429	$1,397	$1,246	$2,685	$2,623	$2,565	$2,524	$2,484
SingleUnit LongHaul	Gasoline	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
MotorHome	Gasoline	$11	$12	$12	$546	$535	$507	$1,268	$1,241	$1,218	$1,199	$1,181
Comb ShortHaul	Diesel	$0	-$59	-$114	$8,737	$8,540	$7,897	$10,586	$10,361	$9,998	$9,763	$9,590
Comb LongHaul	Diesel	$0	-$70	-$115	$11,172	$10,944	$10,212	$13,435	$13,178	$12,752	$12,508	$12,312
53' dry van		$588	$550	$524	$1,207	$1,157	$1,113	$1,504	$1,465	$1,437	$1,409	$1,382
53' rfr van		$588	$550	$524	$1,207	$1,157	$1,113	$1,371	$1,333	$1,306	$1,280	$1,254
Container ch		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
28' dry van		$514	$501	$489	$1,146	$1,127	$1,090	$1,304	$1,282	$1,267	$1,253	$1,239
Platform		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Tanker		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Other trailer		$868	$847	$827	$807	$793	$752	$739	$726	$715	$704	$693
Vocational	Diesel	$0	$0	$0	$2,333	$2,282	$2,061	$4,126	$4,041	$3,955	$3,892	$3,825
Vocational	Gasoline	$11	$12	$12	$1,146	$1,121	$1,009	$2,230	$2,179	$2,132	$2,098	$2,065
Vocational	Weighted Avg	$3	$3	$3	$1,997	$1,954	$1,763	$3,589	$3,514	$3,439	$3,385	$3,327
Tractor	Weighted Avg	$0	-$65	-$114	$10,065	$9,862	$9,179	$12,174	$11,941	$11,552	$11,321	$11,145
Trailer	Weighted Avg	$639	$613	$592	$1,084	$1,053	$1,012	$1,231	$1,204	$1,184	$1,165	$1,146
Tractor/Trailer	Weighted Avg	$639	$548	$478	$11,149	$10,915	$10,191	$13,404	$13,144	$12,736	$12,487	$12,292

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Chapter 3: Test Procedures

Test procedures are a crucial aspect of the heavy-duty vehicle GHG and fuel consumption program. This rulemaking is proposing to establish several new test procedures for both engine and vehicle compliance. This chapter will describe the development process for the test procedures being proposed, including the assessment of engines, aerodynamics, rolling resistance, chassis dynamometer testing, powertrain testing, and duty cycles.

3.1 Heavy-Duty Engine Test Procedure

The agencies are controlling heavy-duty engine fuel consumption and greenhouse gas emissions through the use of engine certification. The program will mirror existing engine regulations for the control of both GHG and non-GHG pollutants in many aspects. The following sections provide an overview of the test procedures.

3.1.1 Existing Regulation Reference

Heavy-duty engines currently are certified for GHG and non-GHG pollutants using test procedures developed by EPA. The Heavy-Duty Federal Test Procedure (FTP) is a transient test consisting of second-by-second sequences of engine speed and torque pairs with values given in normalized percent of maximum form. The cycle was computer generated from a dataset of 88 heavy-duty trucks in urban operation in New York and Los Angeles. These procedures are well-defined, mirror in-use operating parameters, and thus we believe appropriate also for the assessment of GHG emissions from heavy duty engines. Further, EPA is concerned that we maintain a regulatory relationship between the non-GHG emissions and GHG emissions, especially for control of CO_2 and NO_X. Therefore, the agencies are proposing to continue using the same criteria pollutant test procedures for both the CO_2 and fuel consumption standards.

For 2007 and later Heavy-Duty engines, 40 CFR Parts 86 – “Control of Emissions from New and In-Use Highway Vehicles and Engines” and 1065 – “Engine Testing Procedures” detail the certification process. 40 CFR 86.007-11 defines the standard settings of Oxides of Nitrogen, Non-Methane Hydrocarbons, Carbon Monoxide, and Particulate Matter. The duty cycles are defined in Part 86. The Federal Test Procedure engine test cycle is defined in 40 CFR part 86 Appendix I. The Supplemental Emissions Test engine cycle is defined in 40 CFR 86.1360(b). All emission measurements and calculations are defined in Part 1065, with exceptions as noted in 40 CFR 86.007-11. The data requirements are defined in 40 CFR 86.001-23 and 40 CFR 1065.695.

The measurement method for CO_2 is described in 40 CFR 1065.250. For measurement of CH_4 refer to 40 CFR 1065.260. For measurement of N_2O refer to 40 CFR 1065.275. We recommend that you use an analyzer that meets performance specifications shown in Table 1 of 40 CFR 1065.205. Note that your system must meet the linearity verification of 40 CFR 1065.307. To calculate the brake specific mass emissions for CO_2, CH_4 and N_2O refer to 40 CFR 1065.650.

3.1.2 Engine Dynamometer Test Procedure Proposed Modifications

3.1.2.1 Fuel Consumption Calculation

EPA and NHTSA propose to calculate fuel consumption, as defined as gallons per brake horsepower-hour, from the CO_2 measurement, just as in the HD Phase 1 rule. The agencies are proposing that manufacturers use 8,887 grams of CO_2 per gallon of gasoline and 10,180 g CO_2 per gallon of diesel fuel.

3.1.2.2 Regeneration Impact on Fuel Consumption and CO_2 Emissions

The current engine test procedures also require the development of regeneration emission rate and frequency factors to account for the emission changes during a regeneration event.[1] In Phase 1, the agencies adopted provisions to exclude CO_2 emissions and fuel consumption due to regeneration. However, for Phase 2, we propose to include CO_2 emissions and fuel consumption due to regeneration over the FTP and RMC cycles as determined using the infrequently regenerating aftertreatment devices (IRAF) provisions in 40 CFR 1065.680. However, we are not proposing to include fuel consumption due to regeneration in the creation of the fuel map used in GEM for vehicle compliance Our assessment of the current non-GHG regulatory program indicates that engine manufacturers have significantly reduced the frequency of regeneration events. In addition, market forces already exist which create incentives to reduce fuel consumption during regeneration.

3.1.2.3 Fuel Heating Value Correction

In the HD Phase 1 rule, the agencies collected baseline CO_2 performance of diesel engines from testing which used fuels with similar properties. The agencies are proposing to continue using a fuel-specific correction factor for the fuel's energy content in case this changes in the future. The agencies found the average energy content of the diesel fuel used at EPA's National Vehicle Fuel and Emissions Laboratory was 21,200 BTU per pound of carbon. This value is determined by dividing the Net Heating Value (BTU per pound) by the carbon weight fraction of the fuel used in testing. We are also proposing to continue using the Phase 1 corrections for gasoline, natural gas, and liquid petroleum gas in 40 CFR 1036.530. We are also proposing to expand the table by adding dimethyl ether.

In addition to the fuel heating value correction, we are proposing the addition of reference carbon mass fraction values for these fuels to the Table in 40 CFR 1036.530. These reference values are used in the powertrain calculations 40 CFR 1037.550 to account for the difference in carbon mass fraction between the test fuel and the reference fuel prior to correcting for the test fuel's mass-specific net energy content.

The agencies are not proposing fuel corrections for alcohols because the fuel chemistry is homogeneous.

3.1.2.4 Urea Derived CO_2 Correction

The agencies are proposing to allow manufacturers to correct compression ignition engine and powertrain CO_2 emission results (for engines utilizing urea SCR for NO_X control) to account for the contribution of urea derived CO_2 emissions to the total engine CO_2 emissions.

Urea derived CO_2 can account for up to 1 percent of the total CO_2 emissions. Urea is produced from gaseous NH_3 and gaseous CO_2 that is captured from the atmosphere, thus CO_2 derived from urea decomposition in diesel SCR emission control systems results in a net emission of zero CO_2 to the environment. In our proposed test procedures for Phase 2, we allow manufacturers to determine CO_2 emissions either by measuring the CO_2 emitted from the engine or to determine it by measuring fuel flow rate during the test. If we do not allow for correction of the urea derived CO_2 emissions, this will result in a positive CO_2 bias for CO_2 emissions determined by measuring the CO_2 emitted from the engine. To perform this correction, we are proposing that you determine the mass rate of urea injected over the duty cycle from the engine's J1939 CAN signal. This value is used as an input to an equation that allows you to determine the mass rate of CO_2 from urea during the duty cycle. This resulting CO_2 mass emission rate value is then used as an input to the steady-state fuel map fuel mass flow rate calculation in 40 CFR 1036.535 and the total mass of CO_2 emissions over the duty cycle calculations in 40 CFR 1037.550. Note that this correction is only allowed for CO_2 measured from the engine and not CO_2 derived from fuel flow measurement.

The calculation for determination of the mass rate of CO_2 from urea requires the user to input the urea solution urea percent by mass. This calculation uses prescribed molecular weights for CO_2 and urea as given in 40 CFR 1065.1005 of 44.0095 and 60.05526 respectively. A 1:1 molar ratio of urea reactant to CO_2 product is assumed.

To facilitate the ability of the agencies to make this correction, we are proposing that the urea mass flow rate be broadcasted on the non-proprietary J1939 PGN (Parameter Group Number) 61475 (and 61478 if applicable).

3.1.2.5 Multiple Fuel Maps

Modern heavy-duty engines may have multiple fuel maps, commonly meant to improve performance or fuel efficiency under certain operating conditions. CO_2 emissions can also be different depending on which map is tested, so it is important to specify a procedure to properly deal with engines with multiple fuel maps. Consistent with criteria-pollutant emissions certification, engine manufacturers should submit CO_2 data from all fuel maps on a given test engine. This includes fuel map information as well as the conditions under which a given fuel map is used (*i.e.* transmission gear, vehicle speed, etc).

3.1.2.6 Measuring GEM Engine Inputs

To recognize the contribution of the engine in GEM the engine fuel map, full load torque curve and motoring torque curve have to be input into GEM. To insure the robustness of each of those inputs, a standard procedure has to be followed. Both the full load and motoring torque curve procedures are already defined in 40CFR part 1065 for engine testing. However, the fuel mapping procedure being proposed would be new. The agencies have compared the proposed procedure against other accepted engine mapping procedures with a number of engines at various labs including EPA's NVFEL, Southwest Research Institute sponsored by the agencies, and Environment Canada's laboratory.[1] The proposed procedure was selected because it proved to be accurate and repeatable, while limiting the test burden to create the fuel map. This proposed provision is consistent with NAS's recommendation (3.8).

The agencies are proposing that engine manufacturers must certify fuel maps as part of their certification to the engine standards, and that they be required to provide those maps to vehicle manufacturers. The one exception to this requirement would be for cases in which the engine manufacturer certifies based on powertrain testing, as described in Section 3.6. In such cases, engine manufacturers would not be required to also certify the otherwise applicable fuel maps. We are not proposing that vehicle manufacturers will be allowed to develop their own fuel maps for engines they do not manufacture.

3.1.3 Engine Family Definition and Test Engine Selection

3.1.3.1 Criteria for Engine Families

The current regulations outline the criteria for grouping engine models into engine families sharing similar emission characteristics. A few of these defining criteria include bore-center dimensions, cylinder block configuration, valve configuration, and combustion cycle; a comprehensive list can be found in 40 CFR 86.096-24(a)(2). While this set of criteria was developed with criteria pollutant emissions in mind, similar effects on CO_2 emissions can be expected. For this reason, this methodology should continue to be followed when considering CO_2 emissions, just as it was in the HD Phase 1 rule.

3.1.3.2 Emissions Test Engine

We are proposing that manufacturers select at least one engine per engine family for emission testing. The methodology for selecting the test engine(s) should be consistent with 40 CFR 86.096-24(b)(2) (for heavy-duty Otto cycle engines) and 40 CFR 86.096-24(b)(3) (for heavy-duty diesel engines). An inherent characteristic of these methodologies is selecting the engine with the highest fuel feed per stroke (primarily at the speed of maximum rated torque and secondarily at rated speed) as the test engine, as this is expected to produce the worst-case criteria pollutant emissions. To be consistent, however, it is recommended that the same methodology continue to be used for selecting test engines.

3.2 Aerodynamic Assessment

3.2.1 Aerodynamics for Tractors

For the Phase 1 rule, the agencies promulgated requirements whereby the coefficient of drag assessment was a product of test data and modeling using good engineering judgment. A

[1] U.S. Environmental Protection Agency. Memo to Docket EPA-HQ-OAR-2014-0827.

group of aerodynamic bins for tractors corresponding to certain known aerodynamic design features (e.g., Classic, Conventional, SmartWay, etc.) were established based on the results of an agency sponsored aerodynamic assessment test program. The rules require tractor manufacturers to take the aerodynamic test result from a tractor and determine the tractor's appropriate bin. To ensure the consistency of the drag assessment results, certain aspects of the truck were defined, including the trailer, location of payload, and tractor-trailer gap. In addition, the agencies specified test procedures for aerodynamic assessment: coastdown testing (also used as the reference method), wind tunnel testing (reduced and full scale), and computational fluid dynamics (CFD). Constant speed testing was also permitted as an alternative test procedure, but the agencies did not develop a specific procedure.

For the HD Phase 2 proposal, we are retaining all the current HD Phase 1 aspects of the aerodynamic assessment protocols with the following revisions and additions: enhancement of the analysis methodology for the coastdown test procedure, which we are proposing to keep as the reference method for the proposed tractor program; specifications for the constant speed test procedure; inclusion of trailers in the aerodynamic assessment test protocols; modifications to the reference trailer used for tractor aerodynamic assessment and establishing a reference tractor for trailer aerodynamic assessment; proposal of wind-average coefficient of drag (C_{Dwa}) as the required aerodynamic Greenhouse Gas Emissions Model (GEM) input for tractors; and considering potential aerodynamic performance for advanced aerodynamic performance of tractor-trailer combinations in the proposed timeframe for this rulemaking. Another proposed modification to the aerodynamic assessment for HD Phase 2 is the use of drag area (coefficient of drag multiplied by the frontal area, or C_dA), rather than the coefficient of drag (C_d), for tractor aerodynamic bin standards. Although this modification would not alter the aerodynamic assessment protocols, it is important to note this since all HD Phase 2 aerodynamic assessment results will be presented in this format, rather than the C_d format used for HD Phase 1.

3.2.2 Modifications to Aerodynamic Assessment Methods for HD Phase 2

Currently, tractor manufacturers are successfully using the established aerodynamic assessment methods established under HD Phase 1 for implementation and compliance with HD Phase 1 emissions standards. Accordingly for HD Phase 2, we are proposing to continue to use the existing aerodynamic assessment methods for generating aerodynamic inputs to GEM with the coastdown test procedure as the reference method, and the constant speed test procedure, wind tunnels, and CFD as the allowed alternative methods (or any other EPA pre-approved test methods). As a result, for HD Phase 2, we are only considering modifications to further enhance, improve or specify the existing aerodynamic assessment methods.

During development and since the beginning of HD Phase 1 implementation, we have received suggestions for improving the coastdown test procedure analysis methodology to reduce data post processing and improve data resolution. Also, as mentioned above, although constant speed testing is allowed as an alternative method, we did not define the specifications and protocols for conducting the testing as was done for the coastdown test procedure reference method and other alternative methods. Finally, by virtue of CFD being software-based, it may be possible to improve the conditions specified for performing CFD analysis to provide a more realistic result. Accordingly, for HD Phase 2 aerodynamic assessment methods, we are proposing to modify the coastdown test procedure analysis methodology, define the specifications and protocols for conducting and analyzing the results of the constant speed test procedure, and update the conditions for performing CFD analysis.

For HD Phase 2, we are not proposing any changes to the existing wind tunnel specifications and protocols other than revising the measured yaw angles to incorporate the wind average coefficient of drag. Under HD Phase 1, we only required manufacturers to conduct wind tunnel testing at a zero degree yaw angle. In contrast, for HD Phase 2, we are proposing to incorporate the wind average coefficient of drag and, consequently, to require measurement at additional yaw angles for generating the yaw sweep curve and calculating the wind average coefficient of drag.

Wind tunnels are pivotal in redefining a standard trailer for tractors, assessing different trailer types to support the proposed trailer standards, and assessing wind averaged drag. Therefore, the test results using the existing wind tunnel specifications and protocols, and the revisions to incorporate the wind average coefficient of drag will be discussed in the context of these areas later in this section.

3.2.2.1 Modification of Coastdown Testing Data Analysis Procedures for HD Phase 2

Based on feedback from the heavy-duty vehicle manufacturing industry and other entities, the agencies finalized a Modified SAE J1263 coastdown procedure in the HD Phase 1 rulemaking. During and since the finalization of HD Phase 1 regulations, stakeholders have suggested analyzing portions of the data rather than the full data set generated during coastdown testing to increase measurement accuracy and/or precision. One OEM suggested the use of the high speed portion of the coastdown test procedure speed range to solely or predominantly isolate the aerodynamic forces. Another OEM suggested using the high speed and low speed portions of the coastdown test procedure speed range in an iterative fashion to isolate the mechanical/frictional losses and rolling resistance predominantly present at lower speeds and removing these forces from the higher speed forces to capture predominantly aerodynamic forces.

As a result of these suggestions, the agencies (via contractors ICF Corporation and Southwest Research Institute (SwRI)) coasted down combination tractors on Farm-to-Market Highway 70, a rural highway, between Bishop, Texas and Chapman Ranch, Texas. A grade survey was performed by SwRI. Filtered USGS elevation data were also obtained for the same stretch of roadway.[2] The grade information was incorporated into our analysis. The testing was conducted overnight, usually between 12 am and 4 am, to minimize traffic and wind. To get a comprehensive data set to conduct various analysis techniques, the vehicles were coasted down from 70 mph to 0 mph. Approximately 20 runs (10 in each direction) were planned for each test, but the number was reduced to 14 runs (7 in each direction), due to the increase in test time associated with coasting all the way to 0 mph. An ultrasonic anemometer was mounted 0.85 m above the leading edge of the trailer at the midpoint of the trailer width. This anemometer recorded air speed and direction onboard the vehicle at 10 Hz. A weather station, which measured wind speed, wind direction, temperature, and air pressure at 1 Hz, was placed alongside the road at the approximate midpoint of the stretch of road being used for the tests. Details of the test setup and vehicle information can be found in the on-road testing summary report from SwRI.[3] The average and maximum wind speeds were calculated for each run to determine validity of the run with respect the wind restrictions. Table 3-1 below shows the ambient conditions desired during coastdown testing, which resembles the SAE J1263 recommended practice.

Table 3-1 Coastdown Ambient Conditions

PARAMETER	RANGE
Average wind speed at the test site (for each run in each direction)	< 10 mph
Maximum wind speed (for each run in each direction)	<12.3 mph
Average cross wind speed (for each run in each direction at the site)	< 5 mph

The position of the onboard anemometer is such that the air speed readings need to be corrected. Located above the trailer, the anemometer's air velocity readings will typically be greater than the free stream air speed. The roadside weather station was used to correct the onboard air speed measurements, using the trigonometric calculations below. For this correction, each coastdown run was split into 5-mph segments, over which the vehicle speed v, measured air speed $v_{r,meas}$, wind speed w, and wind direction θ_w were averaged.

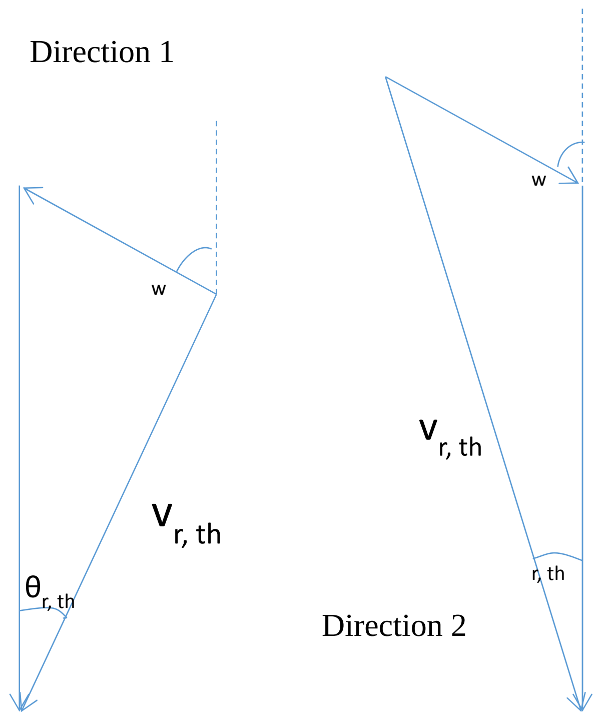

Figure 3-1 Diagram of vehicle speed and air speed vectors during coastdowns in opposite directions

The law of cosines was used to calculate the theoretical air speed $v_{r,th}$ from the vehicle speed and weather station measurements, as described in the equation below. The bars over the variables indicate averages over the 5-mph segments.

$$\overline{v}_{\mathrm{r,th}} = \begin{cases} \sqrt{\overline{w}^2 + \overline{v}^2 - 2\overline{v}\overline{w}\cos\overline{\theta}_{\mathrm{w}}}, & direction = 1 \\ \sqrt{\overline{w}^2 + \overline{v}^2 + 2\overline{v}\overline{w}\cos\overline{\theta}_{\mathrm{w}}}, & direction = 2 \end{cases}$$

The resulting theoretical air speed values were regressed against the measured air speed values for every test, and this linear relationship was used to correct the air speed measurements in the real-time data. This relationship is shown by the equations below and from the test results given in Figure 3-2.

Regression equation for air speed correction: $\overline{v}_{\mathrm{r,th}} = \alpha_0 + \alpha_1 \overline{v}_{\mathrm{r,meas}}$
Applied to air speed measurements: $v_{\mathrm{r}} = \alpha_0 + \alpha_1 v_{\mathrm{r,meas}}$

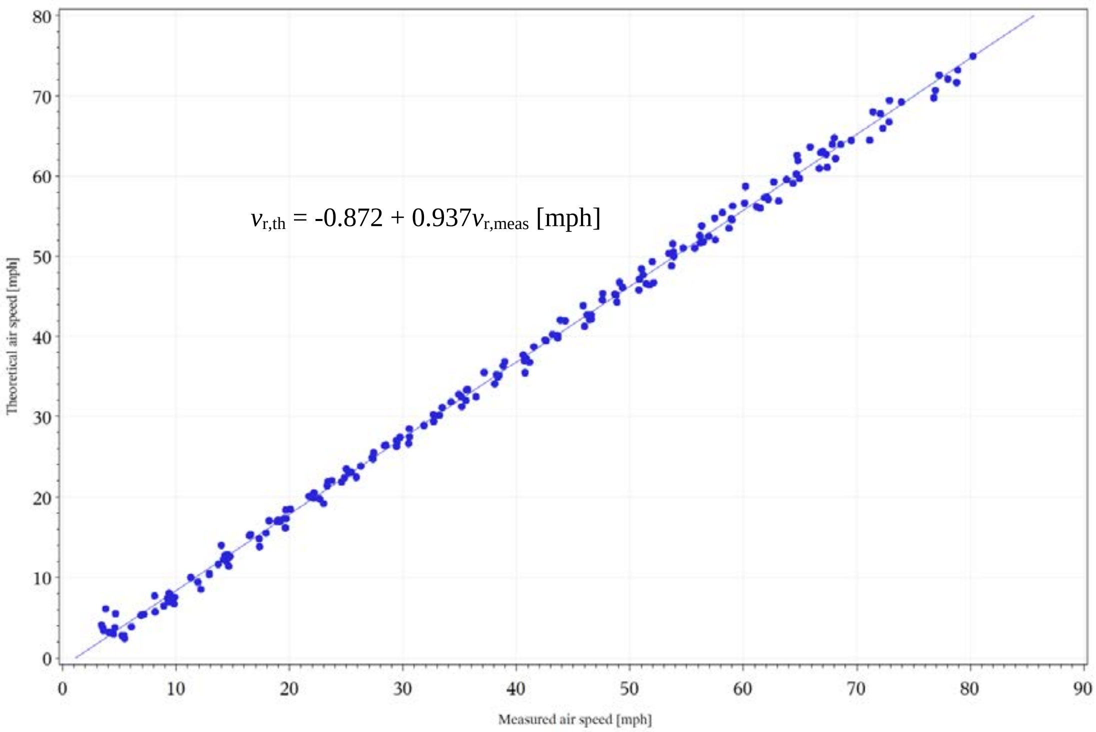

Figure 3-2 Example of theoretical air speed vs. measured air speed shows a consistent relationship that can be used to correct the onboard air speed measurements.

The 10-Hz data were filtered using a one-second weighted centered moving average prior to further analysis.

3.2.2.1.1 High-low Iteration Analysis

This analysis involves analyzing the coastdown over two separate speed ranges. A low-speed range is used to estimate mechanical losses and subtract them out of a high-speed range to estimate aerodynamic drag. This process is iterated until mechanical and aerodynamic drag forces converge. The force is not calculated at each measurement, but instead the net force over each speed range is calculated by measuring the time taken to decelerate through each speed range. We assumed a linear decrease in speed (i.e. constant deceleration), because the speed ranges are small. We are also incorporating a simple speed-dependent rear axle loss adjustment to subtract out what we have learned to be a small but speed-dependent non-aerodynamic drag. We are also in the process of collecting data on the speed effect of tire rolling resistance and are considering including a simple adjustment for this in the final rule.

While this analysis can be done for any pair of speed ranges, we are focusing this discussion on a low speed range of 25 to 15 mph and a high speed range of 70 to 60 mph. Table 3-2 below describes the analysis methodology step by step.

Table 3-2 Drag Area Calculation Steps for High-Low Iteration Analysis

STEP 0: FIND THE TIMES BRACKETING THE LOW-SPEED AND HIGH-SPEED RANGES $V_{LO1}<V_I<V_{LO2}$ (LOW SPEED) $V_{HI1}<V_I<V_{HI2}$ (HIGH SPEED)	$t_{\mathrm{LO1}}, t_{\mathrm{LO2}}, t_{\mathrm{HI1}}, t_{\mathrm{HI2}}$	*V = VEHICLE SPEED* LO1=*15MPH,* LO2=*25MPH* HI1=*60MPH,* HI2=*70MPH*
Step 1: Calculate acceleration for each speed range.	$a_{\mathrm{lo}} = \frac{v_{\mathrm{lo2}} - v_{\mathrm{lo1}}}{t_{\mathrm{lo2}} - t_{\mathrm{lo1}}} = \frac{\Delta v_{\mathrm{lo}}}{\Delta t_{\mathrm{lo}}}$ $a_{\mathrm{hi}} = \frac{v_{\mathrm{hi2}} - v_{\mathrm{hi1}}}{t_{\mathrm{hi2}} - t_{\mathrm{hi1}}} = \frac{\Delta v_{\mathrm{lo}}}{\Delta t_{\mathrm{lo}}}$	*a = vehicle acceleration* *t = time*
Step 2: Calculate average road grade force over each speed range.	$F_{\mathrm{grade,lo}} = Mg\left(\frac{\Delta h}{\Delta s}\right)_{\mathrm{lo}} = Mg\,\frac{h_{\mathrm{lo2}} - h_{\mathrm{lo1}}}{s_{\mathrm{lo2}} - s_{\mathrm{lo1}}}$ $F_{\mathrm{grade,hi}} = Mg\left(\frac{\Delta h}{\Delta s}\right)_{\mathrm{hi}} = Mg\,\frac{h_{\mathrm{hi2}} - h_{\mathrm{hi1}}}{s_{\mathrm{hi2}} - s_{\mathrm{hi1}}}$	*M = vehicle mass* *h = elevation (relative)* *s = travel distance* *g = gravitational acceleration = 9.81 m/s²*
Step 3: Inertial and Effective Mass (Add 125 lbm per tire to account for rotational inertia).	$M_{\mathrm{inertial}} = 125\,\frac{lbm}{tire}\cdot n_{\mathrm{tires}} = 56.7\,\frac{kg}{tire}\cdot n_{\mathrm{tires}}$ $M_{\mathrm{e}} = M + M_{\mathrm{inertial}}$	$M_{inertial}$ = *additional inertia from rotating components* M_e = *effective mass* n_{tires} = *total number of tires in test configuration*
Step 4: Road load force for each speed range, also accounting for rear axle loss estimate (F_{axle}).	$F_{\mathrm{lo}} = -M_{\mathrm{e}}a_{\mathrm{lo}} + F_{\mathrm{grade,lo}} - F_{\mathrm{axle,lo}}$ $F_{\mathrm{hi}} = -M_{\mathrm{e}}a_{\mathrm{hi}} + F_{\mathrm{grade,hi}} - F_{\mathrm{axle,hi}}$	*F = force* $F_{axle,lo}$ = *100 N* $F_{axle,hi}$ = *200 N*
Step 5: Air density during each high speed section.	$\rho = \frac{1000 \times \mathrm{P}}{\mathrm{R}(\mathrm{T} + 273.15)}$	*ρ = density of air* *P= average ambient pressure during high speed run in kPa* *T = average ambient temperature during high speed run in °C* *R = gas constant for air =287.058 J/(kg-K)*
Step 6: Average relative air speed over each speed range.	$v_{\mathrm{r,lo,avg}} = \sum_{v_{\mathrm{lo1}}}^{v_{\mathrm{lo2}}} \frac{v_{\mathrm{r}}}{n_{\mathrm{lo}}}$ $v_{\mathrm{r,hi,avg}} = \sum_{v_{\mathrm{hi1}}}^{v_{\mathrm{hi2}}} \frac{v_{\mathrm{r}}}{n_{\mathrm{hi}}}$	v_r = *relative air speed*
Step 7: Initial conditions (i=0). Start with no aerodynamic forces in the low speed range.	$F_{\mathrm{aero,lo,0}} = 0$	

Step 8: Subtract low-speed aerodynamic forces from low speed forces to estimate mechanical forces.	$F_{\mathrm{mech,i}} = F_{\mathrm{lo}} - F_{\mathrm{aero,lo,i}}$	
Step 9: Subtract mechanical forces from high speed forces to estimate aerodynamic forces.	$F_{\mathrm{aero,hi,i}} = F_{\mathrm{hi}} - F_{\mathrm{mech,i}}$	
Step 10: Adjust aerodynamic forces by speed to estimate low-speed aerodynamic forces.	$F_{\mathrm{aero,lo,i+1}} = F_{\mathrm{aero,hi,i+1}} \left(\frac{v_{\mathrm{r,lo,avg}}^2}{v_{\mathrm{r,hi,avg}}^2} \right)$	
Step 11: Repeat steps 8-10 until both high-speed aerodynamic and low-speed mechanical forces both converge less than 1%.	Repeat steps 8-10 until: $\left\lvert 1 - \frac{F_{\mathrm{aero,hi,i+1}}}{F_{\mathrm{aero,hi,i}}} \right\rvert < 0.01$ and $\left\lvert 1 - \frac{F_{\mathrm{mech,lo,i+1}}}{F_{\mathrm{mech,lo,i}}} \right\rvert < 0.01$	
Step 12: Calculate drag area.	$C_{\mathrm{d}}A = \frac{2F_{\mathrm{aero,hi,i+1}}}{\rho v_{\mathrm{r,hi,avg}}^2}$	

There are some advantages to using this method over the Phase 1 method. Focusing on segmented speed ranges may open up more test locations, as less road or track space would be required to collect a full data set. The middle range of speeds that would be eliminated contains a higher proportion of rolling resistance forces and also sweeps through greater yaw angles, even at modest crosswind conditions, which can increase the aerodynamic drag of certain runs and subsequently increase the variability of a test. This method does not account for yaw angle, but with the proper wind constraints and the use of a high-speed range to estimate aerodynamic drag, the yaw angle effect should be small or statistically indiscernible. The result of this analysis method is considered to be a zero-yaw C_dA.

3.2.2.1.2 High-low Intercept Analysis

This method is similar to the previous method, with a few important differences. Instead of calculating force over speed intervals, like in the iteration method, the force is calculated at every speed measurement, similar to the HD Phase 1. The mechanical forces are determined through the low speed range that goes all the way to 0 mph though a force versus vehicle speed regression. The force intercept is then adjusted by a generic rolling resistance speed adjustment to estimate rolling resistance forces throughout the coastdown. These forces are then subtracted from the total road load forces to estimate aerodynamic drag forces. The aerodynamic drag forces are then adjusted for yaw angle through an adjustment previous determined by a CFD run.

The agencies did not evaluate this method in detail for the proposal due to lack of CFD or other yaw sweep data for the specific tractors that were tested. The agencies also did not have data to support a specific rolling resistance speed correction. The agencies are in the process of collecting some of this data and may evaluate this method for the final rule.

3.2.2.1.3 High-speed Yaw Angle Analysis

Another suggested analysis method was to use only the high-speed range from each coastdown (70-50 mph) and use the onboard anemometry to develop a wind-average C_dA, as opposed to a zero-yaw C_dA. One main advantage to this method is that it would allow for less road or track space to be used because only a high speed range would be needed. This allows for minimal acceleration and deceleration, which consume significant amounts of space and time, and subsequently allows for more runs to be conducted.

A second-order regression with no linear term is used to separate the mechanical forces from the aerodynamic forces; the regression is done similar to Phase 1, but using the smaller speed range and air speed instead of vehicle speed.

$$F = M_{\mathrm{e}} \frac{\Delta v}{\Delta t} = A + D v_{\mathrm{r}}^2$$

The D coefficient is used to estimate drag area C_dA, using the temperature and pressure during the speed range to calculate air density, just as in the analysis methods discussed earlier in this section. The yaw angle θ_r is averaged over the speed range, and the absolute value is used. The C_dA is fit to a second order regression with the absolute value of the yaw angle.

$$C_{\mathrm{d}}A = \frac{2D}{\rho}$$

$$\overline{C_{\mathrm{d}}A} = a_0 + a_1|\overline{\theta_{\mathrm{r}}}| + a_2|\overline{\theta_{\mathrm{r}}}|^2$$

This C_dA curve would then be used to conduct a yaw sweep to develop a wind-average C_dA value for certification, rather than a zero-yaw C_dA. While air direction was measured onboard, the accuracy of the anemometer is only ±2°, according the product specifications.[4] Over the speed range recommend for analysis, yaw angles would only occur between 0° (for a direct headwind/tailwind) and 6° (for a direct crosswind). The accuracy of the instrument is not sufficient to measure average yaw angle. Instead, the roadside weather station was used to more accurately determine the average yaw angle. Trigonometric equations using the weather station measurements were used to calculate the average yaw angle for each coastdown run; the anemometer air direction readings were not used. The yaw angle was calculated using the law of sines. See Figure 3-1 earlier for variable references.

$$\overline{\theta_{\mathrm{r}}} = \overline{\theta_{\mathrm{r,th}}} = \begin{cases} \sin^{-1}\left(\dfrac{\overline{w}}{\overline{v}_r}\sin\overline{\theta}_{\mathrm{w}}\right), & direction = 1 \\ -\sin^{-1}\left(\dfrac{\overline{w}}{\overline{v}_{\mathrm{r}}}\sin\overline{\theta}_{\mathrm{w}}\right), & direction = 2 \end{cases}$$

Using the recommended speed range (70-50 mph) and regression fit equation, we found that the standard errors for the *D* values for individual runs ranged from 16 to 76 percent, with a median value of 31 percent. The standard error for the *A* value was even larger, ranging from 25 to 186 percent. These values are extremely high, compared to applying this method through the full speed range (70-0 mph), where the median of the standard errors for the *D* values was approximately 3 to 4 percent.

In a typical unloaded coastdown from 70 to 50 mph, the average vehicle speed is approximately 59 mph. The SAE J1263 and HD Phase 1 limit for cross wind is 5 mph. Under this limiting scenario, the average yaw angle experienced during this speed range would be 4.8° [$\tan^{-1}(5/59)$]. This does not provide a large enough spread in yaw angle to develop a yaw sweep to produce a statistically meaningful wind averaged drag area. Furthermore, if winds are relatively constant throughout a test, the constant cross wind would provide yaw angles around 5° and -5°, without much in between. If winds are not exactly perpendicular, then there would be more of a distribution closer to 0°, but with less data at wider angles.

The data collected here show that the bulk of the yaw angles from the data collected within Phase 1 wind requirements falls between -4° and 4°. Further analysis shows that statistically significant curves of C_dA versus yaw angle could not be formed due to the variability of the data. Since the absolute value of the yaw angle is used in the analysis, this method also assumes that the aerodynamic characteristics are symmetrical, which is a not a safe assumption. Even using the absolute values, the C_dA versus yaw angle curve is not statistically meaningful, as shown in Figure 3-3.

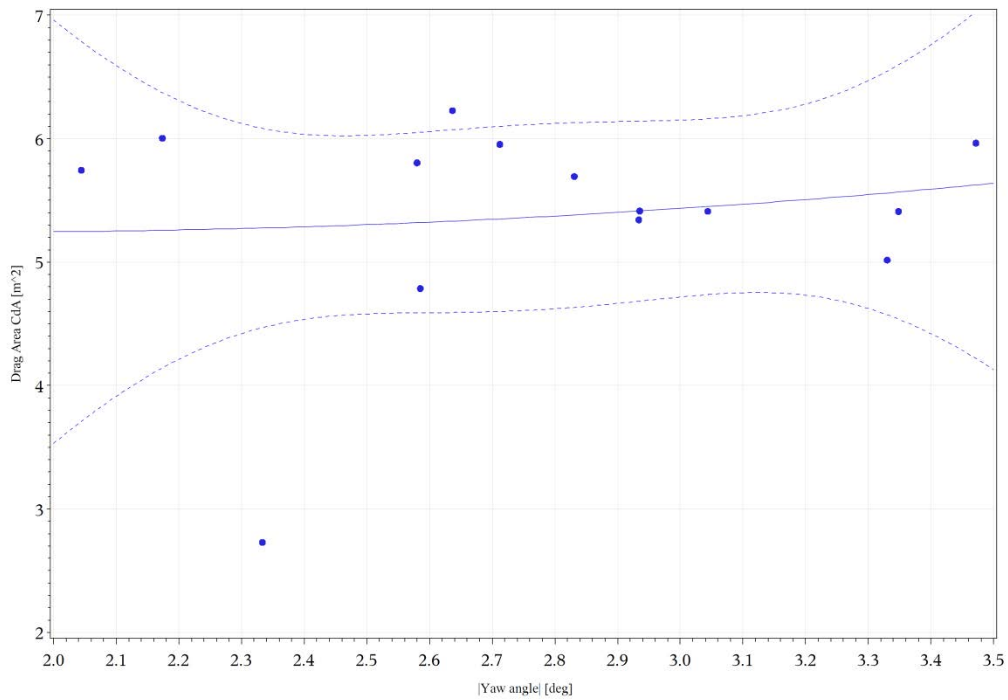

Figure 3-3 Example data from the high-speed yaw angle analysis shows high uncertainty of the statistical fit. The solid line is the yaw curve with the dashed lines representing the upper and lower 95% confidence limits of the mean.

After evaluating the methods described above, the agencies are proposing that the high-low iteration analysis method be used to determine the drag area GEM input. In general, while coastdown tests are used to determine the aerodynamic drag, the procedure itself is a road load procedure, not an aerodynamic one. That is, the measured or calculated forces represent the total road load from which the aerodynamic forces must be calculated or inferred; they are not measured directly. As a result, all analysis methods that are used in conjunction with coastdowns must calculate or infer aerodynamic forces.

3.2.2.2 Specifications and Protocols for Conducting Constant Speed Testing

Similar to the Coastdown Test Procedure, the Constant Speed Test Procedure is conducted on road and used to measure the forces acting on the tractor. In contrast to the Coastdown Test where the vehicle is accelerated to a set speed and then allowed to coast to a lower speed in neutral, the Constant Speed Test is conducted by measuring torque along the driveline at various constant speeds. This helps to reduce measurement uncertainty due to potential driveline vibration experienced during coastdown and better isolate the force contributions between speed transitions over the speed range (e.g., aerodynamic drag dominance at high speed; a mix of aero drag and mechanical/frictional forces in middle speeds; and mechanical/frictional force dominance at low speeds). In addition, whereas the total force, and consequently the total drag force, is derived based on the speed and time for the coastdown test, the constant speed test measures the total force at the wheels using wheel hub torque meters and/or a driveshaft torque meter. It can also incorporate, where needed and available, engine speed and torque, transmission gear ratio, rear axle losses, or other relevant data. The constant speed test has the potential to reduce uncertainty compared to a coastdown because it can collect data at a single speed for a sustained amount of time. For HD Phase 1, we allowed the use of Constant Speed testing as an alternate aerodynamic method but did not promulgate specific test procedure requirements. In lieu of this, a manufacturer would have been required to develop its own test procedure for constant speed testing and submit it to the agencies for approval.

For HD Phase 2, we are proposing specific requirements for conducting the constant speed test, to be used by manufacturers choosing this testing method. Accordingly, we evaluated the constant speed testing using the same vehicles receiving the coastdown test procedure. For our evaluations, we used several speeds to determine the optimal speeds for constant speed testing. In addition, we performed the testing with both wheel hub torque meters and a driveshaft torque meter to quantify the benefits and detriments of both methods. More details on our test set up for constant speed testing and our results are discussed below.

In addition to evaluating the constant speed test procedure, we are also seeking comment regarding making the constant speed test procedure the reference aerodynamic method. We received suggestions to this effect from industry during the HD Phase 1 rulemaking process, since some of the OEMs have European controlling interest. Thus, use of the constant speed test would allow them to harmonize test procedures with their European counterparts, who are required to use constant speed testing. We did not have data to support use of the constant speed test as the preferred method for Phase 1. Since then we have evaluated and are proposing specific constant speed testing requirements for HD Phase 2. Thus, we are taking this opportunity to explore this approach again.

3.2.2.2.1 Constant Speed Test Procedure Specifications

For our evaluation of the constant speed test, we used the following procedure and specifications:

- Used four High Resolution Truck Torque Wheel Transducers with approximate 5 lb-ft resolution during testing of each of the tractors. Mechanical protection against high torque application (both acceleration and braking) telemetry, and associated wheel adapters, encoder, amplifier, and power supply was employed.
- Used an in-line strain-gauged torque flange, which was used to measure driveshaft torque during the testing each of the tractors (i.e., driveshaft torque sensor). The torque flange was an ANSI C12.20 0.5 class meter with a range of 0 to 5,000 Newton- meters (N-m). This torque meter utilizes special adapters and cannot be connected directly to the drive shaft. A modified drive shaft shall was acquired for each tractor to accommodate the torque meter. These drive shafts were dynamically balanced.
- Used a driveshaft torque sensor and wheel hub meter simultaneously to collect data at the drive shaft and the wheels for comparison. The driveshaft torque sensor was calibrated according to 40 CFR 1065.310.
- During the test, the following parameters were monitored (data collected), similar to the coastdown tests:
  - Air speed data using an anemometer mounted on the trailer approximately 0.85 m above the trailer roof, at the midpoint of the trailer width, at the leading edge of the trailer.
  - Vehicle speed using an optical fifth wheel.
  - Engine speed using the electronic control unit (ECU).
  - Grade data along the location of track or road where testing was performed.
- The vehicle was warmed-up by being driven for 30 minutes prior to the test. The same road was used for the constant speed testing coastdown to ensure grade/location consistency.
- Testing was performed at the following speeds and durations while recording torque and engine data. Cruise control was used to maintain speeds, except for the lower one or two speeds for certain tests.
  - 10 mph – 7.5 minutes in each direction
  - 20 mph – 7.5 minutes in each direction
  - 30 mph – 7.5 minutes in each direction
  - 50 mph – 8-10 minutes in each direction
  - 70 mph – Approximately 11.25 miles or 9.6 minutes in each direction.
- If necessary, multiple passes were conducted.

The agencies conducted constant speed testing through Southwest Research Institute along the same stretch of roadway as the coastdown testing.

3.2.2.2.2 Constant Speed Test Procedure Analysis Methodology

For analysis of the constant speed test procedure data, the 10-Hz data were filtered using a two-second centered moving average and then split into 10-second segments over which the forces, air speed, and air direction were averaged. For tractors equipped with the driveshaft torque meter, the road load force was calculated as follows:

$$F_{\mathrm{RL,shaft}} = \frac{\tau_{\mathrm{shaft}}\omega_{\mathrm{eng}}}{GR \cdot v} + F_{\mathrm{grade}}$$

For tractors also equipped with the wheel torque meters, the road load force was calculated as follows:

$$F_{\mathrm{RL,wheel}} = \frac{\tau_{\mathrm{wheel}}\omega_{\mathrm{wheel}}}{v} + F_{\mathrm{grade}}$$

Where:

τ_{shaft} = driveshaft torque
ω_{eng} = engine speed
GR = transmission gear ratio
$F_{\mathrm{RL,shaft}}$ = road load force calculated from the driveshaft torque
τ_{wheel} = wheel torque, sum of all four wheel torque measurements
ω_{wheel} = wheel speed, average of all four wheel speed measurements
$F_{\mathrm{RL,wheel}}$ = road load force calculated from the wheel torque

The analysis method involved a force subtraction method where the average road load force at 10 mph was assumed to be made up of just rolling resistance and mechanical forces. This value was subtracted from each 50-mph and 70-mph road load force measurement to estimate aerodynamic forces, and C_dA was calculated similar to coastdowns.

$$F_{\mathrm{mech}} = \bar{F}_{\mathrm{RL,10mph}}$$

$$F_{\mathrm{aero}} = F_{\mathrm{RL}} - F_{\mathrm{mech}} \text{ (50 \& 70 mph runs only)}$$

$$C_{\mathrm{d}}A = \frac{2F_{\mathrm{aero}}}{\rho v_{\mathrm{r}}^2}$$

Since wind conditions would vary from one test day to another, the yaw angle would also change, creating larger yaw angles and different yaw angle spreads for some tests. In order to compare the constant speed results to one another, the C_dA values were regressed against a fourth-order polynomial of yaw angle to determine the zero-yaw C_dA. Any tests that were conducted outside of the wind speed constraints were included along with tests within the wind constraints because the yaw angle distribution helped developed the polynomial fit.

$$C_{\mathrm{d}}A(\theta_r) = C_{\mathrm{d}}A(0) + a_1\theta_{\mathrm{r}} + a_2\theta_{\mathrm{r}}^2 + a_3\theta_{\mathrm{r}}^3 + a_4\theta_{\mathrm{r}}^4$$

If over 75 percent of the points occurred at yaw angles between -2 and +2 degrees, then the zero-yaw C_dA was determined by using the average of the C_dA values between those yaw angles. This would occur on test days where the prevailing winds were more parallel to the direction of travel, resulting in low yaw angles. A regression was not used in this case because the F test showed a low level significance of the polynomial fit given above. These regressed or averaged zero-yaw C_dA values are the constant speed test results that are reported in this document.

Since the wheel torque measurements are downstream of the rear axle losses, they are a more accurate measurement of actual road load forces than the driveshaft torque measurements. The first several tests were conducted without wheel torque meters, so those tests' results, which were determined only through the driveshaft torque measurements, were reduced by 6 percent, based on the ratio of C_dA determined from one of the vehicles with a similar axle that was equipped with both driveshaft and wheel torque meters.

3.2.2.3 Results for Coastdown and Constant Speed Testing Using Modified/Specified Test Procedures

Using the coastdown test procedure with modified analysis methodology and the specifications and protocols for the constant speed test procedure, we evaluated four Class 8, high roof sleeper cabs, one from each of the heavy-duty tractor OEMs, and a Class 8, high roof, tandem axle sleeper cab with a 53' dry box van trailer. The results using these procedures on tractor-trailer combinations with the trailer in the standard configuration (e.g., a 53' dry box van with no trailer devices installed) are shown below in Table 3-3 and Table 3-4 for the coastdown and constant speed test procedure, respectively.

Table 3-3 Summary of Results from Coastdown Testing

CAB TYPE	ROOF HEIGHT	TRAILER CONFIGURATION	C_dA [m^2]	STD. ERROR	# OF VALID RUNS
Sleeper 1	High	Standard	5.9	0.5 %	14
Sleeper 2	High	Standard	6.2	2.1 %	14
Sleeper 3	High	Standard	6.1	2.3 %	14

Based on this test procedure, the results from our constant speed testing are shown in Table 3-4 below.

Table 3-4 Summary of Results from Constant Speed Testing

CAB TYPE	ROOF HEIGHT	TRAILER CONFIGURATION	C_dA [m^2]	STD. ERROR
Sleeper 1	High	Standard	6.1	0.7%
Sleeper 2	High	Standard	5.9	1.8%
Sleeper 3	High	Standard	5.9	0.3%

The coastdown and constant speed results show a similar range of C_dA values. Using different speed ranges in the coastdown method or analysis techniques in either method may produce slightly different C_dA ranges, depending on certain factors such as the temperature and speed dependence of tire rolling resistance.

The uncertainties, however, are unlikely to change significantly, since they are based on run-to-run variability for a given analysis technique. To ensure the required test repeatability and method acceptance needed for future certification and compliance purposes, we looked at the standard error of the test and the alignment between the test procedures for each tractor. The standard error of the constant speed tests was determined through the statistical fit of the ten-second segments through the yaw polynomial where the polynomial fit was used. In this case, the standard error represents that of the zero-yaw C_dA from that fit. Otherwise, the standard error is of the mean of the C_dA values between -2 and 2 degrees. This may slightly underestimate the uncertainty due to the precision error that may be introduced in the low-speed segments. Other trailer configurations tested with coastdowns show lower uncertainties than the standard trailer. Consequently, either on-road test should be acceptable for aerodynamic assessment. The agencies are still collecting data using both test procedures and will continue to evaluate the accuracy and repeatability of both.

Accordingly, we are proposing to require the use of the coastdown test procedure as the reference method with the high-low iteration analysis method discussed above. We are also specifying the constant speed aerodynamic assessment test procedure based on our above analysis. For constant speed testing, manufacturers may use a driveshaft torque meter or wheel hub torque meters for constant speed testing provided they meet or exceed the specifications given above for each type of device.

We are completing testing on an additional sleeper cab tractor from another OEM and on a day cab tractor. Although all of the on-road testing for tractors is not complete, we believe the results of future on-road testing will be consistent with the trends emerging from the existing data. Once all on-road testing is complete, a full report will be included in the docket and further considered in the context of the tractor aerodynamic standards.

3.2.2.4 Modifications to Computational Fluid Dynamics for HD Phase 2

Computational Fluid Dynamics, or CFD, capitalizes on today's computing power by modeling a full size vehicle and simulating the flows around this model to examine the fluid dynamic properties, in a virtual environment. CFD tools are used to solve either the Navier-Stokes equations that relate the physical law of conservation of momentum to the flow relationship around a body in motion or a static body with fluid in motion around it, or the Boltzmann equation that examines fluid mechanics and determines the characteristics of discreet, individual particles within a fluid and relates this behavior to the overall dynamics and behavior of the fluid. CFD analysis involves several steps: defining the model structure or geometry based on provided specifications to define the basic model shape; applying a closed surface around the structure to define the external model shape (wrapping or surface meshing); dividing the control volume, including the model and the surrounding environment, up into smaller, discreet shapes (gridding); defining the flow conditions in and out of the control volume and the flow relationships within the grid (including eddies and turbulence); and solving the flow equations based on the prescribed flow conditions and relationships.

This approach can be beneficial to manufacturers since they can rapidly prototype (*e.g.*, design, research, and model) an entire vehicle without investing in material costs; they can modify and investigate changes easily; and the data files can be re-used and shared within the company or with corporate partners.

For HD Phase 1, we established some CFD procedures based on our results and industry collaboration since there were no standardized practices at the time. In addition, to ensure data consistency, a minimum set of characteristics and criteria was included for CFD analysis to ensure that the boundary and surface conditions are not too coarse and, thus, not representative of the real tractor and environmental conditions.

For HD Phase 2, we are proposing to either use the existing criteria from HD Phase 1 or require adherence to a newly established, Society of Automotive Engineering (SAE) standard for CFD, SAE J2966.[5] Accordingly, we are comparing the criteria we set forth in HD Phase 1 with SAE J2966 to assess the efficacy of adopting this new standard.

In addition, we are considering enhancements to the specified conditions for performing CFD analysis. Specifically, we specified the use of a simulated vehicle speed of 55 miles per hour and "ambient conditions consistent with the coastdown test procedures." These conditions are ambiguous and may require greater specificity to ensure that the CFD analysis is more closely simulating the real world conditions. As a result, we are seeking comment on the need to improve the simulated ambient environmental conditions for conducting CFD analysis.

Also, similar to wind tunnels, we are proposing to modify the measured yaw angles used in the CFD analysis to incorporate the concept of the wind average coefficient of drag. Under HD Phase 1, we only required manufacturers to perform the CFD analysis at a zero degree yaw angle. For HD Phase 2, we are requiring the CFD analysis to be performed at additional yaw angles for generating the yaw sweep curve and calculating the wind average coefficient of drag. This is discussed further in the following section.

Finally, our CFD specifications do not include or require the use of turbulence intensity in the CFD analysis, and the use of a turbulence model is only required "if applicable." As a result, there is less ability to capture transient flow phenomena in the CFD analysis. Based on developments since HD Phase 1, the ability to include turbulence in the CFD analysis without severely impacting the analysis run time has improved. Therefore, we are seeking comment on the inclusion of turbulence in CFD analysis.

As we consider these proposed modifications and a revised standard reference trailer for tractor aerodynamic assessment, it is important to evaluate the ability of CFD to characterize the aerodynamics when aerodynamic trailer devices are employed. Therefore, we will be evaluating trailer aerodynamic devices for CFD method validation to support HD Phase 2.

3.2.3 Aerodynamic Assessment and Use of Wind Averaged Drag Area

Finally, we received comments in HD Phase 1 regarding the use of the wind averaged coefficient of drag (WAC_d) since WAC_d accounts for aerodynamic performance across a broader spectrum of wind conditions rather than a pure headwind or tailwind (e.g., zero degree yaw). Consequently, the use of WAC_d for aerodynamic assessment may better reflect real-world aerodynamic performance and fuel consumption. Therefore, we assessed the use of WAC_d for HD Phase 2 and the results are discussed below in this section.

EPA and NHTSA recognize that wind conditions have a greater impact on real world CO_2 emissions and fuel consumption of heavy-duty tractors than light-duty vehicles. As stated in the NAS report[6], the wind averaged drag coefficient is about 15 percent higher than the zero degree coefficient of drag (C_d). The large ratio of the side area of a combination tractor and trailer to the frontal area illustrates that winds will have a significant impact on drag. One disadvantage of the agencies' approach to aerodynamic assessment in Phase 1 is that the test methods have varying but limited degrees of ability to assess wind conditions. Wind tunnels are currently the only demonstrated tool to measure the influence of wind speed and direction on a vehicle's aerodynamic performance. The coastdown test and computational fluid dynamics modeling both have limited ability to assess yaw conditions. The constant speed test has the potential for yaw angle measurement capability but it is not certain how its ability to measure the influence of wind speed and direction on a vehicle's aerodynamic performance compares to the wind tunnel.

To address this issue in HD Phase 1, the agencies finalized the use of coefficient of drag values that represented zero yaw (i.e., representing wind from directly in front of the vehicle, not from the side). The agencies recognized that the results of using the zero-yaw approach will produce fuel consumption results in the regulatory program which are slightly lower (i.e. predict better fuel consumption results) than in-use, but we believed this approach was appropriate since not all manufacturers were using wind tunnels for the aerodynamic assessment to the extent needed for wind averaged C_d quantification purposes.

During HD Phase 1, we examined full yaw sweep data from the reduced-scale wind tunnel test for three manufacturer 1/8th scale models. Below in Figure 3-4 are the yaw sweep graphs for three manufacturers' vehicles in the reduced-scale wind tunnel with the WAC_d shown for comparison. This graph indicates that, although the zero-yaw C_d results for two tractors can be nearly identical at zero yaw, their aerodynamic performance may diverge as the yaw angle is increased. As a result, although the two tractors exhibit similar zero-yaw aerodynamic performance, their aerodynamic performance in non-zero yaw conditions may be drastically different and, consequently, so would their real-world fuel efficiency.

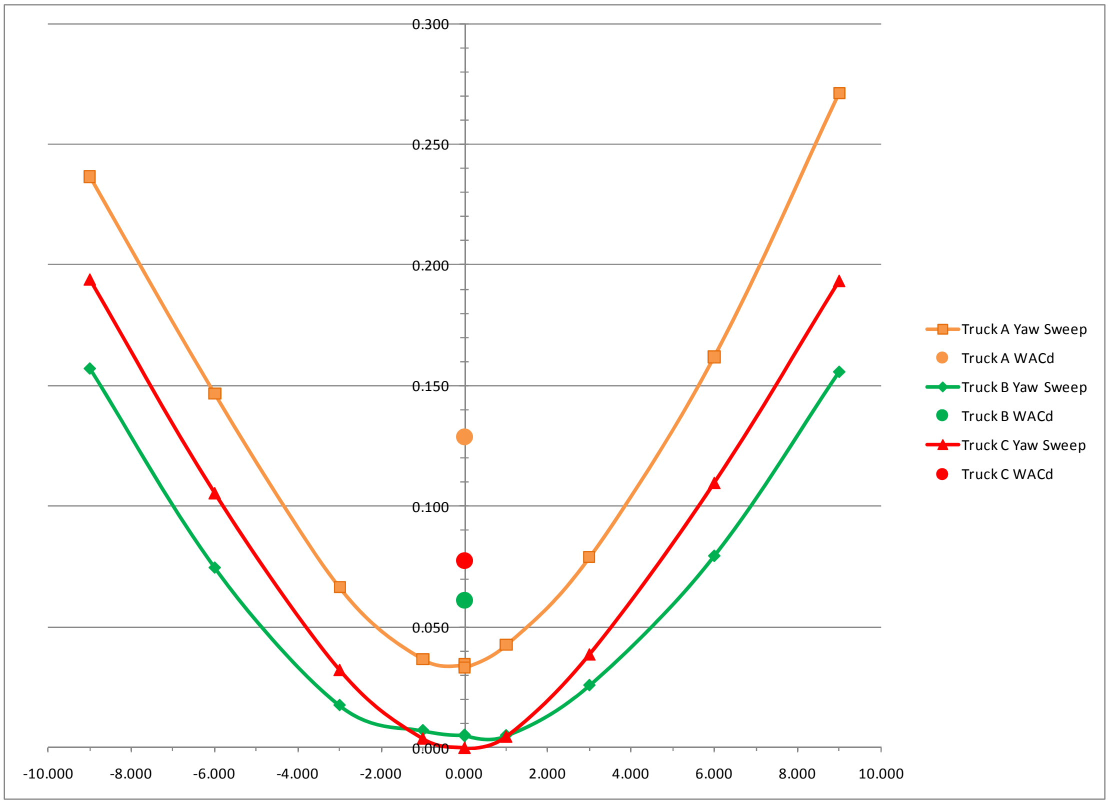

Figure 3-4 Full yaw sweeps and wind-average coefficients of drag (*WAC*ds) for three manufacturer, 1/8th scale, tractor models in the reduced scale wind tunnel.

Table 3-5 below shows the results of an analysis on the impact of improving the non-zero yaw performance on the coefficient of drag for Tractor A versus Tractor B and Tractor C, respectively.

Table 3-5 Absolute Deltas and Percent Difference for Individual Yaw Points for Tractor A versus Tractor B and Tractor C.

+/- YAW ANGLE AVERAGES	TRACTOR A VERSUS TRACTOR B		TRACTOR A VERSUS TRACTOR C	
	Delta C_d	Delta C_d % Difference	Delta C_d	Delta C_d % Difference
Zero Degree	0.001	0.18%	-0.031	-5.84%
One Degree	-0.003	-0.53%	-0.035	-6.65%
Three Degrees	-0.018	-3.33%	-0.052	-9.58%
Six Degrees	-0.035	-5.85%	-0.078	-13.05%
Nine Degrees	-0.042	-6.24%	-0.098	-14.52%

Based on the results, although Tractor A and Tractor B have similar zero degree aerodynamic performance, their aerodynamic performance at higher yaw angles results in a 0.53 to 6.24 percent loss in aerodynamic efficiency. This difference is exacerbated for the case of Tractor A versus Tractor C where the zero degree performance of Tractor C is worse than Tractor A.

Due to this decreased aerodynamic performance at each individual yaw angle, the WAC_d values are impacted as follows when again comparing Tractor A versus Tractor B and Tractor C, respectively, as shown in Table 3-6.

Table 3-6 Absolute Deltas and Percent Difference for Wind Averaged Coefficient of Drag (WAC_d) for Tractor A versus Tractor B and Tractor C.

COMPARISON	ABSOLUTE DELTA	% DIFFERENCE
Tractor A vs. B	-0.021	-3.5%
Tractor A vs. C	-0.069	-11.7%

Consequently, by focusing solely on zero degree yaw angle drag, there is an additional 3.5 to 11.7 percent of benefit lost due to higher aerodynamic drag at greater yaw angles.

As a result of this data and comments we received during and since HD Phase 1, we are proposing the use of additional yaw data to develop a wind-average drag area to be used for input into the GEM model and assigning a GHG emissions score. Further, the agencies are proposing to require manufacturers to use the yaw sweep calculation in SAE J1252 to determine WAC_d and, coupled with the frontal area, the wind averaged drag area (WAC_dA).

Specifically, we are proposing to require the C_dA data for zero degrees, positive/negative one degree, positive/negative three degrees, positive/negative six degrees and positive/negative nine degrees to calculate WAC_dA. This is in accordance with SAE J1252 which requires a minimum of six points for the calculating WAC_d rather than just using zero degrees as is currently required for the HD Phase 1 version of GEM input and positive/negative six degrees currently used for the generation of the HD Phase 1 WAC_d as a yaw sweep correction factor. This proposed methodology would apply for any aerodynamic method that is used to generate the WAC_d using an approved series of yaw angles. Alternatively, a manufacturer may use request to use a series of different angles (e.g., 0, ±2, ±4, ±6, ±8 , ±10 degrees) or fewer angles (e.g., ±3, ±6, ±9) with advanced approval by and demonstration to the agencies that the series of different/reduced yaw angles provides equivalent results to the required yaw angles.

We will also need to generate a yaw sweep curve and WAC_dA based on the coastdown reference method results to determine the appropriate GEM model inputs. At present, the coastdown procedure does not account for the varying wind direction well enough to reliably generate a yaw sweep curve. Therefore, one approach we are proposing to require is for a manufacturer to generate the yaw sweep curve using an alternate method, in particular, the wind tunnel or CFD, by taking the differential of the coastdown result and zero-yaw result from the alternate method and additively applying the coastdown-alternate method zero yaw to each of the points on the alternate method yaw sweep curve. Both of these techniques are demonstrated below in Figure 3-5.

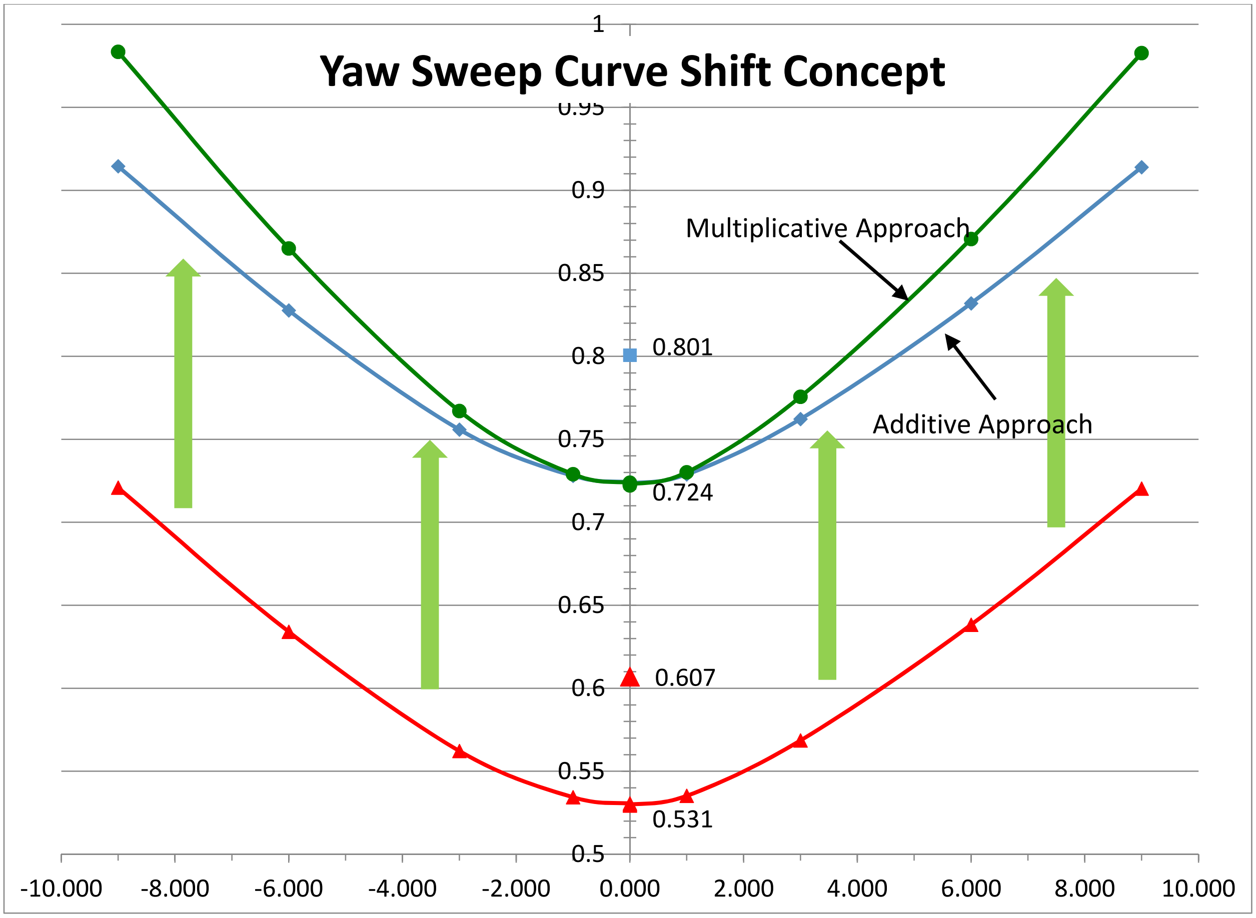

Figure 3-5 Proposed development of a coastdown yaw sweep curve based on additive offset from alternate method yaw sweep curve.

Using the results in Figure 3-5 as it applies to the entire yaw sweep curve; a multiplicative approach changes the shape of the yaw sweep curve whereas the additive approach maintains the yaw sweep curve shape. Therefore, the additive approach is a more appropriate to use than the multiplicative approach when using the full yaw sweep curve to generate the coastdown yaw sweep curve. This, however, requires the addition of the offset to each point on the yaw sweep curve, to shift and maintain the shape of the yaw sweep curve, and recalculating the wind average drag area based on the shifted curve.

Alternatively, a simpler approach is to use the offsets between the zero degree yaw and the coastdown values to calculate $F_{alt\text{-}aero}$; the zero degree yaw and WAC_dA values to calculate a wind average drag offset from the alternate method; and apply them to the coastdown results which reduces the complexity of calculating a virtual coastdown wind average drag area. This approach is explored in further detail in Section 3.2.9.

Accordingly, we are proposing to require WAC_dA as the aerodynamic GEM input for HD Phase 2 and invite comment on the methodology used to generate a coastdown equivalent WAC_dA. Although the data above is shown in C_d format, we will use WAC_dA format for alternate method results for HD Phase 2. The WAC_dA values used to support HD Phase 2 are discussed below in Section 3.2.9.

3.2.4 HD Phase 1 Yaw Sweep Correction

In this proposal, the agencies propose to correct the Phase 1 yaw sweep correction factor equation to create equivalency between the two methods currently allowed by the regulations to determine the yaw sweep coefficient of drag area. The HD Phase 1 aerodynamic bins are based on zero degrees yaw. However, the current regulations allow manufacturers the option of determining the aerodynamic bin levels based on their wind average drag performance relative to the nominal wind averaged drag performance of the baseline fleet evaluated in Phase 1. The yaw sweep correction factor, as defined currently in 40 CFR 1037.521, allows the determination of the C_DA based on (1) averaging the measurements at positive six degrees and negative six degrees (± 6 degrees) of yaw and (2) a full yaw sweep as defined by SAE J1252. However, these two methods do not produce the same wind averaged drag C_DA value, as shown below in Table 3-7. The C_DA based full yaw sweeps produce lower values, on the average of 3.3 percent.

Table 3-7: C_DA Values

	C_DA (ZERO YAW)	C_DA (AVG ± 6 DEGREES)	C_DA (FULL YAW SWEEP)
Sleeper Cab 1	5.425	6.239	6.043
Sleeper Cab 2	5.553	6.619	6.405
Sleeper Cab 3	5.622	6.442	6.285
Sleeper Cab 4	5.563	6.663	6.373

The value used to represent the nominal wind average drag performance of the fleet developed for Phase 1 was based on ± 6 degree measurement values. In order to remove the discrepancy in measurement methods, the agencies developed a new factor for determining the yaw sweep correction factor for data based on full yaw sweeps. We propose that manufacturers use the following equation when using wind averaged drag values based on the full yaw sweep.

$$CF_{ys} = [C_DA \text{ from full yaw sweep} * 0.8330] / [C_DA \text{ at zero yaw}]$$

3.2.5 Aerodynamics for Trailers

For HD Phase 2, the agencies are proposing GHG standards reflecting GHG and fuel consumption reductions from trailers. Aerodynamic improvements are among the technologies on which those proposed standards are predicated. New aerodynamic technologies have been implemented on box trailers to improve their aerodynamic efficiency and lower overall tractor-trailer fuel consumption. In addition, the agencies have assessed the extent that some of these technologies may migrate to the trailer sector without regulation, and the extent these improvements should be reflected in the reference trailer used in tractor certification testing.

Consistent with the proposed trailer regulations, our aerodynamic assessment of different trailer configurations (applicable to coastdown, constant speed and reduced-scale wind tunnel testing) and trailer types (applicable to reduced scale wind tunnel testing only) was limited to box van type trailers including dry box, reefer, and pup. Specifics on the applicable trailer types and certification protocols are discussed further in Section IV. D(2), of the preamble.

3.2.5.1 On-Road Aerodynamic Assessment of Different Trailer Configurations

We are also proposing to use the on-road test procedures as one method to determine aerodynamic performance for the proposed trailer program. Specifically, the on-road testing would estimate the delta drag area between a tractor-trailer combination for a trailer equipped without and with aerodynamic trailer devices (i.e., A to B testing; A constitutes a test without the technology; B constitutes a test with the technology). In addition, we used these test procedures to evaluate the ability of on-road testing to capture the aerodynamics of trailers equipped with and without aerodynamic devices for the standard trailer used in the tractor program.

Consequently, we assessed different trailer configurations using the proposed coastdown and constant speed test procedures with and without trailer aerodynamic devices installed on the trailer. Specifically, we performed coordinated, HD Phase 2 and SmartWay testing on-road for 53' dry box van trailers; which represent the bulk of the trailer market. The results of testing 53' dry box van trailers in different configurations are shown below in Table 3-8 and Table 3-9.

Table 3-8 Summary of Results from Coastdown Testing with Different Trailer Configurations

CAB TYPE	ROOF HEIGHT	CONFIGURATION	C_dA [m^2]	STANDARD ERROR	DELTA C_dA (VS. STANDARD)	% DELTA C_dA (VS. STANDARD)
Sleeper 1	High	Standard	5.9	0.5%	--	--
		With Trailer Skirt	5.4	1.0%	0.5	8.5%
		With Trailer Skirt and Boat Tail	5.0	1.0%	0.9	15%
Sleeper 2	High	Standard	6.2	2.1%	--	--
		With Trailer Skirt	5.6	1.3%	0.6	10%
		With Trailer Skirt and Boat Tail	5.1	1.1%	1.1	18%
Sleeper 3	High	Standard	6.1	2.3%	--	--
		With Trailer Skirt	5.6	1.2%	0.5	8.2%
		With Trailer Skirt and Boat Tail	5.4	1.1%	0.7	11%

Table 3-9 Summary of Results from Constant Speed Testing

CAB TYPE	ROOF HEIGHT	CONFIGURATION	C_DA [m^2]	STANDARD ERROR	DELTA C_dA (VS. STANDARD)	% DELTA C_dA (VS. STANDARD)
Sleeper 1	High	Standard	6.1	0.7%	--	--
		With Trailer Skirt	5.2	2.2%	0.7	12%
		With Trailer Skirt and Boat Tail	4.9	0.7%	1.2	20%
Sleeper 2	High	Standard	5.9	1.8%	--	--
		With Trailer Skirt	5.5	0.7%	0.4	6.7%
		With Trailer Skirt and Boat Tail	5.1	1.0%	0.8	14%
Sleeper 3	High	Standard	5.9	0.3%	--	--
		With Trailer Skirt	5.7	0.4%	0.2	3.4%
		With Trailer Skirt and Boat Tail	5.2	0.6%	0.7	12%

In addition to our on-road testing of 53’ dry box vans, we are coordinating with the California Air Resources Board (ARB) and U.S. Department of Energy’s (U.S. DOE) National Renewable Energy Laboratory (NREL) to evaluate twin, 28-foot (also known as “pup”) trailers using the coastdown and the SAE J1526 Type III[7] test procedure. Also, we are planning additional on-road testing of reefer box van trailers in the same location and identical tractors used for our evaluations of 53’ dry box vans.[8]

The agencies used the results from the on-road testing of 53’dry box vans to assist in developing aerodynamic standards for the trailer types covered under this proposed rulemaking. Specifically, the delta C_dA for trailers configured with various devices will be used to determine categories of values for GEM input; as discussed further under Section 3.2.7.

Although all of the on-road testing for different trailer types is not complete at the time of proposal, we do have data on other trailer types using alternate aerodynamic methods (e.g., reduced-scale wind tunnel) and discussed further below. Therefore, the combination of existing, on-road and alternate method data on other trailer types is a good foundation to develop aerodynamic standards for other trailer types. Further, we believe the results of future on-road testing will be consistent with the trends emerging from the existing data. Once all testing is complete, a full report will be included in the docket and further considered in the context of the trailer aerodynamic standards.

3.2.5.2 Reduced-Scale Wind Tunnel Testing of Different Trailer OEMs, Configurations, and Trailer Types

In addition to the on-road coastdown and constant speed procedures presented previously, we are proposing to allow additional aerodynamic assessment methods (e.g., wind tunnel, CFD) to generate delta C_dA values for the HD Phase 2 trailer program. In contrast to the on-road test procedures, the wind tunnel provides a stable, controllable environment yielding a more repeatable test and allows for more accurate measurement of the aerodynamic impact of tractor-trailer modifications. In addition, wind tunnels provide testers with the ability to yaw the vehicle in a controlled, specific manner at positive and negative angles relative to the original centerline of the vehicle to accurately capture the influence of non-uniform wind direction on the C_d (e.g., wind averaged C_d). Most trailers in the U.S. are 28’ or longer and the agencies are not aware of any viable, available wind tunnels that can accommodate full scale tractor-trailer combination vehicles. As a result, we exclusively used reduced-scale wind tunnel (RSWT) testing to support the HD Phase 2 aerodynamic assessment rather than a mix of full scale wind tunnel (FSWT) and RSWT testing as performed in HD Phase 1.

For HD Phase 2, we are proposing to carry over the use of SAE J1252 with the exceptions and modifications noted above. In addition, since the finalization of HD Phase 1, SAE J1252 has been updated and we are incorporating by reference the most recent version for HD Phase 2. For HD Phase 2, we are performing wind tunnel testing to inform revisions to the standard trailer test article for the tractor program and to develop separate trailer standards.

The RSWT testing was performed at the Automotive Research Center (ARC) in Indianapolis Indiana. The ARC wind tunnel is a closed single return tunnel with 3/4 open-jet working section and moving ground plane (2.3 m wide x 2.1 m high x 5.5 m long (7.5 ft x 6.8 ft x 18 ft)). It is powered by an air-cooled 373kW (274 hp) variable speed DC motor that drives a 9-bladed fan with carbon fiber blades. Its speed may be varied and set at any value from 0 to 610 rpm. The maximum wind speed is about 50 m/s (164 ft/s). The wind tunnel can accommodate a model up to 50 percent scale (1/2 scale) for race car applications down to 12.5 percent scale (1/8th scale) for Class 8 tractor and trailer combinations. The wind tunnel is equipped with a moving ground plane (*i.e.*, rolling road), four-stage boundary layer suction system, and a top-mounting “Sting” system that allows for yawing of the model. For model development, ARC has in-house model developers and can create highly detailed scale models using original computer aided design and engineering (CAD/CAE) drawings or using in-house scanning equipment to perform scanning and digitizing to create CAD/CAE drawings (see Figure 3-6 below).

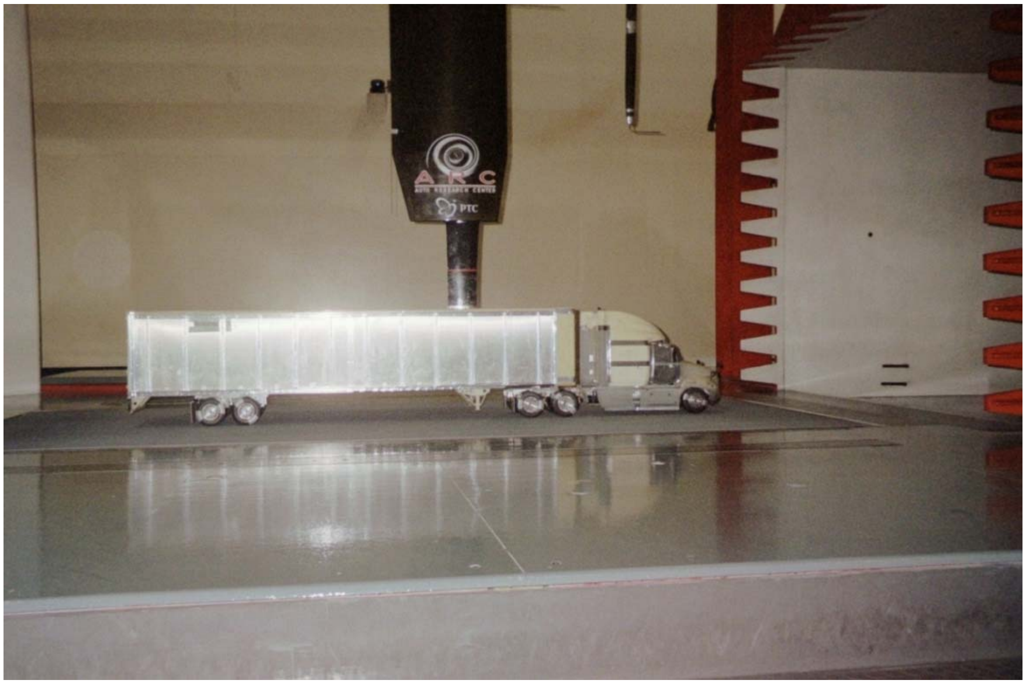

Figure 3-6 1/8th scale tractor-trailer model in ARC reduced scale wind tunnel.

The RSWT testing was conducted simulating an actual vehicle speed of 65 miles per hour (mph) using a tunnel speed of 111.8 mph and Reynolds number (*Re*) of greater than one million ($1x10^6$) on one eighth scale models of heavy-duty, Class 8 sleeper and day cab tractors equipped with the full aerodynamics package components sold on the full size version of the tractor; consistent with our HD regulatory requirements. For our test program, we assumed a base tractor-trailer gap of 45 inches and a bogey position of 40 feet (California position) from the leading edge of the trailer.

To support HD Phase 2, we tested the latest model year tractor available from each of the four tractor OEMs in sleeper cab form and one tractor OEM in day cab form. The tractor models used in the RSWT matched the tractor models used for the on-road testing to the extent feasible. For one manufacturer, we were not able to match the exact tractor model but did test models from that OEM in the RSWT and on-road. While the results across the tractor models are not directly comparable, the data provides some representativeness of the expected performance from that OEM's tractors.

In addition, we also tested three 53 foot dry box van trailers from three different trailer OEMs: Wabash, Great Dane, and Hyundai Translead; to evaluate aerodynamic trailer devices. For aerodynamic trailer devices, we focused on technologies that may improve areas on the tractor-trailer where large amounts of aerodynamic drag can occur and tested: one OEM trailer front treatment (e.g., front end trailer gap reduction device), two OEM side treatments (e.g., trailer side skirts) and one OEM aft treatment (e.g., trailer boat tail). In the case of the trailer side skirts and boat tail, a portion of the trailer devices used in the RSWT matched those used for the on-road testing. Thus, we ensured some overlap between the RSWT and on-road testing, although we were able to test a broader range of trailer devices.

Below in Table 3-10 are the RSWT results for the various configurations of four OEM sleeper cabs, one OEM day cab, three OEM 53-foot dry box van trailers, and four aerodynamic trailer devices (two trailer skirts, one rear boat tail, one front trailer gap reducer); averaged across trailer OEMs. The variation across the three OEM 53-foot dry box van trailers was small and should be considered negligible at 1.0 percent on average. The variation ranged from 0.5 to 0.9 percent for three of the four sleeper cab tractors and the day cab and a high of 2.3 percent for one of the four sleeper cab tractors. Where there were multiple runs on the same tractor, trailer, and device, the results were averaged across those runs and then included in the overall average.

Table 3-10 Results of Reduced-Scale Wind Tunnel Testing to Assess Tractor Trailer Performance with Various Aerodynamic Trailer Devices.

CAB TYPE	ROOF HEIGHT	CONFIGURATION	C_dA [m^2]	DELTA C_dA (VS. STANDARD)	% DELTA C_dA (VS. STANDARD)
Sleeper 1	High	Standard	5.425	--	--
		With Trailer Skirt #1	5.002	0.423	7.8%
		With Trailer Skirt #2	4.914	0.511	9.4%
		With Boat Tail	5.085	0.340	6.3%
		With Trailer Gap Reducer	5.450	-0.024	-0.5%
		With Trailer Skirt #2 and Boat Tail	4.453	0.972	17.9%
		With Trailer Skirt #2, Boat Tail, and Trailer Gap Reducer	4.460	0.965	17.8%
Sleeper 2	High	Standard	5.556	--	--
		With Trailer Skirt #1	5.054	0.586	10.5%
		With Trailer Skirt #2	4.962	0.594	10.7%
		With Boat Tail	5.191	0.365	6.6%
		With Trailer Gap Reducer	5.565	-0.020	-0.4%
		With Trailer Skirt #2 and Boat Tail	4.464	1.092	19.6%
		With Trailer Skirt #2, Boat Tail, and Trailer Gap Reducer	4.449	1.106	19.9%
Sleeper 3	High	Standard	5.622	--	--
		With Trailer Skirt #1	5.145	0.477	8.5%
		With Trailer Skirt #2	5.056	0.566	10.1%
		With Boat Tail	5.305	0.318	5.6%
		With Trailer Gap Reducer	5.632	-0.009	-0.2%
		With Trailer Skirt #2 and Boat Tail	4.566	1.056	18.8%
		With Trailer Skirt #2, Boat Tail, and Trailer Gap Reducer	4.560	1.062	18.9%
Sleeper 4	High	Standard	5.563	--	--
		With Trailer Skirt #1	5.079	0.481	8.7%
		With Trailer Skirt #2	5.003	0.557	10.1%
		With Boat Tail	5.229	0.332	6.0%
		With Trailer Gap Reducer	5.547	0.015	-0.3%
		With Trailer Skirt #2 and Boat Tail	4.436	1.121	20.2%
		With Trailer Skirt #2, Boat Tail, and Trailer Gap Reducer	4.445	1.112	20.1%
Day	High	Standard	5.609	--	--
		With Trailer Skirt #1	5.353	0.256	4.6%
		With Trailer Skirt #2	5.298	0.311	5.6%
		With Boat Tail	5.240	0.370	6.6%
		With Trailer Gap Reducer	5.596	0.014	0.2%

		With Trailer Skirt #2 and Boat Tail	4.910	0.699	12.5%
		With Trailer Skirt #2, Boat Tail, and Trailer Gap Reducer	4.902	0.707	12.6%

We believe that most trailers in the U.S. fleet will adopt some aerodynamic technologies by 2021. We are proposing to revise the standard trailer definition for 53-foot air ride dry box van trailers to include aerodynamic trailer devices. Specifically, we are proposing trailer skirts as part of the standard configuration for tractor aerodynamic evaluation. We are using the results in Table 3-10, to inform the proposed tractor aerodynamic bin categories for use as GEM inputs.

In addition to evaluating the aerodynamics of 53 foot dry box vans in the RSWT, we also evaluated the aerodynamics of shorter, 28 foot dry box van trailers, singular or in tandem/dual/twin configuration, known as "pup" trailers. This testing was performed using a single-axle, day cab tractor using similar trailer devices (e.g., trailer skirts, rear boat tail, and front trailer gap reducer) with a tractor-to-first trailer gap of 44 inches and a first pup-to-second pup trailer gap of 48 inches. Table 3-11 shows the results of this testing for the configurations tested:

Table 3-11 Results of Reduced-Scale Wind Tunnel Testing to Assess Tractor Trailer Performance with Various Aerodynamic Trailer Devices.

DUAL PUP TRAILER RESULTS			
Configuration	C_dA [m^2]	Delta C_dA (vs. Standard)	% Delta C_dA (vs. Standard)
Standard	6.022	--	--
Skirt on First Trailer Only	5.902	0.120	1.99%
Skirt on Second Trailer Only	5.735	0.286	4.76%
Skirt on Both Trailers	5.586	0.436	7.24%
Skirt and Gap Reducers on Both Trailers	5.289	0.733	12.2%
Skirt and Gap Reducers on Both Trailers w/ tail on second trailer	5.208	0.814	13.5%
SINGLE PUP TRAILER RESULTS			
Standard	5.384	--	--
Skirt on Trailer	5.226	0.159	2.95%
Skirt and Gap Reducer on Trailer	4.971	0.414	7.68%

Based on the results in Table 3-11 above, the potential to significantly improve the aerodynamic performance of pup trailers, singular or in tandem/dual/twin, exists using various trailer devices. The maximum package of trailer side skirts on both trailers, gap reducers on both trailers, and a boat tail on the second trailer produced a benefit of 13.5 percent over the standard dual pup trailer configuration.

However, since pup trailers may be frequently interchanged (e.g., drop off the second pup trailer or both pup trailers at one destination; proceed to the next destination to pick up a new first pup trailer, second pup trailer or both pup trailers), the most practical application may be dual pup trailers with just trailer side skirts and gap reducers on both trailers. The presence of boat tail/aft treatment restricts that trailer to a second/rear position, depending on the length of the aft trailer device, and omitting this device allows for pup trailer symmetry. Even with the omission of an aft trailer device, the trailer side skirts and gap reducers on both trailers configuration still achieves a benefit of 12.2 percent. Notwithstanding, the added use of aft trailer devices; with proper consideration for the length of the device to accommodate operational constraints versus the potential tradeoff in aerodynamic performance with reduced, aft trailer device length; should be investigated further to identify additional dual pup trailer optimization.

Installing skirts/gap reducers on both trailers for dual pup trailer configurations also produces benefits from the use of a single pup trailer with trailers side skirts and gap reducer; achieving a benefit of 7.68 percent versus the standard, single pup trailer without any devices. There may be occasions where a dual pup tractor-trailer must travel between destinations in single pup trailer configuration. Thus, the presence of trailer side skirts and gap reducers on both pup trailers also aids the aerodynamic performance for the occasions where it is operated in a single pup trailer configuration.

Finally, we also evaluated the impact of aerodynamic devices on reefer trailer performance. Reefer trailers are similar in basic shape to 53-foot dry box van trailers, but are equipped with a thermal refrigeration unit (TRU) on the front of the trailer. Thus, the TRU fills the gap space between the tractor-trailer where gap reduction technology would normally be fitted. In addition, based on conversations with reefer trailer manufacturers, although reefer trailers are less prevalent in the field, they tend to see much more operation than the typical 53-foot dry box van trailer due to their smaller numbers (1.5-2.2 to 1 for tractor to reefer trailer ratio versus 3 to 1 for conventional 53-foot dry box van trailers). As such, there is more opportunity to realize the benefits from optimizing reefer trailers.

Table 3-12 Results of Reduced-Scale Wind Tunnel Testing of Reefer Trailer Using a 2012 Model Year Tractor

CONFIGURATION	C_DA (ZERO YAW) [m^2]	DELTA C_dA FROM STANDARD REEFER (% DELTA)	DELTA C_dA VS. STANDARD DRY BOX VAN TRAILER FROM THE SAME TRAILER OEM	% DELTA (VS. STANDARD TRAILER)
Standard Reefer	5.840	--	-0.264	-4.7%
Skirt Only	5.141	0.699 (12.0%)	-0.196	-4.0%
Boat tail only	5.607	0.232 (4.0%)	-0.448	-8.7%
Skirt +Boat Tail	4.596	1.244 (21.3%)	-0.114	-2.5%
Vs. OEM standard trailer w/ Skirt + Boat Tail + Gap	--	--	-0.146	-3.3%

The results in Table 3-10, Table 3-11, and Table 3-12 will also be used to support the newly proposed, trailer regulations. Specifically, the delta C_dA for trailers configured with various devices will be used to determine categories of values for GEM input; as discussed further in Section 3.2.7.

3.2.6 Standardized Trailer Definitions for Heavy-Duty Tractor Testing

In HD Phase 1, we finalized the use of a model input (i.e., an input to GEM at certification) reflecting a standardized trailer for each subcategory of the Class 7/8 tractors based on tractor roof height. The height of the roof fairing is designed to minimize the height differential between the tractor and typical trailer to reduce the air flow disruption. Low roof tractors are designed to carry flatbed or low-boy trailers. Mid roof tractors are designed to carry tanker and bulk carrier trailers. High roof tractors are designed to optimally pull box trailers. However, we recognize that during actual operation tractors sometimes pull trailers that do not provide the optimal roof height that matches the tractor. In order to assess how often tractor and trailer mismatches are found in operation, EPA conducted a study based on observations of traffic across the U.S.[9] Data was gathered on over 4,000 tractor-trailer combinations using 33 live traffic cameras in 22 states across the United States. Approximately 95 percent of tractors were "matched" – i.e. optimized – per our definition (*e.g.* box trailers were pulled by high roof tractors and flatbed trailers were pulled with low roof tractors). The amount of mismatch varied depending on the type of location. Over 99 percent of the tractors were observed to be in matched configuration in Indiana at the I-80/I-94/I-65 interchange, which is representative of long-haul operation. On the other hand, only about 90 percent of the tractors were matched with the appropriate trailer in metro New York City, where all mismatches consisted of a day cab and a tall container trailer. The study also found that approximately 3 percent of the tractors were traveling without a trailer or with an empty flatbed. The agencies therefore concluded in Phase 1 that given this very limited degree of mismatch, it is reasonable to use a standardized definition which optimizes tractor-trailer matching. For purposes of compliance testing, the agencies also finalized bob-tail testing for low roof and mid roof tractors to facilitate repeatability and reproducibility of test data in response to concerns raised by tractor manufacturers.

Recently, trailer OEMs and aftermarket manufacturers have begun implementing new aerodynamic technologies on box trailers, to improve their aerodynamic efficiency and to lower overall tractor-trailer fuel consumption. There are a range of technologies to affix to the front (e.g., nose cones, gap reducers, front lip devices); sides and underbody (e.g., skirts, wedge shaped devices aft of trailer landing gear and fore of trailer rear axles/bogeys); top (e.g., vortex generating devices to promote turbulent flow and delay boundary layer separation along the length of the trailer) and rear (e.g., tails, rear lip spoilers and diffusers) of the trailer. However, the most widely implemented devices in the market today are trailer side skirts that extend in the gap between the fifth wheel and the trailer bogey to restrict underbody air flow and subsequent drag and rear/aft trailer treatments extending from the rear of the trailer (e.g., boat tails, that reduce the low pressure region, and associated, subsequent drag, on the rear of the tractor-trailer). As discussed in Section III.E(2)(a)(iii) and Section IV.D(2) of the preamble, we estimate that approximately 50 percent of the new trailers sold in 2018 will have trailer side skirts.[10,11] As the agencies are proposing tractor standards for model year 2021 and beyond, we believe that it is appropriate to update the standardized box trailer definition to reflect the technologies we project will be used on the majority of the trailers in the fleet during that timeframe. Therefore, we are proposing for Phase 2 that the standardized box trailer used for tractor certification be updated to include a trailer skirt starting in model year 2021. Although we are proposing GHG standards for trailers that capture the drag area improvement for various trailer devices, including trailer skirts, beginning in model year 2018, this proposed update to include a test article to the standardized trailer is strictly for the purpose of certifying tractors beginning in model year 2021, and is not related to the proposed trailer GHG standards themselves.

Based on the test results shown above in Table 3-10, Table 3-11, and Table 3-12 and comments from stakeholders, the agencies have chosen to update the test article specifications for 53’ dry box van trailers below in Table 3-13. Specifically, the standardized, 53’ air ride dry van test article we are proposing for Phase 2 will include trailer side skirts on the standardized trailer for tractor aerodynamic assessment. We propose that the skirt meet the dimensions shown in Table 3-13 based on the devices used for the agencies’ aerodynamic assessment, accounting for potential design, differences, variations and tolerances for other trailer attributes (e.g., landing gear overlap, rear bogey clearance, ground clearance). Trailer side skirts that do not meet the size specifications (e.g., length and width) below can be used, with prior approval from the agencies , on the standardized trailer used for the aerodynamic assessment of tractors, provided that they do not exceed the dimensions in Table 3-13 but are no shorter than 270 inches ± 4 inches in length when measured along the top edge of the trailer side skirt; and meet all other specifications for positioning on the trailer; except for the distance from the front and rear trailer edge which may vary based on a shorter skirt length. Finally, the tractor must be a stock OEM tractor without additional devices installed, unless devices are included as part of a stock OEM aero package (e.g., drive axle wheel covers, fairings or fenders).

Table 3-13 53' Dry Box Van Trailer Test Article

53' AIR RIDE DRY BOX VAN TRAILER	
Length:	53 feet (636 inches; 1615.44 cm) ± 1 inch
Width:	102 inches ± 0.5 inches
Height:	102 inches (162 inches or 13 feet, 6 inches (+0.0 inch/-1 inch) from the ground)
Capacity:	3,800 cubic feet
Assumed trailer load/capacity:	45,000 lbs
Suspension:	Any (see "trailer ride height" below)
Corners:	Rounded with a radius of 5.5 inches ± 0.5 inches
Bogie/Rear Axle Position:	Tandem axle (std), 146 inches ± 4.0 inches from rear axle centerline to rear of trailer. Set to California position.
Skin:	Generally smooth with flush rivets
Scuff band:	Generally smooth, flush with sides (protruding $\leq$ 1/8 inch)
Wheels:	22.5 inches. Duals. Std mud flaps.
Doors:	Swing doors.
Undercarriage/Landing Gear:	Std landing gear, no storage boxes, no tire storage, 105 inches ± 4.0 inches from front of trailer to centerline of landing gear
Underride Guard	Equipped in accordance with per 49 CFR 393.86
Aerodynamic Trailer Device Type:	Trailer Side Skirts
Aerodynamic Trailer Device Specifications Applicable to Trailer Side Skirts:	Skirts must be installed on both sides of the trailer Skirts must be designed to fit between the landing gear and the rear bogey, in the most forward position (California), of the trailer and must be: 118 inches ± 4 inches measured from the front of the trailer to the leading, forward-most point of the upper/top edge of the skirt Skirts must be straight and flush with the trailer sides Skirts must be: 341 inches, ± 4 inches in total length, measured along the top/upper edge The same total length on the bottom/lower edge as the top/upper edge (e.g., rectangular in shape) but shall be no less than 268 inches ± 4 inches in length along the bottom edge (e.g., angled front/rear edge or front edge only) 36 inches ± 2 inches in total width, measured between the top/upper and bottom/lower edge, at the midpoint of the skirt Skirts may minimally (e.g., 10% or less) overlap the trailer landing gear at the forward-most point along the upper/top edge but should not cover the trailer landing gear with any portion of the skirt leading/front edge (e.g., skirt may not extend forward beyond the landing gear position
Tires for the Standard Trailer and the Tractor: a. Size: 295/75R22.5 or 275/80R22.5 b. C_{rr}<5.1 kg/metric ton c. Broken in per Section 8.1 of SAE J1263 d. Pressure per Section 8.5 of SAE J1263 e. No uneven wear f. No re-treads g. If these tires or appropriate Smart Way tires are unavailable, the Administrator testing may include tires	

used by the manufacturer for certification.
Test Conditions: Tractor-trailer gap: 45 inches ± 2.0 inches. King pin setting: 36 inches ± 0.5 inches from front of trailer to king pin center line. Trailer ride height: 115 inches ±1.0 inches from top of trailer to fifth wheel plate, measured at the front of the trailer, and set within trailer height boundary from ground as described above. Mud flaps: Positioned immediately following wheels of last axle.

For special cases in which a trailer would be used for coastdown testing for mid-roof and low-roof tractors, the specifications for the tanker and flatbed trailers are being carried over from HD Phase 1, and are shown, unchanged, in Table 3-14 and

Table 3-15 below, respectively.

Table 3-14 Tanker Trailer Specifications for Special Testing

TANKER TRAILER	
Length:	42 feet ± 1 foot, overall 40 feet ± 1 foot, tank
Width:	96 inches ± 2
Height:	140 inches (overall, from ground)
Capacity:	7,000 gallons
Suspension:	Any (see "trailer ride height" below)
Tank:	Generally cylindrical with rounded ends.
Bogie:	Tandem axle (std). Set to furthest rear position.
Skin:	Generally smooth
Structures:	(1) Centered, manhole (20 inch opening), (1) ladder generally centered on side, (1) walkway (extends lengthwise)
Wheel fairings:	
Wheels:	24.5 inches. Double wide.
Tanker Operation	Empty

Table 3-15 Flatbed Trailer Specifications for Special Testing

FLATBED TRAILER	
Length	53 feet
Width	102 inches
Flatbed Deck Heights:	Front: 60 inches ± 0.5 inches Rear: 55 inches ± 0.5 inches
Wheels / Tires	22.5 inch diameter tire with steel or aluminum wheels
Bogie	Tandem axles, may be in "spread" configuration up to 10 feet ± 2 inches. Air suspension
Load Profile: 25 inches from the centerline to either side of the load; Mounted 4.5 inches above the deck. Load height 31.5 inches above the load support. Trailer should be empty.	

The regulations in 40 CFR 1037.501 prescribe the standardized trailer for each tractor subcategory (low, mid, and high roof) including trailer dimensions based on the tables above.

3.2.7 Standardized Tractor Definition for Heavy-Duty Trailer Testing

Similar to the standardized trailer definition for tractor aerodynamic assessment, the agencies are proposing to define a standardized tractor definition for trailer aerodynamic assessment. The proposed standardized tractor definition is based on tractor attributes such as a Class 8, high roof, tandem axle tractor equipped with, at a minimum, a roof fairing, cab side extenders and fuel tank/chassis skirts. This type of tractor typically meets a Bin III or better tractor aerodynamic level under HD GHG Phase 1 and is expected to meet the proposed Bin III level for HD GHG Phase 2. We believe the majority of tractors in the U.S. trucking fleet will be Bin III or better in the timeframe of this rulemaking and trailer manufacturers have the option to choose higher-performing tractors in later years as tractor technology improves. As with the standardized trailer's test article specification, the aerodynamic specification for the standardized tractor here is strictly for the purpose of certifying trailers beginning in model year 2018 model year. Therefore, although the aerodynamic level of the standardized tractor for trailer certification potentially overlaps with tractors designed to meet the 2021 and beyond tractor GHG standards, it is only intended to serve as a specification for trailer certification to the 2018 and beyond trailer GHG standards.

Accordingly, we are proposing that trailer manufacturers would use this standardized tractor definition with their trailers to conduct A to B testing to capture the delta C_dA for their trailers that are either: equipped with aerodynamic devices to meet the proposed trailer standards or are designed to be more aerodynamic than current, standard trailers. Specifically, the trailer manufacturers would use the standardized tractor to generate A to B test values where the "A" represents a standard test and "B" represents the modified/advanced trailer; both tests performed using the same standardized tractor.

Subsequently, the tractor manufacturer would input their trailer OEM-specific delta C_dA value in the GEM model and the model would determine the appropriate, default trailer delta C_dA GEM value; where the default delta C_dA GEM value is based on the test results in Sections 3.2.5.1 and 3.2.5.2 above. This value is applied to a default tractor/trailer C_dA value based on a Bin III or greater Class 8 sleeper cab tractors with a standard trailer. Finally, the default tractor/trailer C_dA value with the default trailer C_dA value applied would be used to determine the greenhouse gas emissions for this configuration by the GEM model.

For trailer OEMs that are certifying a trailer where devices are added to an existing OEM trailer design, the trailer used for both "A" and "B" test uses a trailer meeting our standardized trailer definition for 53' air ride dry box vans shown above in Section 3.2.6, Table 3-13, without any trailer devices installed; with the same standard reference tractor used for both tests.

In contrast, for trailer OEMs that certify a completely new trailer design, the "A" test uses a trailer meeting our standardized trailer definition for 53' air ride dry box vans shown above in Section 3.2.6, Table 3-13, without any trailer devices installed and the "B" test would be the new, OEM trailer design; with a standard reference tractor used for both tests. In summary, the standard reference tractor would be used for all trailer OEM "component" level testing; where the "component" in the B test can range from an add-on trailer device up to a completely different trailer design.

To assist in defining the standardized tractor for different trailer types, below are the proposed trailer sub-categories used for GEM from Chapter IV of the preamble.

Table 3-16 Description of Baseline Tractor-Trailers Used In GEM from Section IV. D(2)(b)(ii), of the Preamble

TRAILER SUBCATEGORY	FEATURES
Dry van 50 feet and shorter	Class 8 high roof day cab, pulling solo 28' dry van C_dA = 6.1, C_{rr} = 6.0 kg/ton
Dry van longer than 50 feet	Class 8 high roof sleeper cab pulling a solo 53' dry van C_dA = 6.2, C_{rr} = 6.0 kg/ton
Refrigerated van 50 feet and shorter	Class 8 high roof day cab pulling a solo 28' ref van C_dA = 6.0, C_{rr} = 6.0 kg/ton
Refrigerated van longer than 50 feet	Class 8 high roof sleeper cab pulling a solo 53' ref van C_dA = 6.1, C_{rr} = 6.0 kg/ton

Based on this table, we are proposing standardized tractor definitions based on tractor type and attributes that reflect the types of tractors used for trailers in each of these subcategories.

Specifically, we are proposing that all tractors for all trailers greater than 50 feet shall use a standardized tractor meeting the following criteria for A to B testing: a Class 8, high-roof sleeper cab, tandem axle tractor that meets HD Phase 2 Bin III or better Class 8 high roof sleeper cab tractor aerodynamic standards. For all trailers less than 50 feet, a standardized tractor meeting the following criteria shall be used for A-B testing: Class 8, high-roof day cab, dual axle tractor that meets HD Phase 2 Bin III or better Class 8 high roof day cab tractor aerodynamic standards.

Table 3-17 Characteristics of Standard Tractor for Aerodynamic Assessment of Trailers

BOX TRAILERS 50 FEET AND LONGER	CLASS 8 HIGH ROOF SLEEPER CAB DUAL-AXLE BIN III OR BETTER TRACTOR, C_DA < 6.5 CAB SIDE EXTENDERS FUEL TANK COVER/CHASSIS SKIRTS ROOF FAIRING
Box trailers shorter than 50 feet	Class 8 high roof day cab Dual-axle Bin III or better tractor, C_dA <6.7 Cab Side extenders Fuel tank covers/Chassis Skirts Roof Fairing

3.2.8 Continued Use of the Aerodynamic Alternate Method Factor ($F_{alt\text{-}aero}$) for HD Phase 2 Tractors

As the agencies showed in Phase 1, aerodynamic test methods differed in their predictions of drag coefficient.[12] On-road methods, such as coastdown and constant speed tests, are performed in uncontrolled real-world environments, whereas wind tunnel testing is performed in constrained, controlled conditions, and CFD is a simulation that attempts to replicate complex aerodynamic events. Different test methods have differences with regards to environmental conditions, assumptions for non-aerodynamic drag forces, tunnel geometry, boundary conditions, and simulation characteristics. These differences can lead to different results, even though they are used to measure or calculate the same parameter. The agencies acknowledged that there will never be perfect alignment between the predicted drag area values from the aerodynamic methods even with full, appropriate correction for every factor, but wanted to allow the use of these methods, which are currently being used by the manufacturers, to limit test burden for certification

As a result, for HD Phase 1, we employed the use of an aerodynamic method adjustment factor (or $F_{alt\text{-}aero}$) factor, to relate the results from the reference method, a coastdown test, to the results from the alternative method as a ratio of the coastdown result to the alternate method result for selected Class 8 high roof sleeper cab. The $F_{alt\text{-}aero}$ is then multiplied to the results generated using the alternative method for all other OEM configurations This allowed manufacturers the convenience and lower test burden of using existing aerodynamic protocols rather than pursuing extensive data correction to produce equivalent results across the aerodynamic methods.

For HD Phase 2, we are proposing to continue to allow the use of data from alternate aerodynamic test methods, and subsequently the aerodynamic method adjustment factor. Thus, for HD GHG Phase 2, we explored the level of agreement between the aerodynamic methods similar to HD GHG Phase 1. The method comparison was used in HD GHG Phase 1 to demonstrate that for a given tractor and trailer model with specified conditions for each of the methods, testing meeting these specifications performed with the required level of precision (e.g., repeated with a low level of error) could yield a reasonable level of agreement across the aerodynamic method. Consequently, there is no guarantee that the same level of agreement would be produced using different facilities, conditions, or test articles. However, although this level of agreement is only applicable for that tractor and trailer model using the specified conditions for those tools in a specific facility, this data was sufficient to demonstrate the level of agreement possible and support the use of specified conditions in HD GHG Phase 1 (as shown in Figure 3-7 a and b).

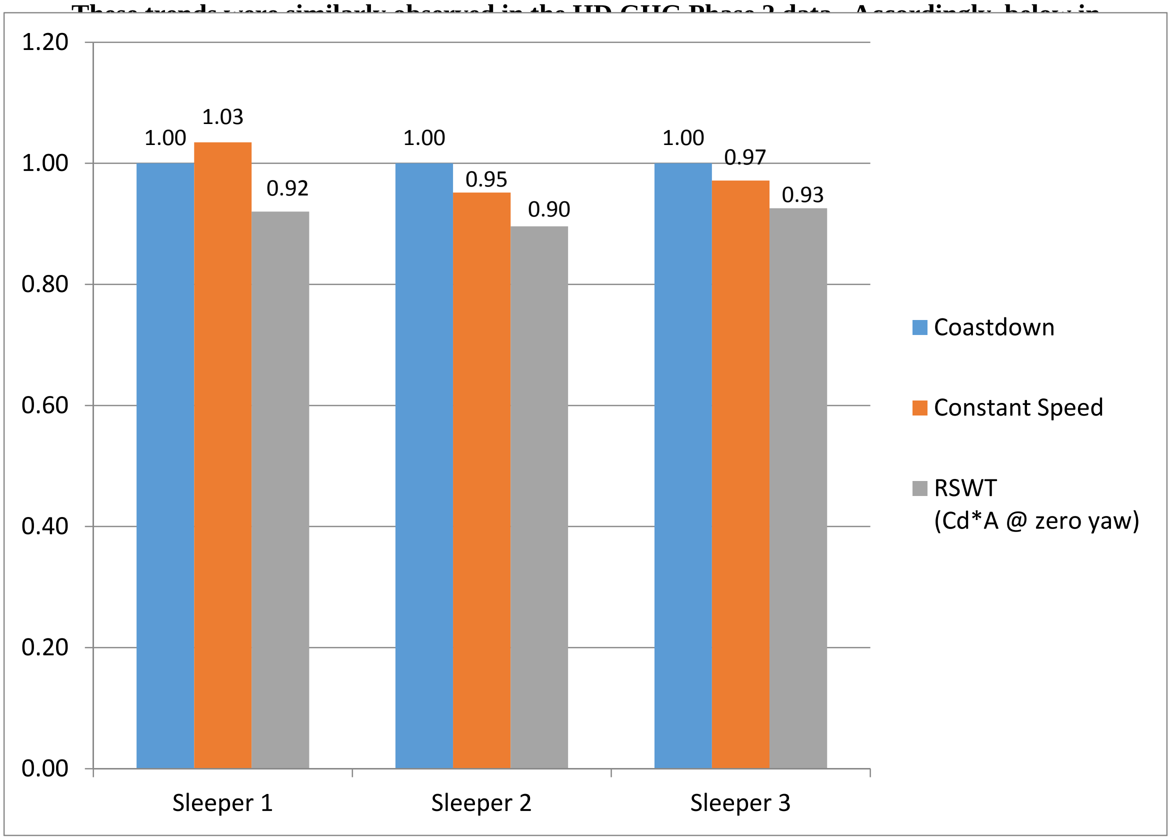

Figure 3-7a is the aerodynamic method comparison using HD Phase 2 test results. The results are shown are for three of the four Class 8, high roof, sleeper cab tractors from coastdown, constant speed and zero degree C_dA RSWT testing; normalized to the coastdown results. The data in Figure 3-7a is presented using the zero yaw C_d values for the reduced scale wind tunnel (RSWT) and the constant speed test results normalized to the coastdown test results (e.g., RSWT or constant speed results divided by the coastdown result) similar to the comparison used for HD GHG Phase 1 for a standard trailer. The HD GHG Phase 2 data shows a similar level of method agreement as HD GHG Phase 1 for the coastdown test and RSWT (constant speed testing was not performed for HD GHG Phase 1).

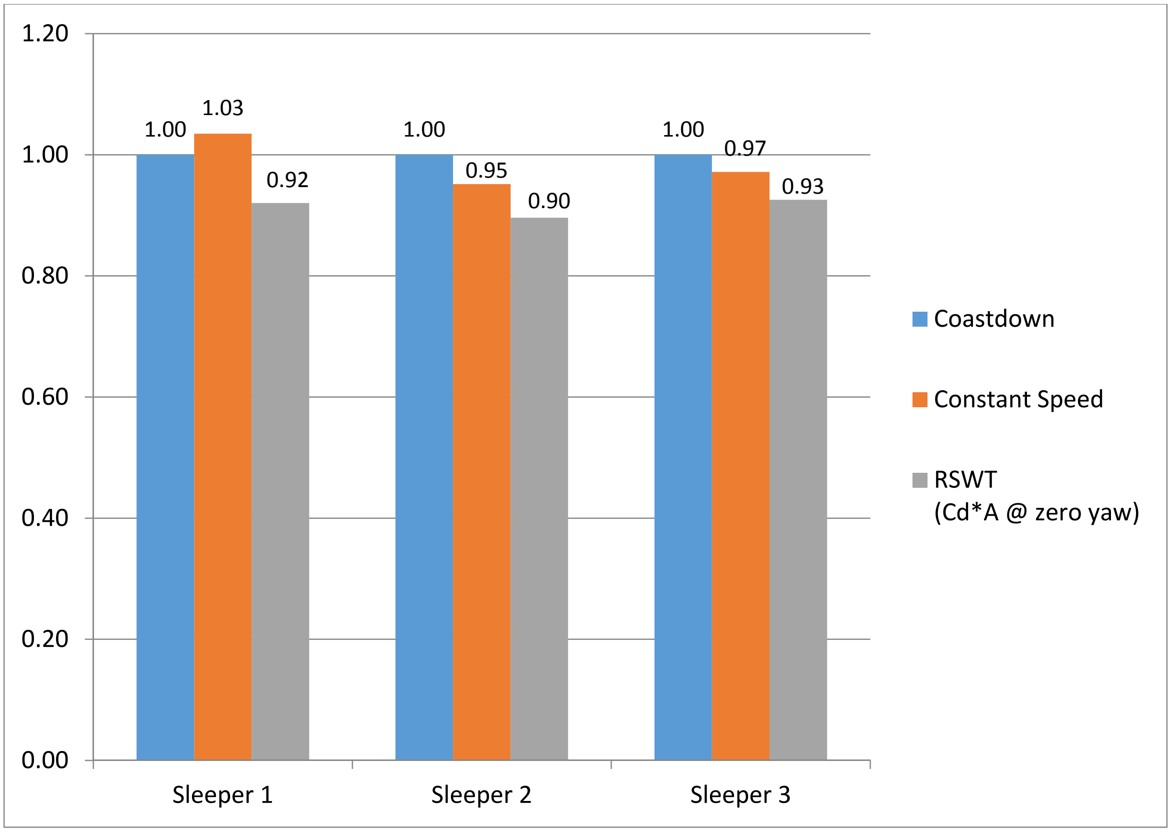

Figure 3-7a Method Comparison for Coastdown, Constant Speed and RSWT (Zero-Yaw C_d) Testing Normalized to the Coastdown Results for Class 8 High Roof Sleeper Cab Tractors and Standard Trailers following a HD GHG Phase 1 approach. (Note: The results of Sleeper 1 and Sleeper 3 are not directly comparable since the test articles do not match but are shown to represent the overall industry trend given a manufacturer's fleet variance.)

It is interesting to note that if the WAC_d concept had been adopted in HD GHG Phase 1, the level of method agreement, and consequently the Falt-aero factor used to characterize and account for method inequality, may have been closer to parity (e.g., Falt-aero closer to 1) based on the HD GHG Phase 2 WAC_d data for a standard trailer, as shown in Figure 3-8b below.

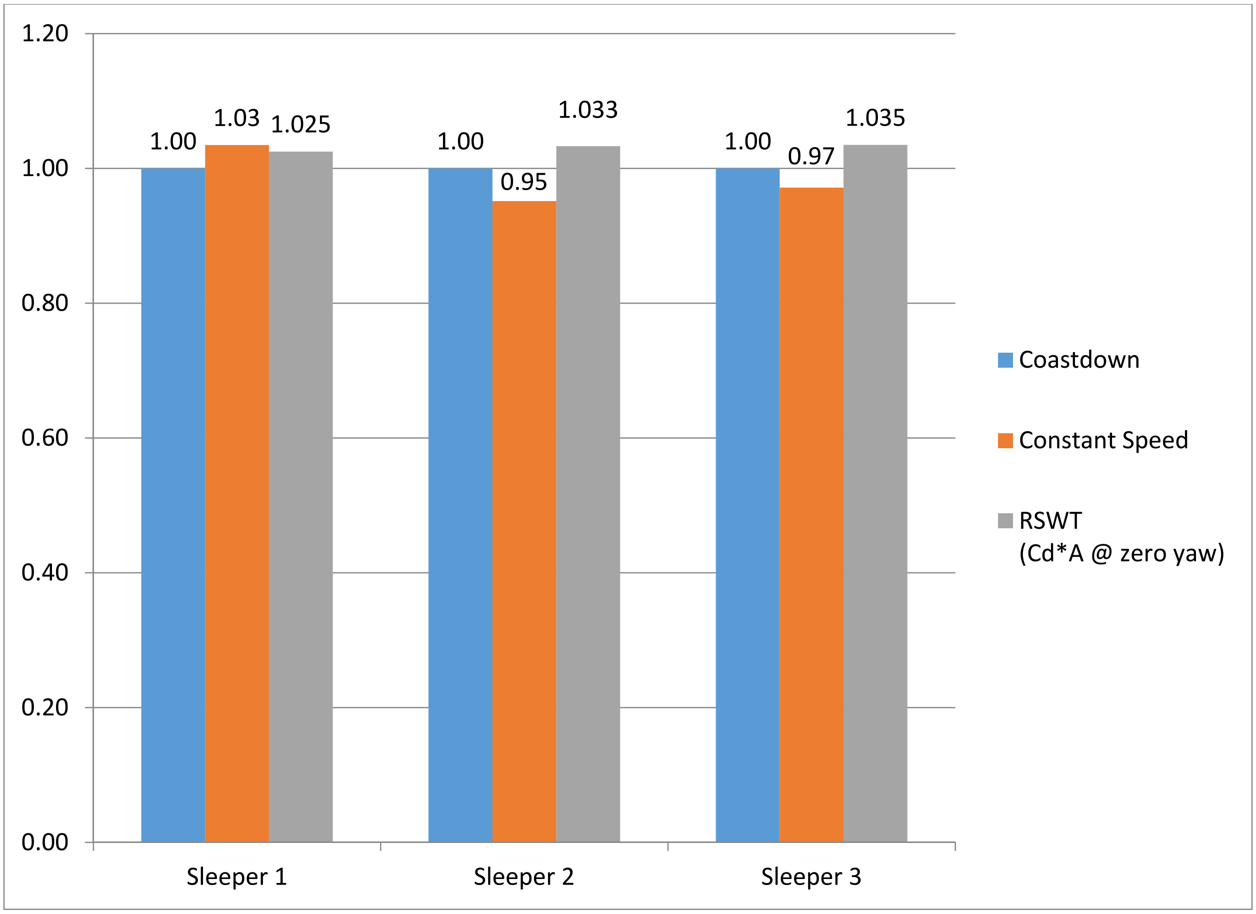

Figure 3-8b Method Comparison for Coastdown, Constant Speed and RSWT (WACdA @ 55 mph w/ 7 mph wind) Testing Normalized to the Coastdown Results for Class 8 High Roof Sleeper Cab Tractors and Standard Trailers. This approach was recommended by commenters for HD GHG Phase 1. (Note: The results of Sleeper 1 and Sleeper 3 are not directly comparable since the test articles do not match but are shown to represent the overall industry trend given a manufacturer's fleet variance.)

For HD GHG Phase 2, we are proposing to include the wind average drag and will discuss this in Section 3.2.9. Further, we will revisit the method comparison with the inclusion of wind average drag for a trailer equipped with side skirts; consistent with the proposed HD GHG Phase 2 approach.

3.2.9 Wind-Averaged Drag Area and General Aerodynamic Assessment Results Based on Proposed HD Phase 2 Tractor Modifications

For HD Phase 2, we are proposing to use the WAC_dA as the main GEM input (Section 3.2.3), revise the standard reference trailer for tractors (Chapter 3.2.6), and continue to use a $F_{alt\text{-}aero}$ when alternative aerodynamic methods are used for certification and compliance demonstration (Chapter 3.2.8). Based on the proposed modifications, this section uses the HD Phase 2 WAC_dA results from RSWT testing for a tractor-trailer combination with trailer side skirts installed to demonstrate the coastdown yaw sweep shift concept, calculation of the alternate method factor ($F_{alt\text{-}aero}$), and provide a cross-method comparison for illustrative purposes.

To begin, below in Table 3-18 are the values for the zero yaw drag areas (C_dA (zero)) and WAC_dA at 55 miles per hour (mph) for each sleeper cab tractor and 53' trailer, averaged across three OEM trailers with trailer side skirt #2 installed on the trailer.

Table 3-18 Zero Yaw and Wind Average Drag Area RSWT Results for Tractor-Trailer Combinations with a Trailer Side Skirt (Results for Trailer Side Skirt #2 Shown).

TRACTOR	C_dA (ZERO)	C_dA DELTA VS. STANDARD TRAILER	C_dA % DELTA VS. STANDARD TRAILER	WAC_dA (@ 55 MPH)	WAC_dA DELTA VS. STANDARD TRAILER	WAC_dA % DELTA VS. STANDARD TRAILER	WAC_DA – C_dA DELTA (WAC_dA OFFSET)	WAC_DA – C_dA % DELTA (VS. C_dA)
Sleeper 1	4.914	0.511	9.42%	5.419	0.624	10.33%	0.505	10.27%
Sleeper 2	4.962	0.594	10.68%	5.705	0.700	10.94%	0.742	14.96%
Sleeper 3	5.056	0.566	10.07%	5.598	0.687	10.93%	0.542	10.73%
Sleeper 4	5.003	0.560	10.07%	5.627	0.714	11.26%	0.625	12.49%
Day	5.298	0.311	5.55%	5.755	0.612	9.61%	0.457	8.63%
Sleeper Average (2 out of 4 tractors w/ matching coastdown data)	4.938	0.552	10.1%	5.562	0.662	10.6%	0.624	12.6%

Based on the results in Table 3-18, there is good alignment in the data (C_dA standard deviation of 0.06, 1.21 percent relative standard error; WAC_dA standard deviation of 0.12, 2.16 percent relative standard deviation) across sleeper cab tractors and trailers equipped with trailer side skirts (e.g., a similar trend was demonstrated in the data for trailer side skirt #1 as well).

Similar to the method comparison in

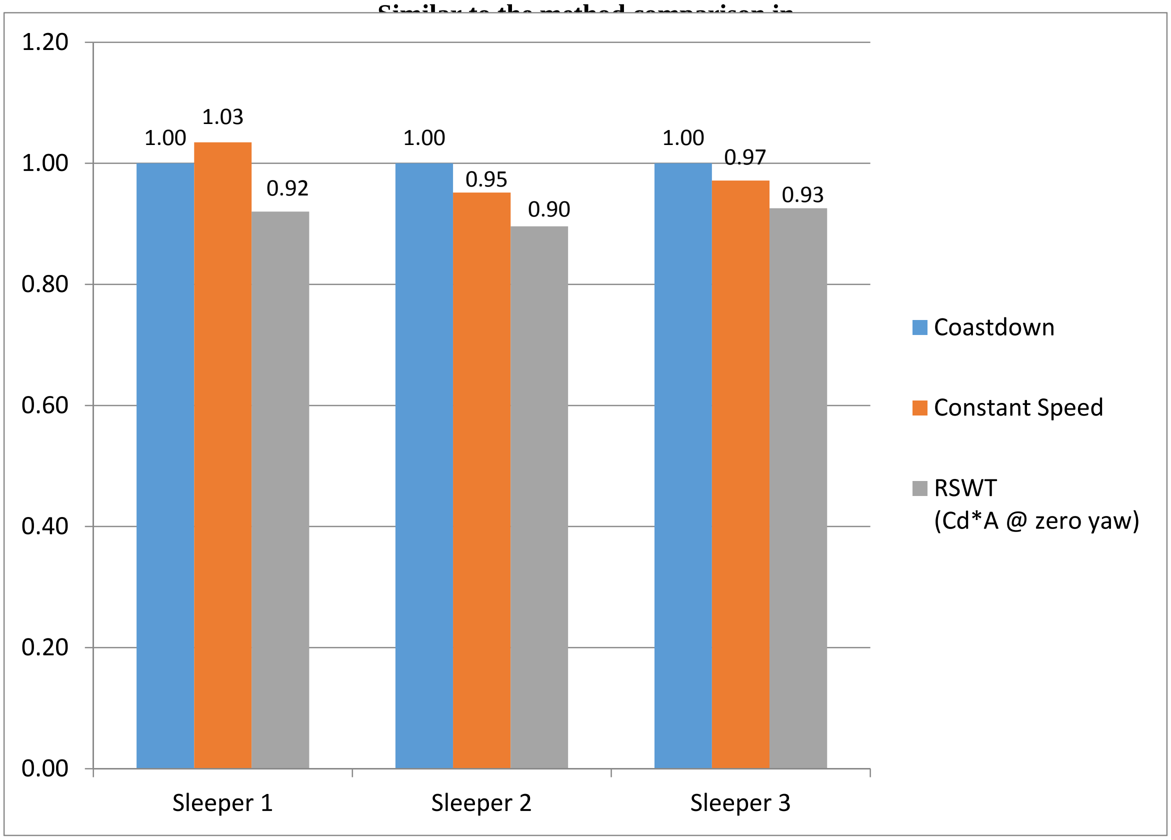

Figure 3-7 for zero degree drag area and a standard trailer, Figure 3-9 below shows the *WAC$_d$A* method comparison for three of the four Class 8, high roof, sleeper cab tractors with a trailer equipped with trailer side skirts consistent with the proposed HD GHG Phase 2 reference trailer modifications. The results are shown for constant speed testing and *WAC$_d$A* RSWT testing at 55mph assuming a 7mph wind speed, normalized to the coastdown test results. As discussed above, these results are for a specific set of tractor-trailer models, specifications and facilities for those tools and, thus, a similar or equivalent level of agreement is not guaranteed for using different criterion. However, as shown for HD GHG Phase 1, there is a certain level of agreement achievable using set conditions for a given tractor-trailer model as proposed under HD GHG Phase 2.

This is prior to any adjustment of the coastdown result to incorporate wind averaging which would theoretically increase the coastdown values upward since the wind average drag area is higher than zero degree yaw drag area. However, this is a useful comparison to demonstrate how the use of wind average drag in HD GHG Phase 1 may have influenced the level of agreement between the methods, and the resulting OEM Falt-aero values (e.g., Falt-aero values closer to 1), versus the use of zero yaw drag adopted in HD GHG Phase 1. We will explore the method comparison further with the inclusion of wind average drag later in this section.

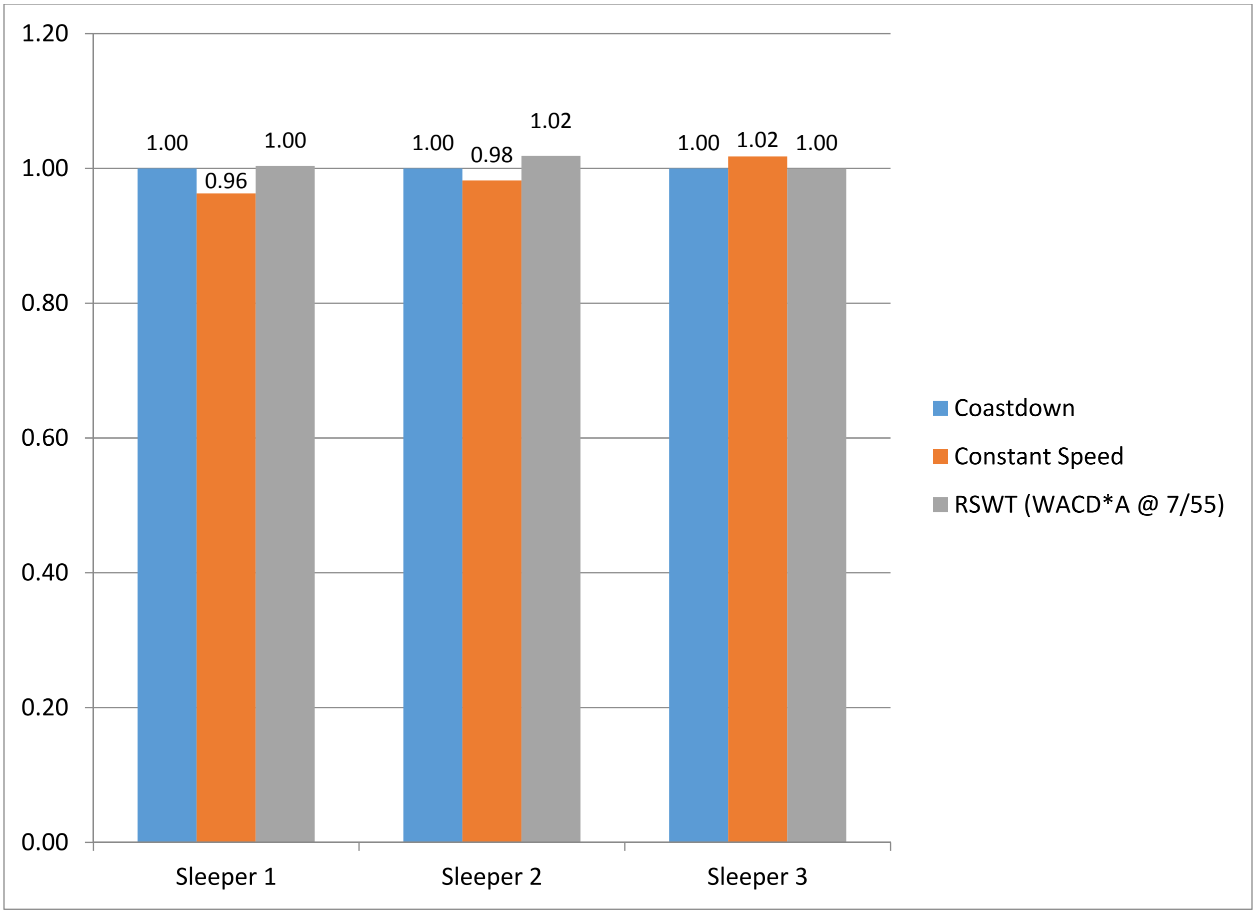

Figure 3-9 Unadjusted Method Comparison for Coastdown, Constant Speed and RSWT (WACdA @ 55 mph w/ 7 mph wind) Testing Normalized to the Coastdown Results, for Class 8 High Roof Sleeper Cab Tractors and Trailers Equipped with Trailer Side Skirts. Note: The results of Sleeper 1 and Sleeper 3 are not directly comparable since the test articles do not match but are shown to represent overall industry trend given a manufacturer's unique fleet.

Next, the results from the RSWT were used to develop a virtual WAC_dA value for coastdown testing. Specifically, the coastdown results and the WAC_dA to C_dA delta will be used to correct the coastdown results. As previously mentioned, we could not match the exact tractor model for RSWT and on-road testing for one of the tractors. In addition, we have not completed on-road testing for another tractor model that has been tested in the RSWT. Therefore, for this exercise, we will use: the average of the RSWT results above for two out of the four sleeper cab tractors with trailer skirts shown in the last row of Table 3-18; and the average of coastdown results for two of the three tested sleeper cab tractors with trailer skirts (average: 5.549 [n=2]); to demonstrate the coastdown yaw sweep correction.

To begin the conversion from alternate method to coastdown, we first calculate certain parameters using the results from above: the wind average drag area – zero yaw drag area offset; and the $F_{alt\text{-}aero}$ using the coastdown and the zero yaw drag area results; shown in Table 3-19 below.

Table 3-19 Converting Wind Average Drag Area from the Alternate Method to Virtual Wind Average Drag Area for the Coastdown Reference Method: Sample Calculations for Certified Configuration Calculations.

CERTIFIED CONFIGURATION USING COASTDOWN REFERENCE METHOD AND ALTERNATE METHOD (SAMPLE DATA: RSWT RESULTS FOR DAY CAB IN TABLE 3-18)		
Test Method/Source	**Variable**	**Value**
Coastdown (reference method)	$(C_dA)_{zero,coastdown}$	5.5
Drag area from RSWT (or other alt. method)	$(C_dA)_{zero,wind\ tunnel}$	4.9
Wind average drag area RSWT (or other alt. method)	$(C_dA)_{wad\ wind\ tunnel}$	5.6
Alternate Method Factor	$F_{alt\text{-}aero}$	$F_{alt\text{-}aero} = (C_dA)_{zero,\ coastdown} / (C_dA)_{zero,wind\ tunnel} = 5.5/4.9 = 1.12$
Wind Average Offset	WACd-CdA0 Offset	$(C_dA)_{wad,wind\ tunnel} – (C_dA)_{zero,wind\ tunnel} = 5.6 – 4.9 = 0.7$
C_dA_{wad} Calculations (for bin determination and GEM input):	Wind Average Equivalent Coastdown $(C_dA)_{wad}$	$(C_dA)_{wad} = (C_dA)_{zero,\ coastdown} + ((C_dA)_{wad,wind\ tunnel} – (C_dA)_{zero,wind\ tunnel})*F_{alt\text{-}aero}$ = 5.5+(5.6-4.9)*1.12 = 5.5 + 0.7*1.12 $(C_dA)_{wad}$ = **6.3**

Using the Wind Average Equivalent Coastdown value of 6.2, a manufacturer would identify the appropriate bin for that value and use the associated aerodynamic GEM input for determining CO_2 emissions and fuel consumption; which is discussed below. For now, the alternate method factor, $F_{alt\text{-}aero}$, is not used, however, it will be important later for certifying additional configurations.

Once the certified configuration values have been derived, the alternate aerodynamic method can be used to certify additional configurations using the $F_{alt\text{-}aero}$ from the certified configuration. For this example, we will use the same data from Table 3-18 and from Table 3-19 above for the Day Cab to represent a completely different configuration since the data from the sleeper cab tractors is all very similar (Note: In reality, a manufacturer would not be allowed to use the day cab for sleeper certification, and vice versa). Thus, this approach is limited to the example calculations for illustrative purposes). Table 3-20 shows the calculations using the data from Table 3-18 and Table 3-19 for the day cab.

Specifically, Table 3-20 shows two cases: a case where the manufacturer has generated the wind average drag area from the alternate method and another case where the manufacturer does not have the wind average drag area but, instead, has the zero yaw drag area from the alternate method. In the latter case where the manufacturer does not have the wind average drag area, we are proposing that the manufacturer would use a default wind average drag area-zero yaw drag area of 0.80.

Table 3-20 Converting Wind Average Drag Area from the Alternate Method to Virtual Wind Average Drag Area for the Coastdown Reference Method: Sample Calculations for Additional Configurations Using RSWT Day Cab Data

ADDITIONAL CERTIFIED CONFIGURATIONS USING ALTERNATE METHOD (SAMPLE DATA: RSWT RESULTS FOR DAY CAB IN TABLE 3-18)			
Test Method/Source	Variable	Example: Previous Certified Configuration Data	Additional Configuration using Alternate Method (Example: Day Cab Data)
Coastdown (reference method)	$(C_dA)_{zero,coastdown}$	5.5	Not Available; alternate method used
Alt. method Drag area	$(C_dA)_{zero,alt\ method}$	4.9	5.3
Alt. method wind average drag area	$(C_dA)_{wad,alt\ method}$	5.6	5.8
Calculated Using Certified Configuration in Table 3-19	Alternate Method Factor ($F_{alt\text{-}aero}$)	$F_{alt\text{-}aero} = (C_dA)_{zero,coastdown} / (C_dA)_{zero,wind\ tunnel} = 5.5/4.9 = 1.12$ *(from Table 3-19 for certified case)*	
Actual Wind Average Offset	WACd-CdA0 Offset	0.7	0.5
Default Wind Average Offset	Default Offset	0.8	0.8
CdA_{wad} Calculations (for bin determination and GEM input):	With $(C_dA)_{wad,\ alt\ method}$	$(C_dA)_{wad} = (C_dA)_{wad,alt\ method} * F_{alt\text{-}aero}$ = 5.6 * 1.12 = **6.3**	$(C_dA)_{wad} = (C_dA)_{wad,alt\ method} * F_{alt\text{-}aero}$ = 5.8 * 1.12 = **6.5**
	Without $(C_dA)_{wad,\ alt\ method}$; Instead, use $(C_dA)_{zero,\ coastdown}$ (if applicable) or $(C_dA)_{zero,\ alt\ method}$ with a default offset value of 0.80	$(C_dA)_{wad} = (C_dA)_{zero,coastdown}$ + default offset = 5.5 + 0.80 = **6.3**	Not Applicable; Only alternate method is used
		$(C_dA)_{wad} = (C_dA)_{zero,alt\ method} * F_{alt\text{-}aero}$ + default offset = 4.9 * 1.12 + 0.80 = **6.3**	$(C_dA)_{wad} = (C_dA)_{zero,\ alt\ method} * F_{alt\text{-}aero}$ + default offset = 5.3 * 1.12 + 0.80 = **6.7**

In contrast to $F_{alt\text{-}aero}$ that is calculated once for the certified configuration and may be applied to additional configurations, the wind average drag area – drag area ($WAC_dA - C_dA$) offset is configuration dependent, and must be calculated for and used solely for that configuration. It may be possible to use a single wind average – drag area offset for grouping similar configurations but this would need to be supported by data showing the level of variation between the configurations to justify such a grouping, and approved by the agencies prior to use.

Now that we have applied the adjustment for wind average drag area to the coastdown, we will revisit the method comparison using this approach. Below in Figure 3-10 is the data from Figure 3-9 with the values for coastdown adjusted to account for wind average drag. In addition, the constant speed test results have been adjusted by the same factor to adjust for wind average and maintain its relative agreement with the coastdown test results. As shown in Figure 3-10, the results for the RSWT are lower than the coastdown test results, as expected. Further, of note is the fact that if we analyze the method agreement for the zero yaw RSWT test results for a trailer with a skirt, prior to wind average adjustment and normalized to the coastdown test results, you would get results of 0.91 for Sleeper 1, 0.89 for Sleeper 2, and 0.90 for Sleeper 3. These are the results shown in Figure 3-10, demonstrating that the equations above are adequately accounting for wind average drag area in the coastdown results (e.g., the relative difference between the adjusted coastdown and RSWT wind average drag area is the same as the relative difference between the original coastdown result and the zero yaw drag area).

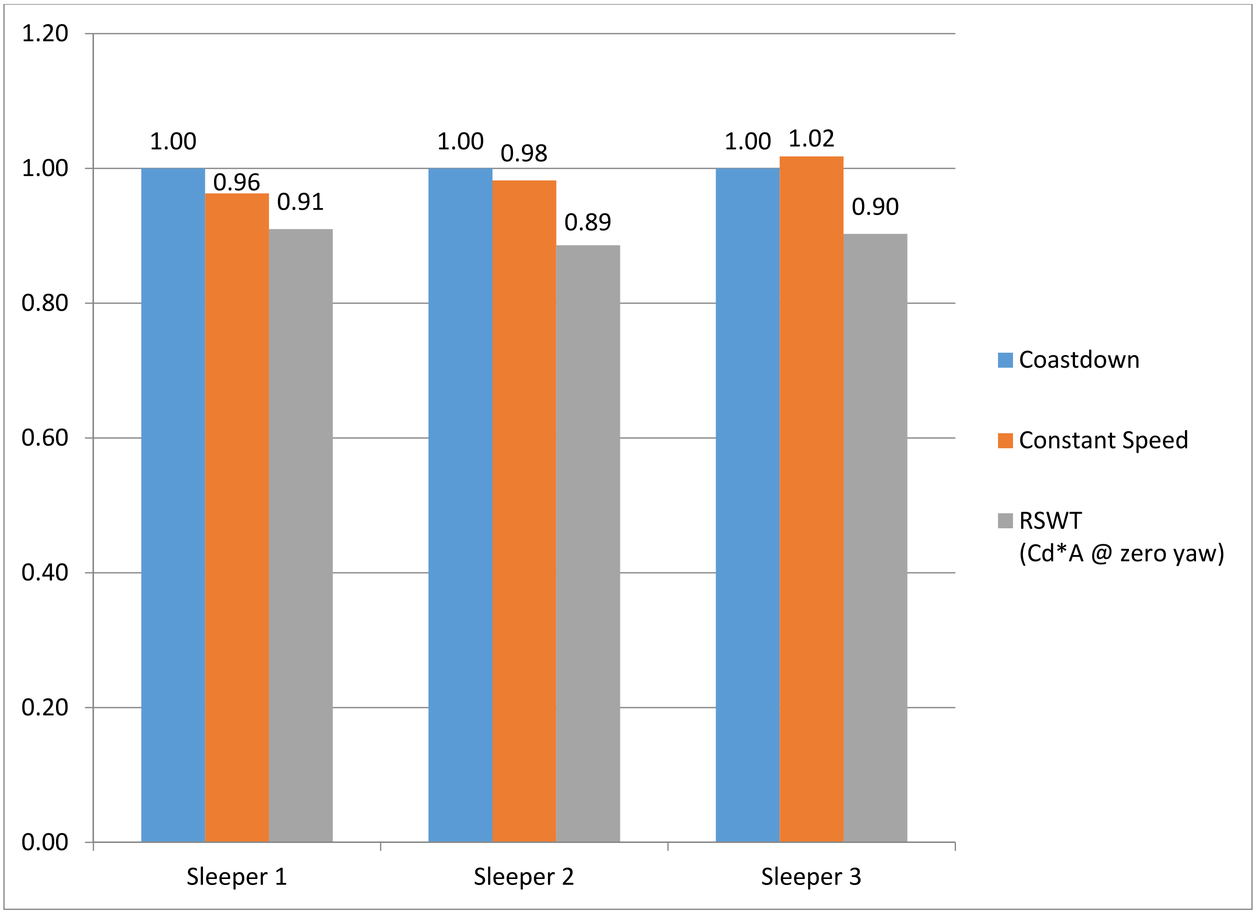

Figure 3-9 Adjusted Method Comparison for Coastdown, Constant Speed and RSWT (WACdA @ 55 mph w/ 7 mph wind) Testing Normalized to the Coastdown Results with wind average adjustment applied, for Class 8 High Roof Sleeper Cab Tractors and Trailers Equipped with Trailer Side Skirts. Note: The results of Sleeper 1 and Sleeper 3 are not directly comparable since the test articles do not match but are shown to represent overall industry trend given a manufacturer's unique fleet.

Finally, below in Table 3-21 are the wind average equivalent coastdown values to illustrate how today's tractors fit into the proposed HD Phase 2 aerodynamic standards. These values were developed using the coastdown results for each tractor and trailer equipped with a trailer side skirt, and applying the principles above with the corresponding zero yaw drag area and wind-average drag area from the RSWT. The corresponding aerodynamic bins and GEM input are provided as well based on the proposed bin values in Section III.E.(2)(a)(iv) of the preamble. A manufacturer would use the resulting aerodynamic GEM input to generate the configuration-specific CO_2 emission and fuel consumption value for certification. As shown below, most tractors today would qualify for Bin III with varying degrees of opportunity to move into improved bins.

Table 3-21 Wind Average Equivalent Coastdown Values Used to Develop the Proposed HD Phase 2 Aerodynamic Standards and Corresponding Aero Bin and Aero GEM Input.

TRACTOR	CONFIG	CSTDWN	C_dA0	WAC_d	$F_{alt-aero}$	WAC_d OFFSET	WAC_d X $F_{alt-aero}$	CSTDWN + WAC_d OFFSET	HD PHASE 2 PROPOSED BIN #	BIN III AERO TEST RESULT	BIN III AERO GEM INPUT
Sleeper 1	skirt	5.4	4.91	5.42	1.11	0.505	**6.0**	**6.0**	Bin III	6.0-6.5	6.3
Sleeper 2	skirt	5.6	4.96	5.70	1.15	0.742	**6.5**	**6.4**	Bin III	6.0-6.5	6.3
Sleeper 3	skirt	5.6	5.06	5.60	1.11	0.542	**6.2**	**6.2**	Bin III	6.0-6.5	6.3

This table is only intended to illustrate how the tractors would fit into the proposed bin structure but may not be completely appropriate for bin setting. Specifically, in two cases, there were tractors where either the model designation or model year did not match between the on-road and RSWT testing. As a result, it is better to look at the data in aggregate rather than on an individual vehicle basis.

Using the average of the coastdown drag areas (avg = 5.5), the average of the wind average offsets (avg = 0.6), and the alternate method factor (Falt-aero) of 1.15 from the tractor (Sleeper 2) with matching vehicles between on-road and wind tunnel testing; in the equation in Table 3-18 for a certified configuration (e.g., $CdA_{zero,\ coastdown} + (CdA_{wad,\ wind\ tunnel} - CdA_{zero,\ wind\ tunnel}) * F_{alt-aero}$) you get a CdA_{wad} value of 6.23. This value is almost exactly in the middle of the proposed Bin III standards and, therefore, we think that the proposed standards are appropriate. Further, the data in the Table 3-21 above provides some insight into the variability and range of high roof sleeper cab tractors from across the manufacturers that might be expected to be certified for HD Phase 2. Thus, although we do not have a complete set of matching datasets in all cases, we believe the values and bandwidth are appropriate for the HD Phase 2 proposed bin standards based on the data and calculations above.

3.2.10 Delta Drag Area Results to Support Proposed HD Phase 2 Trailer Regulations

Similar to the tractor aerodynamic assessment in Section 3.2.9 above, we can use the data generated during our aerodynamic assessment test programs to support development of trailer aerodynamic standards. As previously discussed in Section 3.2.5, the proposed trailer regulations would use the delta C_dA from any of the accepted aerodynamic methods. Table 3-22 below shows the delta C_dAs across tractors, trailers, trailer configurations and aerodynamic test methods using data from Table 3-8, Table 3-9 and Table 3-10. The corresponding trailer certification bin and trailer aerodynamic GEM inputs are provided as well based on the proposed values in Section IV of the preamble, IV.F.(3)(b)(iv), Table IV-31.

Table 3-22 Delta C_DAs from Various Tractors, Trailers, Trailer Configurations and Aerodynamic Test Methods with Corresponding Trailer Aerodynamic Bins

CAB TYPE	CONFIGURATION	DELTA C_dA (VS. STANDARD)	TRAILER CERT. BIN	TRAILER AERO GEM INPUT
Coastdown Testing				
Sleeper 1	With Trailer Skirt #2	0.5	III	0.5
	With Trailer Skirt and Boat Tail	0.9	IV	0.9
Sleeper 2	With Trailer Skirt #2	0.6	III	0.5
	With Trailer Skirt and Boat Tail	1.1	IV	0.9
Sleeper 3	With Trailer Skirt #2	0.5	III	0.5
	With Trailer Skirt and Boat Tail	0.7	IV	0.9
Constant Speed Testing				
Sleeper 1	With Trailer Skirt #2	0.7	IV	0.9
	With Trailer Skirt and Boat Tail	1.1	IV	0.9
Sleeper 2	With Trailer Skirt #2	0.5	III	0.5
Reduced Scale Wind Tunnel Testing (RSWT)				
Sleeper 1	With Trailer Skirt #1	0.423	III	0.5
	With Trailer Skirt #2	0.511	III	0.5
	With Boat Tail	0.340	III	0.5
	With Trailer Skirt #2 and Boat Tail	0.972	IV	0.9
Sleeper 2	With Trailer Skirt #1	0.586	III	0.5
	With Trailer Skirt #2	0.594	III	0.5
	With Boat Tail	0.365	III	0.5
	With Trailer Skirt #2 and Boat Tail	1.092	IV	0.9
Sleeper 3	With Trailer Skirt #1	0.477	III	0.5
	With Trailer Skirt #2	0.566	III	0.5
	With Boat Tail	0.318	III	0.5
	With Trailer Skirt #2 and Boat Tail	1.056	IV	0.9
Sleeper 4	With Trailer Skirt #1	0.481	III	0.5
	With Trailer Skirt #2	0.557	III	0.5
	With Boat Tail	0.332	III	0.5
	With Trailer Skirt #2 and Boat Tail	1.121	IV	0.9
Day	With Trailer Skirt #1	0.256	II	0.2
	With Trailer Skirt #2	0.311	III	0.5
	With Boat Tail	0.370	III	0.5
	With Trailer Skirt #2 and Boat Tail	0.699	III	0.5

In general, Table 3-22 shows that individual components (e.g., trailer side skirts, boat tails) added to a trailer might qualify for Bin III while combinations of devices (e.g., trailer side skirt and boat tail) added to a trailer might qualify for Bin IV. For the day cab, a basic skirt such as Skirt #1 would qualify for Bin II as opposed to an advance skirt such as Skirt #2 which would qualify for Bin III.

Trailer manufacturers would follow a similar process of using the delta C_dA values for their trailer devices or improved trailer designs to identify the appropriate trailer certification bin and the trailer aero GEM input for that bin. Accordingly, these values were used to develop the trailer certification bins and aero GEM inputs to support the trailer regulations in HD Phase 2.

3.3 Tire Rolling Resistance

The agencies are proposing that the ISO 28580 test method be used to determine rolling resistance and the coefficient of rolling resistance. A copy of the test method can be obtained through the American National Standards Institute.[13]

3.3.1 Reason for Using ISO 28580

EPA's SmartWay Partnership Program started to identify equipment and feature requirements for SmartWay-designated Class 8 over-the-road tractors and trailers in 2006. In order to develop a tire rolling resistance specification for SmartWay-designated commercial trucks, EPA researched different test methods used to evaluate tire rolling resistance, reviewing data and information from tire manufacturers, testing laboratories, the State of California, the Department of Transportation, tractor manufacturers, and various technical organizations. After assessing this information, EPA determined that its SmartWay program would use the SAE J1269[14] tire rolling resistance method until the ISO 28580[15] method (at that time under development) was finalized, at which time the Agency would consider moving to this method for its SmartWay program.

During this same time period, the National Highway Traffic Safety Administration (NHTSA) conducted an evaluation of passenger vehicle tire rolling resistance test methods and their variability.[16] Five different laboratory test methods at two separate labs were evaluated. The NHTSA study focused on passenger tires; however, three of the four test methods evaluated can be used for medium-duty and heavy-duty tractor tires. The methods evaluated were SAE J1269, SAE J2452[17] (not applicable for medium-duty or heavy-duty tractor tires), ISO 18164[18] and ISO 28580. The NHTSA study showed significant lab to lab variability between the labs used. The variability was not consistent between tests or types of tire within the same test. The study concluded that a method to account for this variability is necessary if the rolling resistance value of tires is to be compared (NHTSA, 2009). Because of laboratory variability, NHTSA recommended that the use of ISO 28580 is preferred over the other test methods referenced.

ISO 28580 is preferred because the test method involves laboratory alignment between a "reference laboratory" and "candidate laboratory." The ISO technical committee involved in developing this test method also has the responsibility for determining the laboratory that will serve as the reference laboratory. The reference laboratory would make available an alignment tire that can be purchased by candidate laboratories. The candidate laboratory would identify its reference machine. However, at this time, the reference laboratory and alignment tires have not been identified.

3.3.2 Measurement Method and Results

The ISO 28580 test method includes a specific methodology for "light truck, commercial truck and bus" tires, and it has 4 measurement methods, force, torque, deceleration, and power, all of which appear to be suitable for use.

The results of the ISO 28580 test are intended for use in vehicle simulation modeling, such as the model used to assess the effects of various technology options for national greenhouse gas and fuel economy requirements for commercial trucks (see Chapter 4). The results are usually expressed as a rolling resistance coefficient and measured as kilogram per metric ton (kg/metric ton) or as dimensionless units (1 kg/metric ton is the same as the dimensionless unit 0.001). The results are corrected for ambient temperature drum surface and drum diameter as specified in the proposed test method.

3.3.3 Sample Size

The rolling resistance of tires within the same model and construction are expected to be relatively uniform. In the study conducted by NHTSA, only one individual tire had a rolling resistance value that was significantly different from the other tires of the same model. The effect of production variability can be further reduced by conducting three replicate tests and using the average as the value for the rolling resistance coefficient. Tire models available in multiple diameters may have different values of rolling resistance for each diameter because larger diameter tires can produce lower rolling resistance than smaller diameters under the same load and inflation conditions. If the size range within a tire model becomes large enough that a given tire size is no longer "substantially similar" in rolling resistance performance to all other tire sizes of that model, then good engineering judgment should be exercised as to whether the differently-sized tire shall be treated, for testing and vehicle simulation purposes, as a distinct tire model. For Class 8 tractors that typically use tires that fit on 22.5" or 24.5" wheels, this situation might occur with 17.5" tires, more commonly used on moving vans and other applications that require a low floor.

3.3.4 Tire Size

In Phase 2, the agencies propose to require manufacturers to enter the tire loaded radius as a GEM input. While this rulemaking does not include tire size among the technologies applied to improve fuel efficiency, this measurement is among the driveline parameters necessary for GEM to calculate a vehicle speed for a given engine speed. Because there is a wide range of possible measurements for loaded radius, the agencies are specifying a proposed measurement procedure. Tire sizes can be measured using an overall diameter or a static loaded radius. Deflection is typically between 24 and 33 percent depending on the tire design. In the first 100-200 miles of a tire's useful life, there will be a break-in process during which a commercial tire can "grow" one to two percent, up to 18 mm. Because this growth affects the air pressure in the tire, it's important to specify the air pressure under which the loaded radius measurement is performed. The Society of Automotive Engineers (SAE) has published recommended practice J1025 for determining the revolutions per mile of new truck tires.[19] Consistent with that recommended practice, the agencies propose that manufacturers would quantify the loaded tire radius of the drive tire, NIST traceable within ±0.5 percent uncertainty, by measuring the perpendicular distance from the axis of rotation of the loaded tire to the surface on which it is rolling. Load the tire to 85 percent of the maximum load capacity specified by the manufacturer, at the corresponding air inflation level. See 40 CFR 1037.520(j).

3.4 Duty Cycle

Certification duty cycles have a significant impact on the GHG emissions from a truck and how technologies are assessed. Every truck has a different duty cycle in-use. Therefore, it is very challenging to develop a uniform duty cycle which accurately assesses GHG improvements and fuel efficiency from technologies relative to their performance in the real world.

The duty cycle attributes that impact a vehicle’s performance include average speed, maximum speed, acceleration rates, deceleration rates, number of stops, road grade, power take-off operation, and idling time. Average and maximum speeds are the attributes which have the greatest impact on aerodynamic technologies. Vehicle speed also impacts the effect of low rolling resistance tires. The effectiveness of extended idle reduction measures is determined by the amount of time spent idling. Lastly, hybrid technologies demonstrate the greatest improvement on cycles which include a significant amount of stop-and-go driving due to the opportunities to recover braking energy. In addition, the amount of power take-off operation will impact the effectiveness of some vocational hybrid applications.

The ideal duty cycle for a line-haul truck would account for a significant amount of time spent cruising at high speeds. A pickup and delivery truck duty cycle would contain a combination of urban driving, some number of stops, and limited highway driving. If the agencies propose an ill-suited duty cycle for a regulatory subcategory, it may drive technologies where they may not see the in-use benefits. For example, requiring all trucks to use a constant speed highway duty cycle would drive significant aerodynamic improvements. However, in the real world a pickup and delivery truck may spend too little time on the highway to realize the benefits of aerodynamic enhancements. In addition, the extra weight of the aerodynamic fairings would actually penalize the GHG performance of that truck in urban driving and may reduce its freight carrying capability.

3.4.1 Duty Cycles Considered

In HD Phase 1, the agencies selected three duty cycles for certification testing: the Transient portion of the California Air Resource Board (CARB) Heavy Heavy-Duty Truck 5 Mode Cycle, 55 mph cruise (without grade), and 65 mph cruise (without grade).

For HD Phase 2, the agencies carefully considered which duty cycles are appropriate for the different regulatory subcategories. We considered several duty cycles in the development of the rulemaking including EPA’s MOVES model; the Light-Duty FTP75 and HFET; Heavy-Duty UDDS; World Wide Transient Vehicle Cycle (WTVC); Highway Line Haul; Hybrid Truck User Forum (HTUF) cycles; and California CARB’s Heavy-Heavy-Duty Truck 5 Mode Cycle.

MOVES Medium-Duty and Heavy-Duty schedules were developed based on three studies. Eastern Research Group (ERG) instrumented 150 medium and heavy-duty vehicles, Battelle instrumented 120 vehicles instrumented with GPS, and Faucett instrumented 30 trucks to characterize their in-use operation.[20] ERG then segregated the driving into freeway and non-freeway driving for medium and heavy-duty vehicles, and then further stratified vehicle trips according the predefined ranges of average speed covering the range of vehicle operation. Driving schedules were then developed for each speed bin by creating combinations of idle-to-idle "microtrips" until the representative target metrics were achieved. The schedules developed by ERG are not contiguous schedules which would be run on a chassis dynamometer, but are made up of non-contiguous "snippets" of driving meant to represent target distributions. This gives MOVES the versatility to handle smaller scale inventories, such as intersections or sections of interstate highway, independently.

The FTP75 and HFET duty cycles are used extensively for Light-Duty emissions and CAFE programs. Our assessment is that these cycles are not appropriate for HD trucks for two primary reasons. First, the FTP has 24 accelerations during the cycle which are too steep for a Class 8 combination tractor to follow. Second, the maximum speed is 60 mph during the HWFEC, while the national average truck highway speed is 65 mph.

The Heavy-Duty Urban Dynamometer Driving Cycle was developed to determine the Heavy-Duty Engine FTP cycle. The cycle was developed from CAPE-21 survey data which included information from 44 trucks and 3 buses in Los Angeles and 44 trucks and 4 buses in New York in 1977. The cycle was computer generated and weighted to represent New York non-freeway (254 sec), Los Angeles non-freeway (285 sec), Los Angeles freeway (267 sec), New York non-freeway (254 sec) to produce a nearly 50/50 weighting of highway cruise and urban transient. We believe this cycle is not appropriate for our program for several reasons. The maximum speed on the UDDS is 58 mph which is low relative to the truck speed limits in effect today. The 50/50 weighting of cruise to transient is too low for combination tractors and too high for vocational vehicles and the single cycle does not provide flexibility to change the weightings. Lastly, the acceleration rates are low for today's higher power trucks.

The World Harmonized WTVC was developed by the UN ECE GRPE group. It represents urban, rural, and motorway operation. The cycle was developed based on data from 20 straight trucks, 18 combination tractors, and 11 buses total from Australia, Europe, Japan, and the US. EPA has a desire to harmonize internationally, however, we believe that this single cycle does not optimally cover the different types of truck operation in the United States and does not provide the flexibility to vary the weightings of a single cycle.

The Highway Line Haul schedule was created by Southwest Research Institute, using input from a group of stakeholders, including EPA, Northeastern States for Coordinated Air Use Management (NESCAUM), several truck and engine manufacturers, state organizations, and others, for a NESCAUM heavy truck fuel efficiency modeling and simulation project. The cycle is 103 miles long and incorporates grade and altitude. This cycle is a good representation of line haul operation. However, the altitude changes cannot be incorporated into a chassis dynamometer or track test and the cycle is also too long for a typical chassis dynamometer test.

The Calstart-Weststart Hybrid Truck Users Forum is developing cycles to match the characteristics of truck applications which are expected to be first to market for hybrids. The cycles include the Manhattan Bus Cycle, Orange County Bus Cycle, Class 4 Parcel Delivery, Class 6 Parcel Delivery, Combined International Local and Commuter Cycle (CILCC), Neighborhood Refuse, Utility Service, and Intermodal Drayage cycles. The cycles are very application-specific and appropriately evaluate each vocation. However, the use of these types of application specific cycles in a regulatory scheme would lead to a proliferation of cycles for every application, an outcome that is not desirable.

The CARB 5 Mode cycle was developed by California CARB from heavy-duty truck data gathered from 1997 through 2000.[21] Data was collected from real world driving from randomly selected vehicles. The data was gathered from 140 heavy-duty trucks by Battelle and from 31 heavy-duty trucks in a study conducted by Jack Faucett and Associates. The final data set included 84 of these heavy duty trucks covering over 60,000 miles and 1,600 hours of activity. The cycles were developed to reflect typical in-use behavior as demonstrated from the data collected. The four modes (idle, creep, transient, and cruise) were determined as distinct operating patterns, which then led to the four drive schedules. The cycle is well accepted in the heavy-duty industry. It was used in the CRC E55/59 Study which is the largest HD chassis dynamometer study to date and used in MOVES and EMFAC to determine emission rate inputs; EPA's biodiesel study which used engine dynamometer schedules created from CARB cruise cycle; the HEI ACES Study: WVU developed engine cycles from CARB 4-mode chassis cycles; CE/CERT test; and by WVU to predict fuel efficiency performance on any duty cycle from CARB 5 mode results. The modal approach to the cycles provides flexibility in cycle weightings to accommodate a variety of truck applications. A downside of the cycle is that it was developed from truck activity in California only.

3.4.2 Proposed Duty Cycles

3.4.2.1 Highway Cruise Cycles

The agencies analyzed the average truck speed limit on interstates and other freeways to identify the appropriate speed of the highway cruise cycles. State speed limits for trucks vary between 55 and 75 mph, depending on the state.[22] The median urban and rural interstate speed limit of all states is 65 mph. The agencies also analyzed the speed limits in terms of VMT-weighting. The agencies used the Federal Highway Administration data on Annual Vehicle Miles for 2008 published in November 2009 to establish the vehicle miles travelled on rural and urban interstates broken down by state. The VMT-weighted national average speed limit is 63 mph based on the information provided in Table 3-23. The results of this analysis led to the adoption of the High Speed (65 mph) and Low Speed (55 mph) Cruise duty cycles in Phase 1.

Table 3-23 VMT-Weighted National Truck Speed Limit

STATE	RURAL INTERSTATE SPEED LIMIT	URBAN INTERSTATE SPEED LIMIT	RURAL INTERSTATE MILES	URBAN INTERSTATE AND OTHER FREEWAYS MILES	U.S. WEIGHTED VMT FRACTION RURAL	U.S. WEIGHTED VMT FRACTION URBAN	VMT WEIGHTED SPEED LIMIT
AL	70	65	5,643	7,950	0.6%	0.8%	0.968
AK	55	55	803	662	0.1%	0.1%	0.086
AZ	75	65	6,966	13,324	0.7%	1.4%	1.474
AR	65	55	4,510	4,794	0.5%	0.5%	0.591
CA	55	55	17,681	123,482	1.9%	13.1%	8.242
CO	75	65	4,409	11,745	0.5%	1.2%	1.161
CN	65	55	715	13,485	0.1%	1.4%	0.837
DE	55	55	-	1,694	0.0%	0.2%	0.099
DC	55	55	-	813	0.0%	0.1%	0.047
FL	70	65	9,591	37,185	1.0%	3.9%	3.279
GA	70	55	9,433	21,522	1.0%	2.3%	1.958
HA	60	60	110	2,403	0.0%	0.3%	0.160
ID	65	65	2,101	1,250	0.2%	0.1%	0.231
IL	65	55	8,972	23,584	1.0%	2.5%	1.996
IN	65	55	7,140	10,850	0.8%	1.2%	1.126
IA	70	55	4,628	2,538	0.5%	0.3%	0.492
KA	75	75	3,242	5,480	0.3%	0.6%	0.694
KE	65	65	6,566	6,834	0.7%	0.7%	0.925
LA	70	70	5,489	7,708	0.6%	0.8%	0.981
ME	65	65	2,207	958	0.2%	0.1%	0.218
MA	65	65	3,484	18,792	0.4%	2.0%	1.537
MS	70	70	1,257	20,579	0.1%	2.2%	1.623
MI	60	60	5,245	20,931	0.6%	2.2%	1.667
MN	70	60	4,150	12,071	0.4%	1.3%	1.077
MS	70	70	4,103	4,004	0.4%	0.4%	0.602
MO	70	60	5,972	16,957	0.6%	1.8%	1.524
MT	65	65	2,350	343	0.2%	0.0%	0.186
NE	75	65	2,590	1,653	0.3%	0.2%	0.320
NV	75	65	1,826	5,286	0.2%	0.6%	0.510
NH	65	65	1,235	2,574	0.1%	0.3%	0.263
NJ	65	55	1,609	25,330	0.2%	2.7%	1.590
NM	75	65	4,530	2,667	0.5%	0.3%	0.545
NY	65	55	6,176	37,306	0.7%	4.0%	2.604
NC	70	70	5,957	19,216	0.6%	2.0%	1.871
ND	75	75	1,394	374	0.1%	0.0%	0.141

OH	65	65	9,039	27,830	1.0%	3.0%	2.544
OK	75	70	5,029	7,223	0.5%	0.8%	0.937
OR	55	55	4,109	5,734	0.4%	0.6%	0.575
PA	65	55	10,864	21,756	1.2%	2.3%	2.020
RI	65	55	404	2,948	0.0%	0.3%	0.200
SC	70	70	7,355	6,879	0.8%	0.7%	1.058
SD	75	75	1,960	648	0.2%	0.1%	0.208
TN	70	70	8,686	13,414	0.9%	1.4%	1.642
TX	70	70	15,397	71,820	1.6%	7.6%	6.481
UT	75	65	3,117	6,165	0.3%	0.7%	0.674
VT	65	55	1,216	443	0.1%	0.0%	0.110
VA	70	70	8,764	18,907	0.9%	2.0%	2.056
WA	60	60	4,392	15,816	0.5%	1.7%	1.287
WV	70	65	3,195	3,175	0.3%	0.3%	0.456
WI	65	65	5,197	9,139	0.6%	1.0%	0.989
WY	75	75	2,482	474	0.3%	0.1%	0.235

In establishing the highway cruise cycles in Phase 1, we realized that we did not address the effect of road grade on emissions. Therefore, for Phase 2, we are proposing to alter the High Speed Cruise and Low Speed Cruise modes to reflect road grade for the constant speed cycles at 65 mph and 55 mph respectively. Based on input from trucking fleets and truck manufacturers, we believe this is representative of in-use operation, wherein truck drivers use cruise control whenever possible during periods of sustained higher speed driving and road grade varies.

To this end, the U.S. Department of Energy and EPA have partnered to support a project aimed at evaluating, refining and/or developing the appropriate road grade profiles for the duty cycles that would be used in the certification of heavy-duty vehicles to the GHG emission and fuel efficiency Phase 2 standards. The National Renewable Energy Laboratory (NREL) is leading a project which will refine the existing highway cruise duty cycles. In the course of this work, NREL has developed several activity-weighted road grade profiles which are representative of U.S. limited-access highways using high-accuracy road grade and county-specific data for vehicle miles traveled. Either a single road grade profile representative of the nation’s limited-access highways will be chosen for use in the highway cruise cycles or two activity-weighted grade profiles will be selected if analysis demonstrates that they should be different for speed limits of 55 and 65 mph. The profiles are distance-based and cover a maximum distance of 15 miles. In addition to NREL work, the agencies have independently developed another candidate road grade profile for use in the 55 mph and 65 mph highway cruise cycles. While based on the same road grade database generated by NREL for U.S. restricted-access highways, its design is predicated on a different approach. This analysis of road grade profile options was not completed in time for use in developing the primary proposal. Therefore, for the proposal, the agencies selected an interim road grade profile for development of the proposed standards, which is described in Section III.E of the preamble to these rules. Based on preliminary results, it appears the interim road grade profile closely matches a national road grade profile on an absolute basis, before VMT weighting. The report documenting the NREL’s and the agencies' road grade work is available to the public in the docket, as is the agencies' analysis of possible alternative vehicle standards developed using alternative road grade profiles.

3.4.2.2 Transient Cycle

The Phase 1 rule requires use of the Transient portion of the CARB's Heavy Heavy-Duty Truck 5 Mode Cycle. The agencies have found that this cycle reasonably represents transient operation of many heavy-duty vehicles, though it is a very short test cycle - less than 3 miles – and can be driven in roughly 11 minutes. We are not proposing any changes to that cycle, and would continue to use it when certifying vehicles to the HD Phase 2 standards.

The agencies would like to note that we have also launched a project at the National Renewable Energy Laboratory (NREL) to determine the extent to which the Transient mode of the CARB Heavy-Duty Truck 5 Mode Cycle is representative of transient operation of Class 2b-8 vocational vehicles. This analysis is being performed using NREL's extensive vehicle activity database and a variety of metrics such as average driving speed, kinetic intensity, idle time, maximum driving speed and standard deviation of speed. Should NREL recommend, and the agencies agree, that any subcategory of vocational vehicles is poorly represented by the Transient mode of the CARB cycle, a more representative transient test cycle will be adopted, possibly selected from test cycles already in use. This analysis was not completed in time for use in developing the primary proposal. The report documenting this work is available to the public in the docket, as is the agencies' analysis of possible alternative vocational vehicle standards developed using an alternative transient duty cycle.

3.4.2.3 Idle Cycle

We are also proposing the addition of an idle-only cycle to determine both fuel consumption and CO_2 emissions when a vehicle is idling, and recognize technologies that either reduce the fuel consumption rate or shut the engine off (and restart) during short-term idle events during the workday. The agencies are not expecting that this cycle would recognize technologies that allow the main engine to remain off during stationary vehicle operation with a PTO engaged and performing work. Those technologies would be recognized over the Hybrid-PTO test procedure defined in 40 CFR 1037.525. In this proposed idle-only cycle, based on user inputs, GEM would calculate CO_2 emissions and fuel consumption at both zero torque (neutral idle) and with torque set to Curb-Idle Transmission Torque (as defined in 40 CFR 1065.510(f)(4) for variable speed engines) for use in the CO_2 emission calculation in 40 CFR 1037.510(b). We are also proposing that GEM would calculate reduced CO_2 and fueling for stop-start systems, based on an assumption that the effectiveness would represent a 90 percent reduction of the emissions that would occur if the vehicle had operated at Curb-Idle Transmission Torque over this cycle. This cycle is proposed to be applicable only for vocational vehicles using either the Regional, Multi-Purpose, or Urban composite duty cycles.

3.4.3 Weightings of Each Cycle per Regulatory Subcategory

Table 3-24 presents the Phase 1 final GEM duty cycle composite weightings for vocational vehicles and tractors.

Table 3-24 Phase 1 Vehicle Duty Cycle Composite Weightings

VEHICLE CATEGORY	PHASE 1 COMPOSITE WEIGHTINGS OF DUTY CYCLE MODE		
	Transient	55 mph Cruise	65 mph Cruise
Vocational	42%	21%	37%
Vocational Hybrid Vehicles	75%	9%	16%
Day Cabs	19%	17%	64%
Sleeper Cabs	5%	9%	86%

3.4.3.1 Vocational Vehicles

In order to properly weight the "idle" time of each vehicle class and category independently of the idle time in the duty cycles, EPA is proposing that idle emissions are weighted with the driving cycles. In the HD Phase 1 rule the duty cycles were weighted by distance to properly reflect the vehicle miles traveled by each category. To incorporate "idle" emissions, the equation had to be modified to allow for the "idle" emissions to be time weighted with the driving cycles. The result of this is that the weighting factors for the driving cycles will still add up to 100 percent while the idle weighting factor will be less than 100 percent, reflecting the actual idle time of the vehicles by category. The agencies are proposing to modify the equation in 40 CFR 1037.510(b) to accommodate both the distance (non-idle) and time based (idle) weighting factors.

The proposed duty cycle weightings for each vocational vehicle test cycle are included in Table 3-25.

Table 3-25 Proposed Phase 2 Duty Cycle Mode Composite Weightings

VEHICLE CATEGORY	DUTY CYCLE MODE			
	Transient	55 mph Cruise	65 mph Cruise	Idle
Vocational Regional	50%	28%	22%	10%
Vocational Multi-Purpose	82%	15%	3%	15%
Vocational Urban	94%	6%	0%	20%

3.5 Tare Weights and Payload

We propose to continue defining the total weight of a truck as the combination of the truck's tare weight, a trailer's tare weight (if applicable), and the payload; as it was defined in the HD Phase 1 rule. The total weight of a truck is important because it in part determines the impact of technologies, such as rolling resistance, on GHG emissions and fuel consumption. As the HD program is designed, it is important that the agencies define weights which are representative of the fleet while recognizing that the final weights are not representative of a specific vehicle. The sections below describe the agencies' approach to defining each of these weights.

3.5.1 Truck Tare Weights

The tare weight of a truck will vary depending on many factors, including the choices made by the manufacturer in designing the truck (such as the use of lightweight materials, the cab configuration (such as day or sleeper cab), whether it has aerodynamic fairing (such as a roof fairing), and the specific options on the truck.

The Class 8 combination tractor tare weights were developed based on the weights of actual tractors tested in EPA's coastdown program. The empty weight of the Class 8 sleeper cabs with a high roof tested ranged between 19,000 and 20,260 pounds. The empty weight of the Class 8 day cab with a high roof tested was 17,840 pounds. The agencies derived the tare weight of the Class 7 day cabs based on the guidance of truck manufacturers. The agencies then assumed that a roof fairing weighs approximately 500 pounds. Based on this, the agencies are proposing the tractor tare weights as shown in Table 3-26.

Table 3-26 Tractor Tare Weights

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,000	11,500	11,000

The agencies developed the empty tare weights of the vocational vehicles based on the EDF report[23] on GHG management for Medium-Duty Fleets. The EDF report found that the average tare weight of a Class 4 truck is 10,343 pounds, of a Class 6 truck is 13,942 pounds, and a Class 8 truck is 23,525 pounds. The agencies are proposing to continue to use the following tare weights:

- Light Heavy (Class 2b-5) = 10,300 pounds
- Medium Heavy (Class 6-7) = 13,950 pounds
- Heavy Heavy (Class 8) = 23,500 pounds

3.5.2 Trailer Tare Weights

We propose to continue to define the trailer tare weights used in the tractor program based on measurements conducted during EPA's coastdown testing and information gathered by ICF in the cost report to EPA, as adopted in the HD Phase 1 rule.[24]

A typical 53 foot box (or van) trailer has an empty weight ranging between 13,500 and 14,000 pounds per ICF's findings. The box trailer tested by EPA in the coastdown testing weighed 13,660 pounds. Therefore, the agencies are defining the empty box trailer weight as 13,500 pounds.

A typical flatbed trailer weighs between 9,760 and 10,760 per the survey conducted by ICF. EPA's coastdown work utilized a flatbed trailer which weighed 10,480 pounds. Based on this, the agencies are defining a flatbed trailer weight of 10,500 pounds.

Lastly, a tanker trailer weight typically ranges between 9,010 and 10,500 pounds based on ICF findings. The tanker trailer used in the coastdown testing weighed 9,840 pounds. The agencies are defining the empty tanker trailer weight of 10,000 pounds.

3.5.3 Payload

The amount of payload by weight that a tractor can carry depends on the class (or GVWR) of the vehicle. For example, a typical Class 7 tractor can carry fewer tons of payload than a Class 8 tractor. Payload impacts both the overall test weight of the truck and is used to assess the "per ton-mile" fuel consumption and GHG emissions. The "tons" represent the payload measured in tons.

M.J. Bradley analyzed the Truck Inventory and Use Survey and found that approximately 9 percent of combination tractor miles travelled empty, 61 percent are "cubed-out" (the trailer is full before the weight limit is reached), and 30 percent are "weighed out" (operating weight equal 80,000 pounds which is the gross vehicle weight limit on the Federal Interstate Highway System or greater than 80,000 pounds for vehicles traveling on roads outside of the interstate system).[25] The Federal Highway Administration developed Truck Payload Equivalent Factors to inform the development of highway system strategies using Vehicle Inventory and Use Survey (VIUS) and Vehicle Travel Information System (VTRIS) data. Their results, as shown in Table 3-27, found that the average payload of a Class 8 truck ranged from 29,628 to 40,243 pounds, depending on the average distance travelled per day.[26] The same results found that Class 7 trucks carried between 18,674 and 34,210 pounds of payload also depending on average distance travelled per day.

Table 3-27 National Average Payload (lbs.) per Distance Travelled and Gross Vehicle Weight Group (VIUS)[27]

	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	CLASS 8
< 50 miles	3,706	4,550	8,023	10,310	18,674	29,628
51 to100 miles	3,585	4,913	6,436	10,628	23,270	36,247
101 to 200 miles	4,189	6,628	8,491	12,747	30,180	39,743
201 to 500 miles	4,273	7,029	6,360	10,301	25,379	40,243
> 500 mile	3,216	8,052	6,545	12,031	34,210	40,089
Average	3,794	6,234	7,171	11,203	26,343	37,190

The agencies are prescribing a fixed payload of 25,000 pounds for Class 7 tractors and 38,000 pounds for Class 8 tractors for their respective test procedures. These payload values represent a heavily loaded trailer, but not maximum GVWR, since as described above the majority of tractors "cube-out" rather than "weigh-out."

NHTSA and EPA are also proposing to continue using the payload requirements for each regulatory subcategory in the vocational vehicle category that were finalized in the HD Phase 1 rule. The payloads were developed from Federal Highway statistics based on the averaging the payloads for the weight classes of represented within each vehicle category.[28] The payload requirement is 5,700 pounds for the Light Heavy trucks based on the average payload of Class 3, 4, and 5 trucks from Table 3-27. The payload for Medium Heavy trucks is 11,200 pounds per the average payload of Class 6 trucks as shown in Table 3-27. Lastly the agencies are defining 38,000 pounds payload for the Heavy Heavy trucks based on the average Class 8 payload in Table 3-27.

3.5.4 Total Weight

In summary, the total weights of the combination tractors are shown in Table 3-28.

Table 3-28 Combination Tractor Total Weight

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7	CLASS 7
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,100	17,000	11,500	11,100	11,000
Trailer Weight (lbs)	13,500	10,000	10,500	13,500	10,000	10,500	13,500	10,000	10,500
Payload (lbs)	38,000	38,000	38,000	38,000	38,000	38,000	25,000	25,000	25,000
Total Weight (lbs)	70,500	66,750	67,000	69,000	65,100	65,500	50,000	46,100	46,500

The total weights of the vocational vehicles are as shown in Table 3-29.

Table 3-29 Vocational Vehicle Total Weights

REGULATORY SUBCATEGORY	LIGHT HEAVY	MEDIUM HEAVY	HEAVY HEAVY
Truck Tare Weight (lbs)	10,300	13,950	27,000
Payload (lbs)	5,700	11,200	15,000
Total Weight (lbs)	16,000	25,150	42,000

3.6 Powertrain Test Procedures

In the HD Phase 1 rule the agencies introduced a powertrain test procedure to allow manufacturers to generate credits for selling advanced powertrains that reduced CO_2 emissions and fuel consumption. In Phase 2 we are proposing to bring the powertrain test procedure into the main program and project that 15 to 30 percent of the vocational vehicles (including both hybrid and non-hybrid applications) would certify using this method. To accommodate this change we are proposing a number of improvements to the test procedure in 40 CFR 1037.550 and reducing the test burden by only requiring testing of the powertrain that is to be certified. The agencies are also proposing modifications to 40 CFR 1037.550 to separate out the hybrid specific testing protocols.

3.6.1 Reason Behind Use Of Powertrain Test Method for Conventional and Hybrid Powertrain Certification

The agencies are proposing a powertrain test option to afford a robust mechanism to quantify the benefits of CO_2 reducing technologies that are a part of the powertrain (conventional or hybrid), that are not captured in the GEM simulation. Among these technologies are transient fuel control, engine and transmission control integration, and hybrid systems. The largest proposed change from the Phase 1 powertrain procedure is that only the advanced powertrain will need to be tested as opposed to the requirement in Phase 1 where the result was an improvement factor calculated from the powertrain results of both the advanced powertrain and the conventional powertrain. This proposed change is possible because the proposed GEM simulation tool uses the engine fuel map and torque curve from the actual engine in the vehicle that is to be certified for all vehicles that do not use the powertrain method to certify the vehicle.

3.6.2 Use of Generic Vehicles to Apply Measurements Broadly Across All Vehicles That the Powertrain Will Be Installed In

To limit the amount of testing, under the proposal, powertrains will be divided into families and will be tested in a limited number of simulated vehicles that will cover the range of vehicles in which the powertrain will be used.

A matrix of 8 to 9 tests would be needed per vehicle cycle, to enable the use of the powertrain results broadly across all the vehicles in which the powertrain will be installed. The individual tests differ by the vehicle that is being simulated during the test. Table 3-30 and Table 3-31 define the unique vehicles being proposed that would cover the range of coefficient of drag, coefficient of rolling resistance, vehicle mass and axle ratio of the vehicles that the powertrain will be installed in.

To allow for a generic tire size definition that will cover the tires and axles installed on the certified vehicles, the agencies are proposing that each tire radius will be set so that when the vehicle is cruising at 65 mph the engine speed will equal the corresponding minimum NTE exclusion speed as defined in 40 CFR part 86.1370(b)(1), intermediate test speed (A, B, or C), or maximum test speed defined in 40 CFR part 1065. To calculate the tire radius, use the equation in 40 CFR 1037.550.

Table 3-30 Proposed Generic Vehicle Definitions for Class 2b-7 Vehicles

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
Mass (kg)	7,257	11,408	7,257	11,408	7,257	11,408	7,257	11,408
C_dA	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Tire C_{rr} (kg/ton)	6.7	6.9	6.7	6.9	6.7	6.9	6.7	6.9
Tire Radius (m)	0.426	0.426	0.426	0.426	0.426	0.426	0.426	0.426
Rotating Inertia (kg)	454	454	454	454	454	454	454	454
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5
Accessory Power (W)	1300	1300	1300	1300	1300	1300	1300	1300
Axle ratio at engine speed	A	A	B	B	C	C	Maximum engine speed	Maximum engine speed

Table 3-31 Proposed Generic Vehicle Definitions for Tractors and Class 8 Vocational Vehicles—General Purpose

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9
Mass (kg)	31,978	22,679	19,051	31,978	22,679	19,051	31,978	22,679	19,051
C_dA	5.4	4.7	4.0	5.4	4.7	4.0	5.4	4.7	4.0
Tire C_{rr} (kg/ton)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Tire Radius (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rotating Inertia (kg)	1,134	907	680	1,134	907	680	1,134	907	680
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5
Accessory Power (W)	1300	1300	1300	1300	1300	1300	1300	1300	1300
Axle ratio at engine speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	B	B	B	Maximum engine speed	Maximum engine speed	Maximum engine speed

Table 3-32 Proposed Generic Vehicle Definitions for Class 8 Combination— Heavy-Haul Vehicle

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9
Mass (kg)	40,895	31,978	22,679	40,895	31,978	22,679	40,895	31,978	22,679
C_dA	6.1	5.4	4.7	6.1	5.4	4.7	6.1	5.4	4.7
Tire C_{rr} (kg/ton)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Tire Radius (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rotating Inertia (kg)	1,134	907	680	1,134	907	680	1,134	907	680
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5
Accessory Power (W)	1300	1300	1300	1300	1300	1300	1300	1300	1300
Axle ratio at engine speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	B	B	B	Maximum engine speed	Maximum engine speed	Maximum engine speed

The main outputs of this matrix of tests is grams of CO_2, the average transmission output shaft speed divided by the average vehicle speed and positive work measured at the output shaft of the powertrain. This matrix of test results will then be used to calculate the vehicle's CO_2 emissions in GEM taking the work per ton-mile from the GEM simulation and multiplying it by the interpolated work specific CO_2 mass emissions from the powertrain test.

3.6.3 Measurement Method and Results

The agencies are proposing to expand upon the test procedures defined 40 CFR 1037.550 for HD Phase 1. The Phase 2 proposed expansion will migrate the current Phase 1 test procedure to a new 40 CFR 1037.555 and will modify the current test procedure in 40 CFR 1037.550, allowing its use for Phase 2 only. The Phase 2 modifications to 40 CFR 1037.550 include the addition of the rotating inertia of the driveline and tires, the axle efficiency and the vehicle's accessory loads. This revised procedure also requires that each of the powertrain components be cooled so that the temperature of each of the components is kept in the normal operation range.

In addition to changing the vehicle model, we are proposing changes to the drive model so that it can compensate when the powertrain gets ahead or falls behind in the duty cycle. Use of this compensation algorithm will ensure that every powertrain drives the complete distance of the cycle, regardless of whether or not it can maintain the target speed of the cycle at a given moment in time.

Although detailed equations for the vehicle and driver models can be found in the proposed 40 CFR 1037.550, the agencies are recommending that manufactures use the MATLAB and Simulink models provided by the agencies. These models can be found at http://www.epa.gov/otaq/climate/gem.htm.

Conventional Powertrain Test Results

The agencies have performed internal test programs, contracted with outside labs, as well as collaborated with manufactures to test out the improvements to the powertrain test procedure. The data presented in Figure 3-10 is from a conventional powertrain that consisted of a Cummins ISX engine and Eaton 10 speed automated manual transmission that was tested in one of these test programs. This data summarizes the results from three different types of tests. The first set of data, labeled "Engine Only", was collected from engine tests where the speed and torque setpoints were determined by GEM. The simulations were done with 9 different vehicle configurations over the three duty cycles that are being proposed as certification duty cycles (55 mph with grade, 65 mph with grade and ARB transient cycle). The "GEM Model" data contains the CO_2 emissions as determined by GEM using the engine's fuel map and the transmission's gear ratios using with the default shift strategy. The x-axis defines the Powertrain test results. The data shows that across all three test cycles the powertrain test procedure produces 2.5 percent less CO_2 emission than the GEM simulation predicted. One must, however, take into account the fact that the GEM simulation was done using the engine steady-state fuel map; thus, the GEM results don't fully take into account the effect of transient fueling on CO_2 emissions. This is evident when looking at the data collected when operating over the transient test cycles (highest CO_2 g/ton-mile results). Here you see that the engine consumed greater than 3 percent more fuel than GEM predicted. When taking the transient test results into account, the powertrain performed 5 to 8 percent better than GEM predicted.

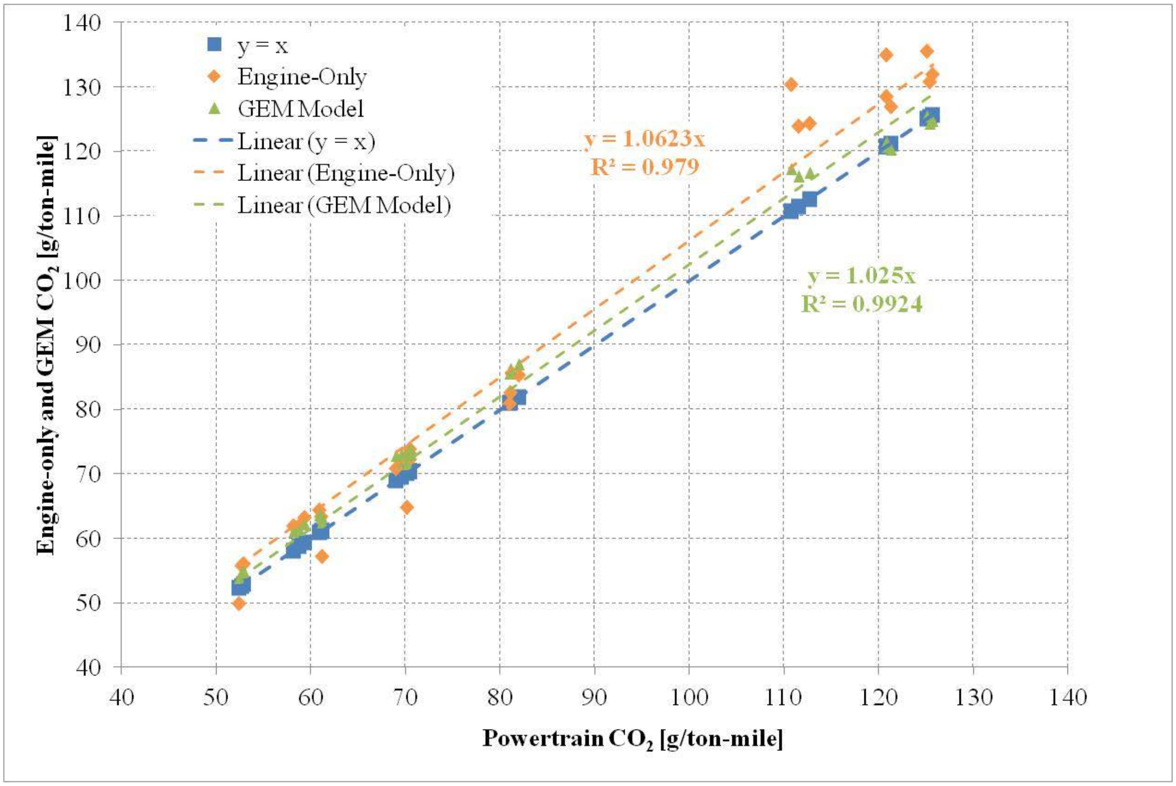

Figure 3-10 Engine only and GEM CO_2 results vs. powertrain.

3.6.4 Powertrain Family Definition

To complement the agencies powertrain procedures we are proposing criteria for defining a powertrain family. The specifics of these criteria can be found in 40 CFR 1037.231 but nominally a powertrain family is made up of one engine family and one transmission family.

3.6.4.1 Criteria for Powertrain Families

The proposed regulations in 40 CFR 1037.231 outline the criteria for grouping transmission models into powertrain families sharing similar emission characteristics. A few of these defining criteria include the transmission's architecture (manual, automatic, automated manual, dual-clutch and hybrid), number of gears in the front box, number of meshes in the back box and dry sump versus regular sump. In addition to the criteria for the transmission, all the engines in the powertrain family have to be from the same engine family.

3.6.4.2 Emissions Test Powertrain

We are proposing that manufacturers select at least one powertrain per powertrain family for emission testing. The methodology for selecting the test powertrain(s) should be consistent with 40 CFR 1037.231. The test powertrain(s) should consist of the engine and transmission combination that results in the highest CO_2 emissions.

3.6.5 Vehicle Certification with Powertrain Results in GEM

For manufactures that choose to use the powertrain method when certifying a vehicle, the powertrain results from the test will be input into GEM instead of the engine's fuel map, torque curve, motoring curve and the transmissions gear ratios. GEM will use the default powertrain inputs, as described in Table 3-33, and the inputs of the to-be certified vehicle to calculate the cycle work (*W*) of the powertrain and the ratio of rotational speed over the vehicle speed (*N*/*V*) as defined by the tire radius and rear-axle ratio.

Table 3-33 GEM Default Parameters for Vehicle Certification Using Powertrain Testing.

REGULATORY CLASS		ENGINE	TRANSMISSION	GEAR RATIOS
Class 8 Combination	Heavy-Haul	2017 MY 15L Engine with 600 HP	13 speed Automated Manual Transmission	12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73
	Sleeper Cab - High Roof	2017 MY 15L Engine with 455 HP	10 speed Automated Manual Transmission	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1, 0.73
	Sleeper Cab - Mid Roof			
	Sleeper Cab - Low Roof			
	Day Cab - High Roof			
	Day Cab - Mid Roof			
	Day Cab - Low Roof			
Class 7	Day Cab - High Roof	2017 MY 13L		

Combination	Day Cab - Mid Roof	Engine with 350 HP		
	Day Cab - Low Roof			
HHD Vocational	Regional Duty Cycle	2017 MY 15L Engine with 455 HP		
	Multi-Purpose Duty Cycle	2017 MY 11L Engine with 345 HP	5 speed HHD Automatic Transmission	4.6957, 2.213, 1.5291, 1, 0.7643
	Urban Duty Cycle			
MHD Vocational	Regional Duty Cycle	2017 MY 7L Engine with 270 HP	5 speed MLHD Automatic Transmission	3.102, 1.8107, 1.4063, 1, 0.7117
	Multi-Purpose Duty Cycle			
	Urban Duty Cycle			
LHD Vocational	Regional Duty Cycle	2017 MY 7L Engine with 200 HP		
	Multi-Purpose Duty Cycle			
	Urban Duty Cycle			

In GEM the cycle work from the powertrain testing will be corrected for the electrical and mechanical accessory power according to the following equation. The accessory power is defined for each vehicle category in Chapter 4 of this RIA.

$$W_{\text{powertrain corrected}} = W_{\text{test}} - P_{\text{acc}} \cdot t_{\text{test}} \cdot \frac{W_{\text{trans.out or wheel hub}(+)}}{W_{\text{engine}(+)}}$$

GEM will use the calculated cycle work and *N*/*V* of the powertrain for the to-be certified vehicle to interpolate the powertrain input table. For vehicle configurations that have cycle work or *N*/*V* outside of the powertrain input table, we are proposing that the closest end points of the table be used instead of extrapolating. GEM will then use the following equation to calculate the CO_2 g/ton-mile result per cycle before any technology inputs are applied. Finally the technology inputs are applied, all the cycles are weighted and the gallons of fuel are then calculated from the mass of CO_2.

$$e_{CO_2} = e\left[\frac{g_{\text{fuel}}}{kWh}\right]_{\text{interpolated}} \cdot W_{\text{GEM}} \cdot \frac{1}{miles_{\text{GEM}} \cdot payload} \cdot \frac{m_{\text{CO}_2}}{m_{\text{fuel}}}$$

3.7 Hybrid Powertrain Test Procedures

As discussed in Section V of the preamble, the agencies see an opportunity to help drive the technology's advancement by predicating the vocational vehicle standards on a small adoption rate of hybrid powertrains in this rulemaking. However, since the projected effectiveness of this technology over the proposed Urban vocational duty cycle is 25 percent, the agencies believe it is no longer appropriate to provide a 1.5 multiplier for credits generated by vehicles applying this technology. EPA and NHTSA are proposing two methods to demonstrate benefits of a hybrid powertrain – chassis and engine testing.

3.7.1 Measurement Method and Results

The agencies are proposing that hybrid powertrains be tested just like conventional powertrains, with the dynamometer connected at either the input shaft of the rear axle or the input shaft to the wheels, using the powertrain method described in Section 3.6 with some additional requirements for the rechargeable energy storage systems (RESS) net energy change (NEC) over the test.

As in the Phase 1 rule, the agencies are proposing that hybrids will be tested under charge sustain operation so that all the energy to drive the cycle comes from the on board hybrid powertrain. The NEC of the RESS must meet the requirements of SAE J2711 for each test.

3.7.2 Engine Hybrid Method

To address hybrid powertrain system performance for hybrids that recover energy between the engine and transmission, the agencies are proposing to retain the engine hybrid procedures defined in 40 CFR 1036.525. The control volume for these hybrids is drawn so as to include the battery, battery support and control systems, power electronics, the engine, motor generator and hybrid control module. The performance of this system is an engine based evaluation in which emission rates are determined on a brake-specific work basis. As such, the duty cycles being proposed to assess this system performance are engine speed and torque command cycles that are similar but not identical to the cycles used for criteria pollutant standards. In addition to the cycles being slightly different between the test for GHG emissions and the test for criteria emissions, the system boundary of the engine for the criteria emission test will remain unchanged and will not include the hybrid components. It is expected that, parallel engine hybrids would be the most likely choice for engine-based hybrid certification. Details related to engine hybrid test procedures may be found in 40 CFR 1036.525.

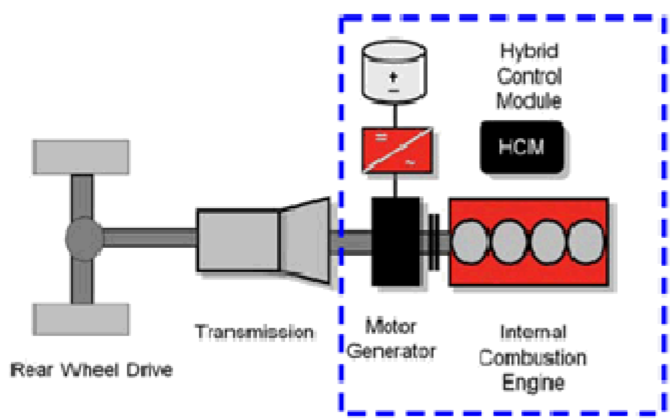

Figure 3-11 Engine Hybrid Test Configuration

3.7.3 Removal of the Chassis Test Option for Hybrids

In the Phase 1 rule the agencies finalized a powertrain and chassis test option for hybrid testing. The agencies are proposing to remove the chassis test option for the Phase 2 program because it appears to be incompatible with the proposed changes regarding use of results from the hybrid test procedure. In the proposed procedure, the output of the hybrid test is brake specific CO_2 emission where the positive work is measured at the output shaft of the hybrid powertrain. Since work cannot be measured at this location on a chassis dynamometer without modifying the vehicle, the agencies are proposing the removal of the chassis testing option. Another reason for the removal of the chassis test option is that there are a number of additional sources of variability when testing a vehicle on a chassis dynamometer. These include electrical and mechanical accessory load, tire temperature and driver variability to name a few.

3.7.4 Electrified PTO Test Method

A power take off (PTO) is a system on a vehicle that allows energy to be drawn from the vehicle's drive system and used to power an attachment or a separate machine. Typically in a heavy-duty truck, a shaft runs from the transmission of the truck and operates a hydraulic pump. The operator of the truck can select to engage the PTO shaft in order for it to do work, or disengage the PTO shaft when the PTO is not required to do work. The pressure and flow from this hydraulic fluid can be used to do work in implements attached to the truck. Common examples of this are utility trucks that have a lift boom on them, refuse trucks that pick up and compact trash, and cement trucks that have a rotating barrel. In each case the auxiliary implement is typically powered by a PTO that uses energy from the truck's primary drive engine.

In most PTO equipped trucks, it is necessary to run the primary drive engine at all times when the PTO might be needed. This is an unoptimized configuration. Typical PTO systems require no more than 19 kW at any time, which is far below the optimal operation range of the primary drive engine of most trucks. Furthermore, in intermittent operations, the primary drive engine is kept running at all times in order to ensure that the PTO can operate instantaneously. This results in excess GHG emissions and fuel consumption due to idle time. Additionally, idling a truck engine for prolonged periods of time while operating auxiliary equipment like a PTO could cause the engine to cycle into a higher idle speed, wasting even more fuel.

Hybridization and changing the operation of a conventional PTO equipped truck are two viable means to lower the GHG emissions and fuel consumption in the real world. The proposed test procedures will allow for manufactures to quantify the reduction of CO_2 emissions and fuel consumption from electrified PTO systems.

In Phase 1, hybrid PTO testing was performed either via chassis or powertrain testing of both the conventional and hybrid systems over the PTO duty cycles described in Appendix II of 40 CFR 1037, in addition to the vehicle duty cycles. An improvement factor was then generated as described in 40 CFR 1037.615 and applied to the g/ton-mile CO_2 emission rate resulting from the GEM output for the advanced vehicle as described in 40 CFR 1037.520.

EPA and NHTSA are proposing to continue the Phase 1 testing methodology outlined in 40 CFR 1037.525 where A to B testing is used to generate an improvement factor either via powertrain or chassis testing. The one change that the agencies are proposing for Phase 2 is how the results are used to calculate the vehicle's emission result. For Phase 2, the agencies are proposing that the reduction in emissions from the electrified PTO system versus the conventional PTO system be subtracted from the composite driving emissions result. Specifics on the applicability of electrified PTOs is discussed further in Chapter V. C of the preamble.

3.8 Rear Axle Efficiency Test

In Phase 2, the agencies developed test procedures to measure axle efficiency. See 40 CFR 1037.515. This procedure ultimately provides for the determination of torque loss versus input speed and input torque for use in the GEM simulation tool. The procedure provides limitations on axle break in procedures and prescribes dynamometer set ups for axles with and without lockable differentials as well as drive-through axles. This procedure puts limitations on the test cell ambient temperature, sump oil temperature, and requires the use of representative commercially available axle lubricating oil. The mapping process requires that you map the axle by testing with an input torque in the range of 0 to 4000 Nm in 1000 Nm steps at wheel speeds that range from 50 rpm to the maximum wheel speed in 50 rpm steps. The procedure sweeps though the torque points at a given wheel speed from the minimum to the maximum torque point and back, with the process repeated twice for a given wheel speed. The four values generated at each speed and torque point are then averaged resulting in one map point per wheel and output torque value.

3.9 HD Pickup Truck and Van Chassis Test Procedure

The agencies are proposing that HD pickup trucks and vans continue to demonstrate compliance using the 40 CFR part 1066 chassis test procedures. For each test vehicle from a family required to comply with the GHG and fuel consumption requirements, the manufacturer would supply representative road load forces for the vehicle at speeds between 15 km/hr (9.3 mph) and 115 km/hr (71.5 mph). The road load force would represent vehicle operation on a smooth level road, during calm winds, with no precipitation, at an ambient temperature of 20 °C (68 °F), and atmospheric pressure of 98.21 kPa. Road load force for speeds below 9.3 mph may be extrapolated.

The dynamometer's power absorption would be set for each vehicle's emission test sequence such that the force imposed during dynamometer operation matches actual road load force at all speeds. Required test dynamometer inertia weight class selections are determined by the test vehicle test weight basis using adjusted loaded vehicle weight from which the corresponding equivalent test weight is determined.

3.9.1 LHD FTP and HWFE Testing

The FTP dynamometer schedule consists of two tests, a "cold" start UDDS test after a minimum 12-hour and a maximum 36-hour soak according to the provisions of 40 CFR 1066.801, 1066.815, and 1066.816, and a "hot" start test following the "cold" start after a 10 minute soak. Engine startup (with all accessories turned off), operation over the UDDS, and engine shutdown constitutes a complete cold start test. Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test. The driving schedule for

EPA's Urban Dynamometer Driving Schedule is contained in Appendix I of 40 CFR part 86. The driving schedule is defined by a smooth trace drawn through the specified speed versus time relationship. The schedule consists of a distinct non-repetitive series of idle, acceleration, cruise, and deceleration modes of various time sequences and rates.

The Highway Fuel Economy Dynamometer Procedure (HFET) consists of preconditioning highway driving sequence and a measured highway driving sequence. The HFET is designated to simulate non-metropolitan driving with an average speed of 48.6 mph and a maximum speed of 60 mph. The cycle is 10.2 miles long with 0.2 stops per mile and consists of warmed-up vehicle operation on a chassis dynamometer through a specified driving cycle. The Highway Fuel Economy Driving Schedule is set forth in Appendix I of 40 CFR Part 600, while the test is carried out according to 40 CFR 1066.840. The driving schedule is defined by a smooth trace drawn through the specified speed versus time relationships.

Practice runs over the prescribed driving schedules may be performed, provided an emission sample is not taken, for the purpose of finding the appropriate throttle action to maintain the proper speed-time relationship, or to permit sampling system adjustment. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided. The driver should attempt to follow the target schedule as closely as possible. The speed tolerance at any given time on the dynamometer driving schedules specified in Appendix I of parts 86 and 600 is defined by upper and lower limits in 40 CFR 1066.425. The upper limit is 2 mph higher than the highest point on trace within 1 second of the given time. The lower limit is 2 mph lower than the lowest point on the trace within 1 second of the given time. Speed variations greater than the tolerances (such as may occur during gear changes) are acceptable provided they occur for less than 2 seconds on any occasion. Speeds lower than those prescribed are acceptable provided the vehicle is operated at maximum available power during such occurrences.

3.9.2 LHD FTP and HWFE Hybrid Testing

Since LHD chassis certified vehicles share test schedules and test equipment with much of Light-Duty Vehicle testing, EPA believes it is appropriate to continue to use the HD Phase 1 test procedure which references SAE J1711 "Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles" instead of SAE J2711 "Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles".

3.9.2.1 Charge Depleting Operation – FTP or "City" Test and HFET or "Highway" Test

EPA would like comment on incorporating by reference SAE J1711 Chapters 3 and 4, as published June 2010, testing procedures for Light-Heavy-Duty chassis certified vehicles with the following exceptions and clarifications:

Test cycles will continue, until the end of the phase of the test cycle, in which charge sustain operation is confirmed. Charge sustain operation is confirmed when one or more phases or cycles satisfy the Net Energy Change requirements below. Optionally, a manufacturer may terminate charge deplete testing before charge sustain operation is confirmed provided that the Rechargeable Energy Storage System (RESS) has a higher State of Charge (SOC) at charge deplete testing termination than in charge sustain operation. In the case of Plug-In Hybrid Electric Vehicles (PHEV) with an all-electric range, engine start time will be recorded but the test does not necessarily terminate with engine start. PHEVs with all electric operation follow the same test termination criteria as blended mode PHEVs. Testing can only be terminated at the end of a test cycle. The regulation allows EPA to approve alternate end of test criteria as described in 40 CFR 1066.501.

For the purposes of charge depleting CO_2 and fuel efficiency testing, manufacturers may elect to report one measurement per phase (one bag per UDDS). Exhaust emissions need not be reported or measured in the phases of the test the engine does not operate.

End of test recharging procedure is intended to return the RESS to a full charge equivalent to pretest conditions. The recharge AC watt hours must be recorded throughout the charge time and soak time. Vehicle soak conditions must not be violated. The AC watt hours must include the charger efficiency. The measured AC watt hours are intended to reflect all applicable electricity consumption including charger losses, battery and vehicle conditioning during the recharge and soak, and the electricity consumption during the duty cycles.

Net Energy Change Tolerance (NEC), is to be applied to the RESS to confirm charge sustaining operation. The agencies are proposing to continue to use the 1 percent of fuel energy NEC state of charge criteria as expressed in SAE J1711 and described in 40 CFR 1066.501. The Administrator may approve alternate NEC tolerances and state of charge correction factors.

3.9.2.2 Hybrid Charge Sustaining Operation – FTP or “City” Test and HFET or “Highway” Test

The agencies are proposing to continue incorporating by reference SAE J1711 Chapters 3 and 4 for definitions and test procedures, respectively, where appropriate, with the following exceptions and clarifications.

The agencies are adopting the 1 percent of fuel energy NEC state of charge criteria as expressed in SAE J1711 and described in 40 CFR 1066.501. The Administrator may approve alternate NEC tolerances and state of charge correction factors.

Preconditioning special procedures are optional for traditional “warm” test cycles that are now required to test starting at full RESS charge due to charge depleting range testing. If the vehicle is equipped with a charge sustain switch, the preconditioning cycle may be conducted per 40 CFR 600.111 provided that the RESS is not charged. Exhaust emissions are not taken in preconditioning drives. Alternate vehicle warm up strategies may be approved by the Administrator.

State of Charge tolerance correction factors may be approved by the Administrator as described in 40 CFR 1066.501. RESS state of charge tolerances beyond the 1 percent of fuel energy may be approved by the Administrator.

The agencies are seeking comment on modifying the minimum and maximum allowable test vehicle accumulated mileage for both EVs and PHEVs. Due to the nature of PHEV and EV operation, testing may require many more vehicle miles than conventional vehicles. Furthermore, EVs and PHEVs either do not have engines or may use the engine for only a fraction of the miles driven.

Electric Vehicles and PHEVs are to be recharged using the supplied manufacturer method provided that the methods are available to consumers. This method could include the electricity service requirements such as service amperage, voltage, and phase. Manufacturers may employ the use of voltage regulators in order to reduce test to test variability with prior Administrator approval.

3.10 Alternative Certification Approach

3.10.1 Purpose and Scope

Under the Phase 1 rule, vocational vehicles and tractors are certified by using GEM with the default engine fuel map pre-defined by the agency, while the engine is certified by either using the SET cycle for tractor engines or the FTP cycle for vocational engines, which are totally different from vehicle drive cycles.

In this section, a new concept as an alternative to the engine fuel mapping test, proposed in Phase 2 is explored. This approach would allow use of the same drive cycles for both the vehicle and engine compliance process, without the need for engine manufacturer providing the steady state engine fuel map for vehicle certification. Therefore, this approach has the potential to totally integrate vehicle and engine certification, while more accurately quantifying the transient engine operation than is possible using a traditional steady state engine fuel map.

The potential approach discussed here would be an alternative to certifying vocational vehicles, tractors, and their engines using a steady-state fuel map. The agencies solicit comment on this alternative, and commenters should include their thoughts on whether this concept can be adequately fleshed out in the time remaining in this rulemaking.

3.10.1.1 Phase 1 Certification Approach

In order to help to understand the vocational vehicle and tractor vehicle certification process under the Phase 1 rule, Figure 3-12 summarizes the GEM-based certification process flow.

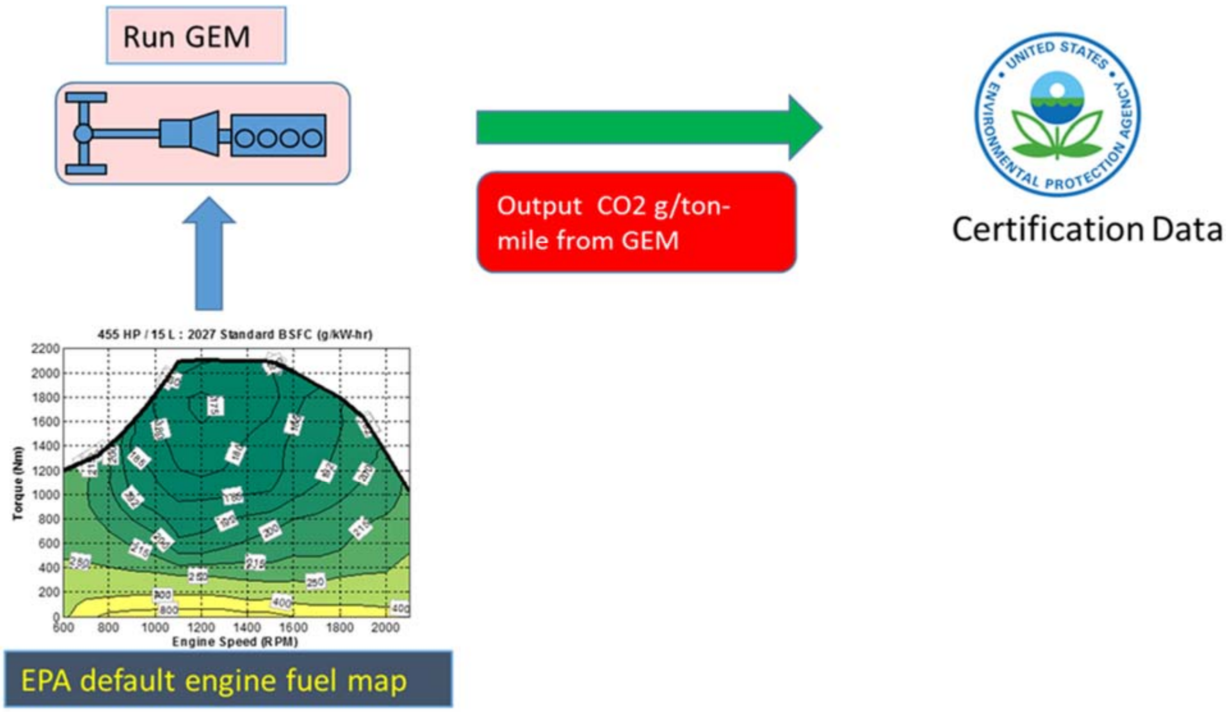

Figure 3-12 Phase 1 Rule for Certification Using GEM

In this approach, vehicle manufacturers can only use up to five input parameters – aero dynamic coefficient, rolling resistance, weight reduction, speed limiter, and idle reduction, to conduct vehicle certifications (although improvements not recognized by GEM can be certified as off-cycle credits under the Phase 1 rules). All other vehicle and engine parameters are the default parameters specified by the agencies.

Figure 3-12 shows that use of the agencies' default engine fuel maps under the Phase 1 rules. This default engine fuel map approach would not be able to recognize the benefits of advanced engine technologies packages. The three drive cycles shown in Figure 3-12used in Phase 1 are 55 mph and 65 mph cruise speed cycles, and ARB transient cycles. In the two cruise speed cycles, there is no road grade, meaning that the vehicle operates with one single operating point inside engine fuel maps, which does not represent the real-life driving condition on the road. On the other hand, engine certifications use completely different cycles. For example, tractor engines use the SET cycle, while vocational engines use the FTP cycle. Those engine cycles have very little connection with how the engine operates in a vehicle over Phase 1 vehicle drive cycles. This means whatever the optimized engine calibration developed for the FTP and SET cycles cell may not be able to be realized in the real-life driving condition on the road. Furthermore, there is no direct linkage between GHG emissions and criteria emissions, since vehicle and engine certification cycles are different.

3.10.1.2 Primary Certification Approach in Phase 2

In order to overcome the deficiencies mentioned in the above section, the agencies are proposing significant improvements and enhancements as part of the Phase 2 proposal. Many of the Phase 1 predefined parameters used in GEM now become the vehicle-specific user-entered inputs in Phase 2. Most significantly, vehicle manufacturers can use engine fuel maps representing the actual engine in the vehicle for certification, which means that it can recognize the benefits due to advanced technologies developed for the engines. Chapter 4 of this draft RIA details the enhancements of GEM and the extensive validations of these proposed changes. Another significant proposed enhancement is the addition of the road grade into 55 mph and 65 mph cruise speed cycles, which represents more realistic driving conditions. In addition, the agencies propose reweighting on the SET cycles with more emphasis on A and B speed modes. The more detailed description on addition of the SET and road grade weighting can be seen in Section II.D(1) and Section III.C of the preamble, respectively.

Even with these improvements, however, certain issues would not be directly addressed. First of all, there would still be no direct linkage between GHG emissions and criteria pollutant emissions, since vehicle and engine certification cycles would still be different. Second, the engine fuel maps used in GEM from individual vehicle manufacturers are still obtained under steady state conditions. The transient behaviors due to smoke control and thermal management control, for example, would not be able to be modeled using steady state engine fuel maps. Third, the agencies' primary certification approach introduces a new concern from independent engine manufacturers, namely concern regarding proprietary technology information that can be found from engine fuel maps.

3.10.2 Description of Alternative Certification Concept

In view of these concerns mentioned above two sections for both Phase 1 and Phase 2, the agencies would like to specifically ask for comments on this alternative approach to Phase 2 certification to address these concerns. This section will introduce the concept and principal of this alternative approach.

3.10.2.1 Vehicle Certification

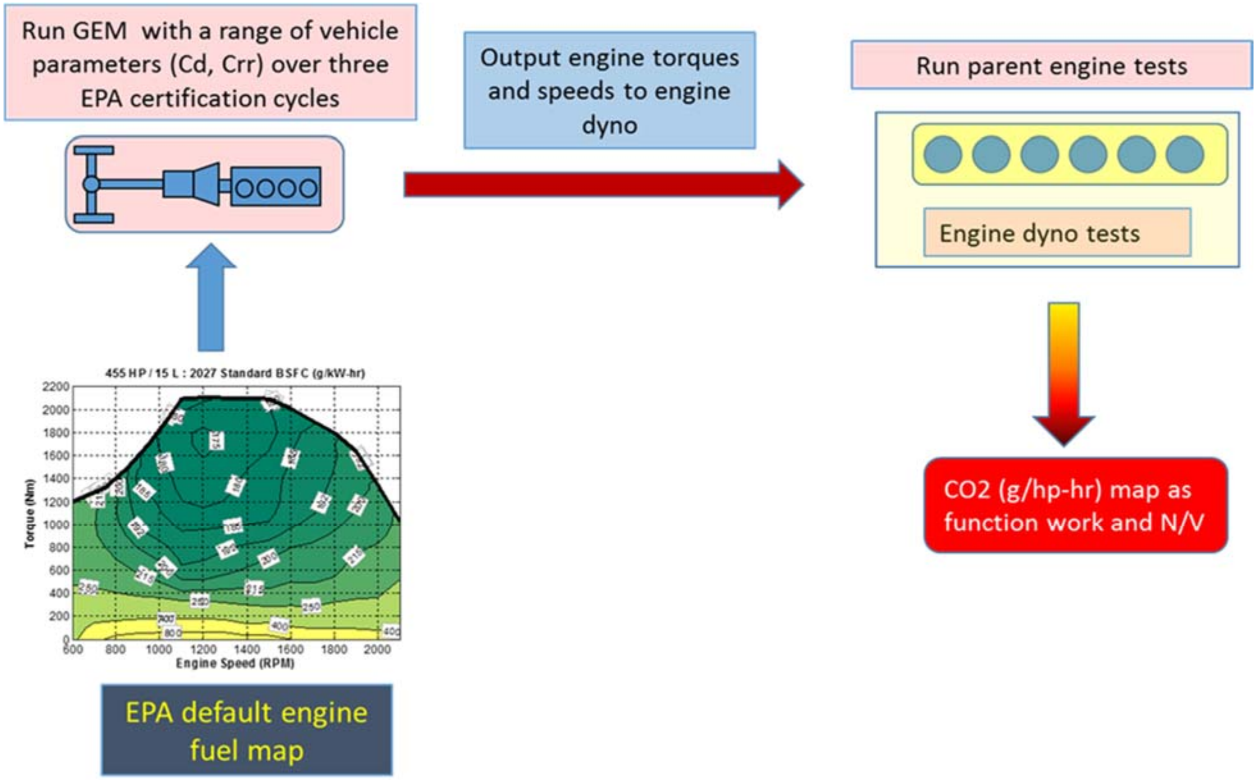

Figure 3-13 Alternative Phase 2 Certification Option II

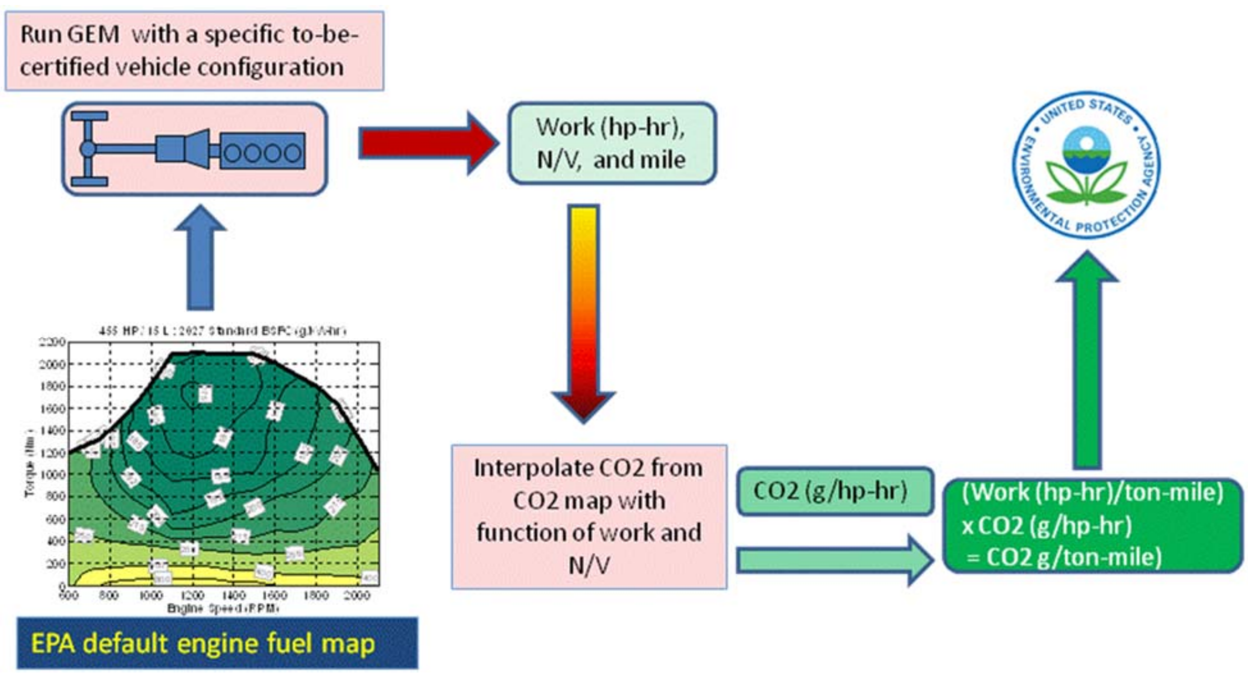

Figure 3-14 Phase 2 Certification Process with Option II

Displayed in Figure 3-13 and Figure 3-14 is the potential alternative vehicle certification approach. The entire process can be further simplified and described as follows.

1. Define nine vehicles that will cover the range of vehicles that the engine will be certified in. In one dimension the vehicles will cover the range of engine cycle work (W) by varying the vehicles mass, C_dA and C_{rr}. The other dimension would cover the range of average engine speed over average vehicle speed (N/V), by varying the vehicles tire size and rear axle ratio or transmission (see the left part of Figure 3-13).
2. Run GEM with the nine vehicle configurations and the three certification cycles to generate 27 engine cycles (three certification cycles multiplied by nine vehicles). Each cycle will define engine speed and torque as a function of time. These cycles will be generated at 10hz to capture engine torque during shifting (see the right part of Figure 3-13).
3. Test the parent engine of the engine family using the 27 engines cycles to create a matrix of brake specific CO_2 consumption in g/hp-hr as a function of Work in hp-hr and N/V in rpm/(mile/hr).
4. For certification, run GEM for each vehicle that will be certified with an engine from the engine family. For each simulation the actual vehicle parameters shall be used. The output of the simulation will be work in hp-hr and N/V in rpm/(mile/hr) for each drive cycle (See the left part of Figure 3-14).
5. Use work and N/V obtained from Step 4 to interpolate CO_2 in g/hp-hr for the engine in the specific vehicle being certified (see the middle part of Figure 3-14.
6. Multiply the interpolated CO_2 in g/hp-hr by work in (hp-hr) from the simulation of the certified vehicle (Step 4) and divide by the ton-miles of each vehicle category and drive cycle (see the right part of Figure 3-14).
7. Supply this final CO_2 in g/ton-mile for certification.

3.10.2.2 Engine Certification

One of the key features for the alternative vehicle certification approach is that supplementation of the engine tests requires running a number of tests at a certified engine dyno. These tests will result in a fuel consumption or CO_2 map in g/kw-hr as function of cycle work and N/V over three certification cycles. Therefore, the engine certification point could be selected from one of the testing points through this fuel consumption or CO_2 map, and therefore there is no need to run engine certification test alone, thus reducing engine test burden from manufacturers as far as GHG emission certification is concerned. How this single point is to be selected is something we need to work out in the near future.

3.10.3 Discussion of Alternative Certification Approach

The previous section only describes the principles of this alternative approach. This section will provide more detailed supporting information, addressing the following questions:

- Would the fuel consumption or CO_2 maps be very well behaved, so that the interpolation or curve fitting can be carried out without losing accuracy?
- Would one map that combines all three certification cycles be adequate to represent the engine or would an individual map for each cycle be needed?
- What would be the most suitable independent axis of the fuel consumption maps to be used to minimize the impact of type of transmissions and their shifting strategies?
- What is the minimum number of engine tests and GEM simulations required to cover the range of vehicles certified for a given engine family?

In order to answer the above questions, a test matrix based on a Class 8 Kenworth T700 tractor with a Cummins ISX engine was carefully designed as follows:

- 32 variations of the Kenworth T700
  - Axel ratio: 2.64, 3.36,3.9 and 4.56
  - C_d: 0.35, 0.45, 0.55, 0.65, and 0.75
  - C_{rr}: 0.005, 0.006, 0.007 and 0.008
- Cycles – with distance correction
  - 55 w/SwRI grade profile
  - 65mph w/SwRI grade profile
  - ARB Transient
- Transmissions – Eaton AMT
  - 10 speed: F016E310C-LAS
  - 13 speed: FO_16E313A_MHP
  - 18 speed: FO-16E318B-MXP
- Transmission shift strategy
  - Eaton's table shift
  - EPA's shift optimizer

In addition, a child rating engine is selected to show its impacts on the accuracy of this approach. This results in a total of 1,152 simulation runs.

3.10.4 GEM Simulations

Phase 2 GEM (as proposed) was used by EPA to perform a large scale of simulations based on the matrix proposed above. The results and plots are arranged as follows. Figure 3-15 to Figure 3-17 display the BSFC (g/hp-hr) surface plots over 55mph, 65mph, and ARB cycles with all points simulated. The next section discusses the evaluation of the results with the engine child ratings.

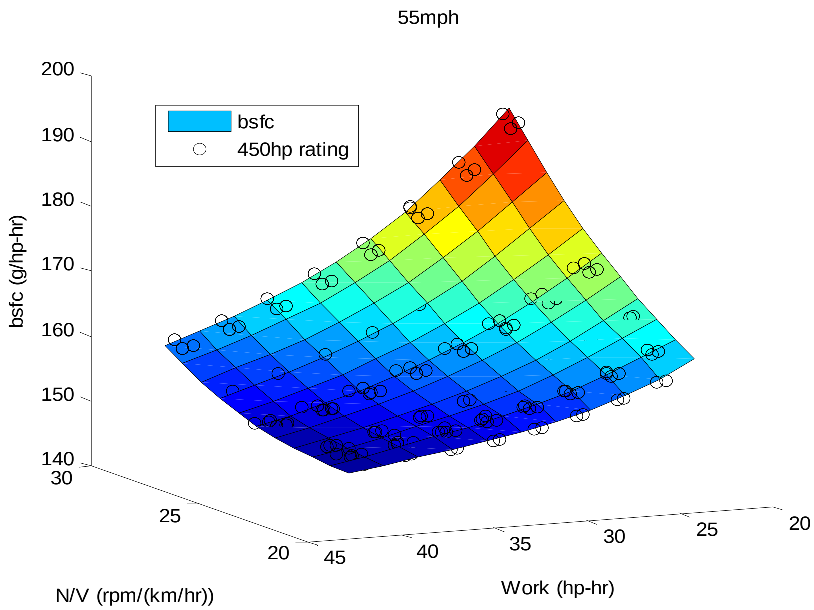

Figure 3-15 Contour plot of CO_2 as function of cycle work and N/V for 55 mph cycle

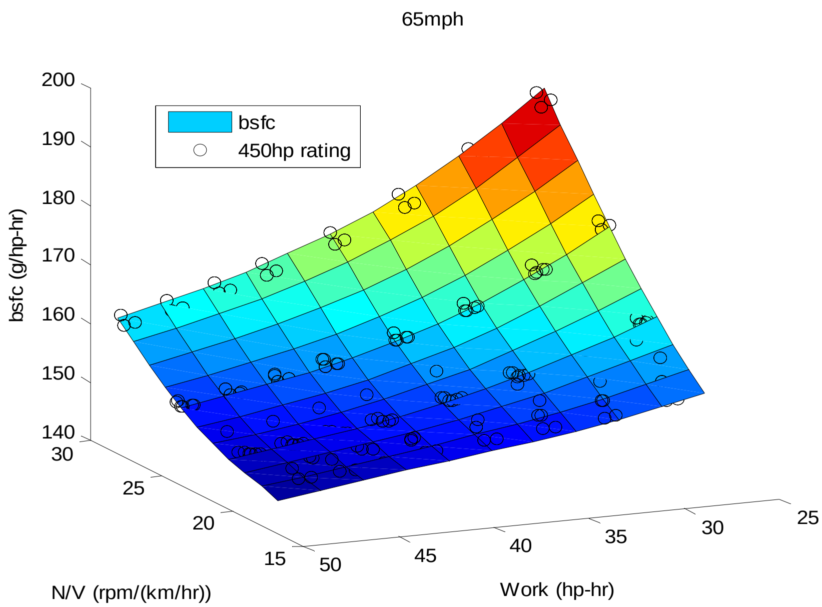

Figure 3-16 Contour plot of CO_2 as function of cycle work and N/V for 65 mph cycle

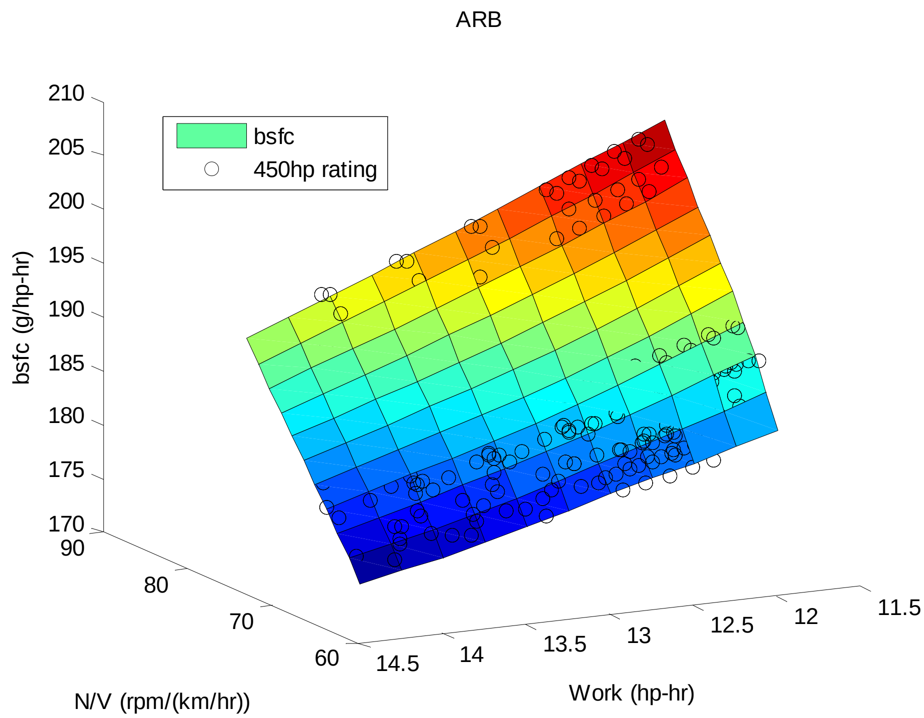

Figure 3-17 Contour plot of CO_2 as function of cycle work and N/V for ABB cycle

As can be seen from these three figures (Figure 3-15 to Figure 3-17), a surface is used to curve fit all points. Also shown in these figures is how well the actual points are fitted with the surface. It is seen from Figure 3-15 and Figure 3-17 that all test cycles are collapsed into one surface with different transmissions, different shifting strategies, and axles. The behavior that all simulation points are very well fitted into one surface plane suggests that impact of transmissions including shifting strategies and numbers of gears, axle ratio be minimal if the plots are designed in such a way that average engine speed (*N*) over average vehicle speed (*V*) defined as *N*/*V* is selected.

Figure 3-18 shows the three-dimensional surface plot of BSFC as function of cycle work and *N*/*V* with all cycles combined into one plot. It can be seen that all points are not very well fitted into one surface plot, suggesting that certification be done in an individual cycle manner.

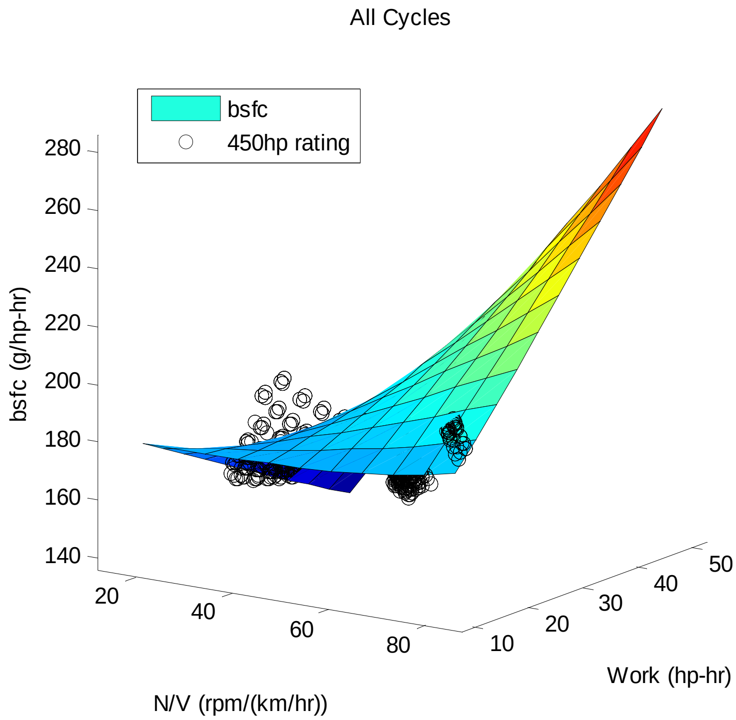

Figure 3-18 Surface plot of CO_2 as function of cycle work and N/V for all three cycles

The simulations are then carried out in order to address child rating impact on this surface fit with each cycle. Figure 3-19 to Figure 3-21 show the behavior of all three individual cycles. It can be seen that all parent and child rating points are still collapsed into one surface plot, which is very similar to the results where only parent ratings are shown in Figure 3-16 to Figure 3-18, suggesting that the same interpolation schemes or the same surface fitting could be applied to both parent and child ratings for those points that are located between the testing points.

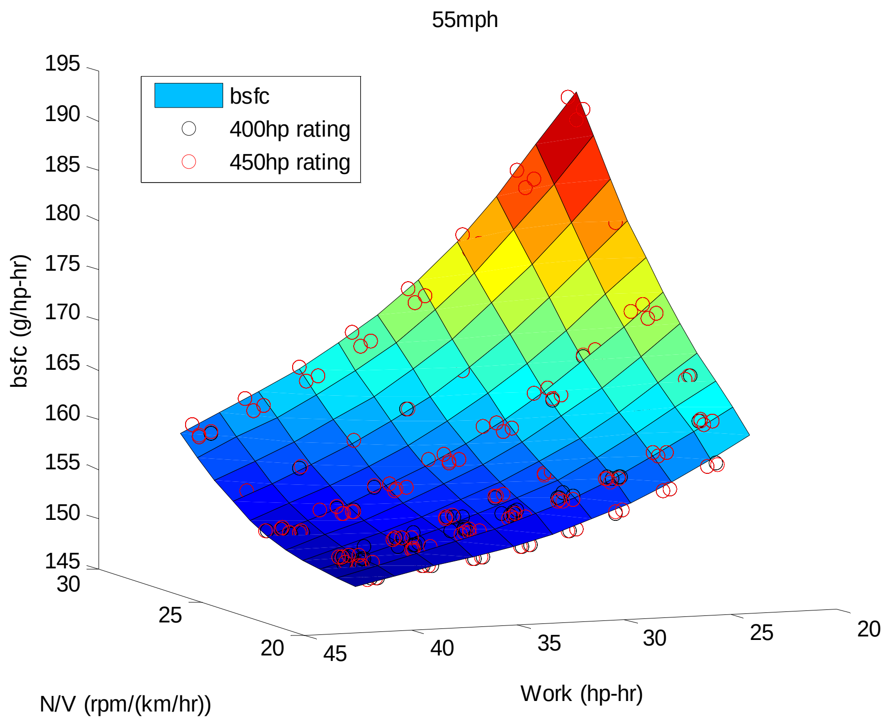

Figure 3-19 Surface plot of CO_2 with child rating engine for 55mph cycle

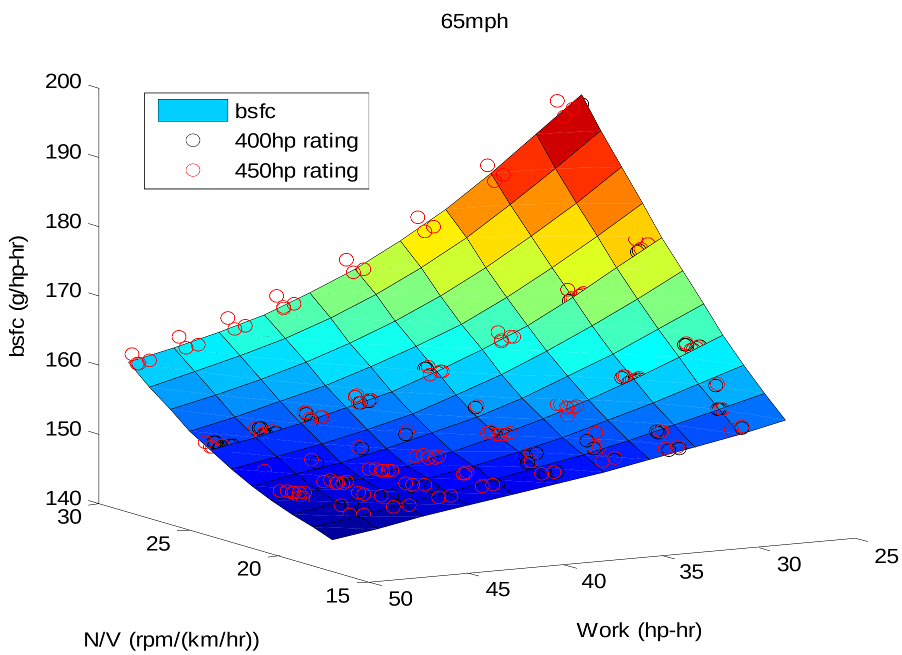

Figure 3-20 Surface plot of CO_2 with child rating engine N/V for 65 mph cycle

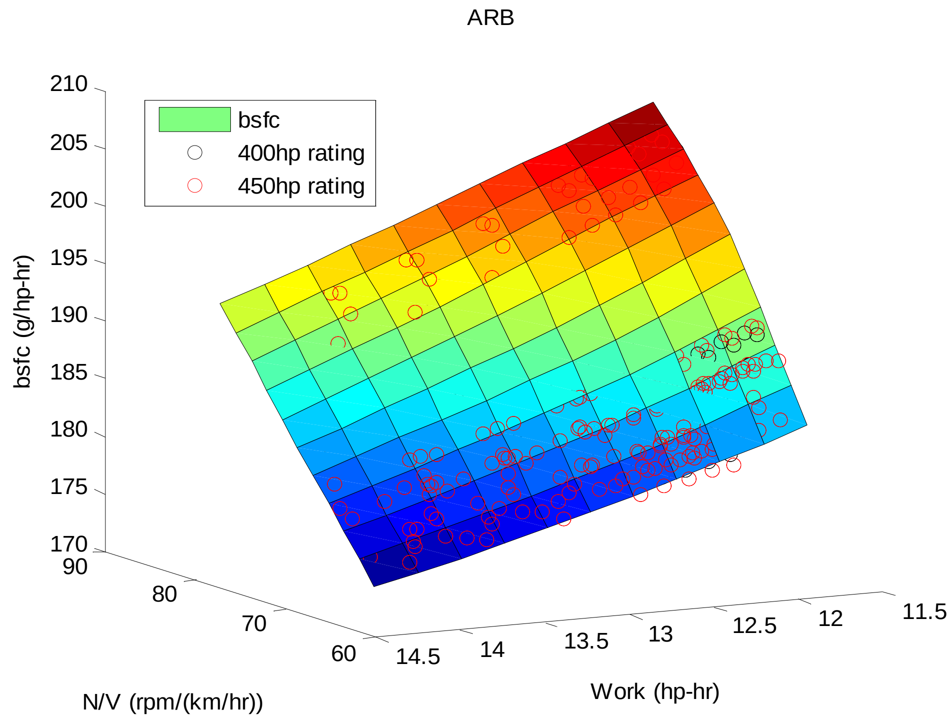

Figure 3-21 Surface plot of CO_2 with child rating engine for ABB cycle

Figure 3-19 to Figure 3-21 demonstrate the well behaving nature of CO_2 surface as a function of work and N/V as long as the surface fitting is conducted in an individual cycle, showing the potential to use surface fitting or interpolation scheme to determine the point resulted from the actual vehicle certification. However, please note that the entire simulations consist of over one thousand points, and it would be impossible to run all engine tests in order to generate a CO_2 map for use in certification. Efforts must be made to greatly simplify the process by reducing the points to a minimum level, which can still very well represent a to-be-certified vehicle. After numerous trials, it is found that a minimum 9 points per cycle is needed, which covers three final drive ratios and three vehicle loads or work. Displayed in Figure 3-22 to Figure 3-24 are the same plots as Figure 3-19 to Figure 3-21, but the numbers of points are reduced to 9 points per cycle.

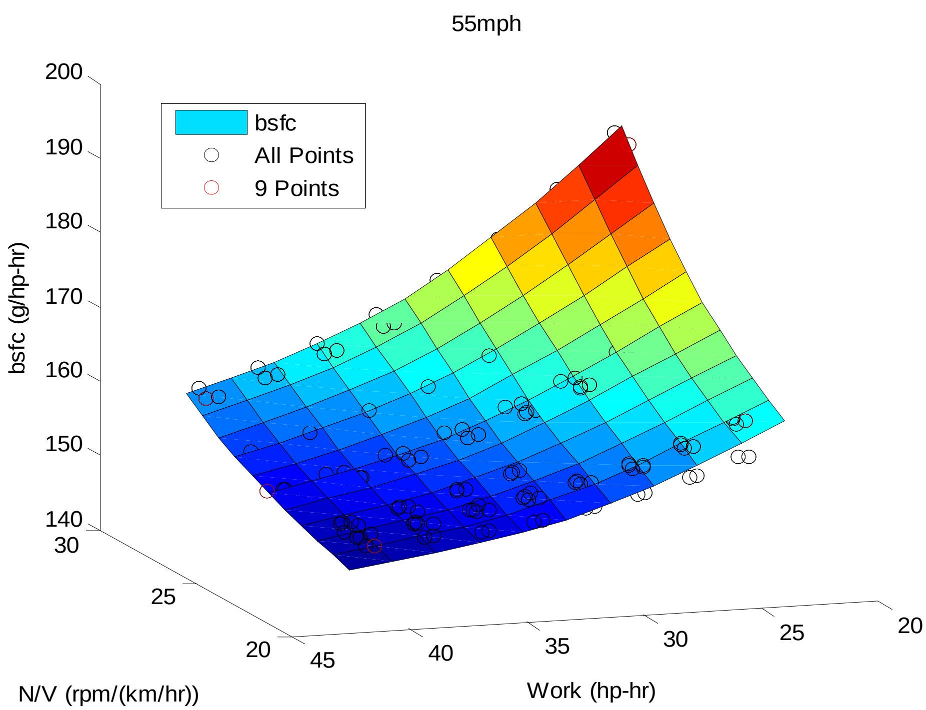

Figure 3-22 Contour plot of CO_2 with only 9 points for 55mph cycle

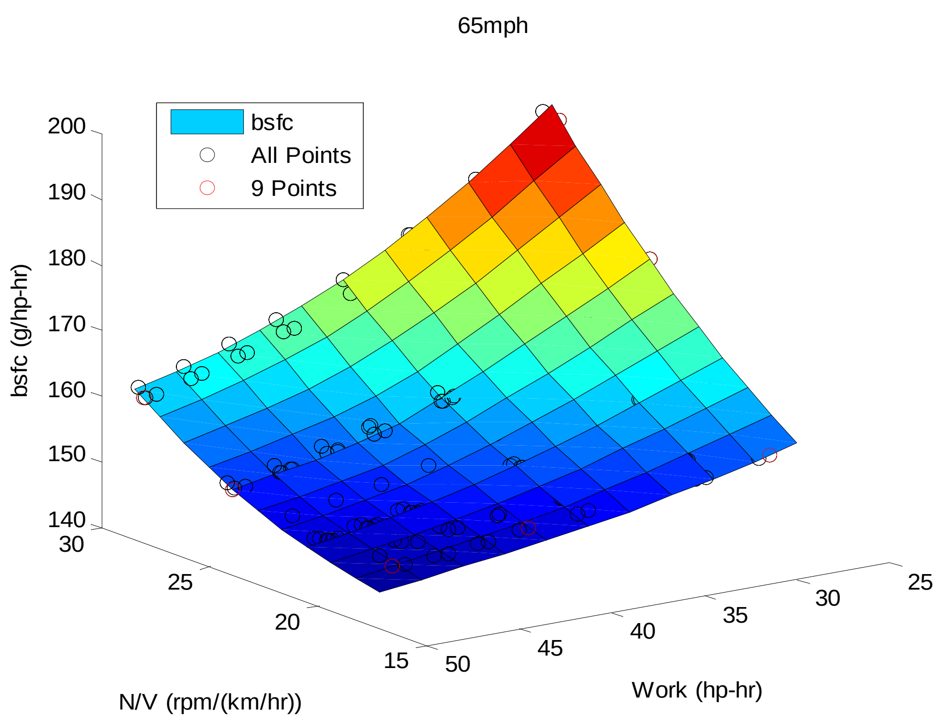

Figure 3-23 Contour plot of CO_2 with only 9 points N/V for 65 mph cycle

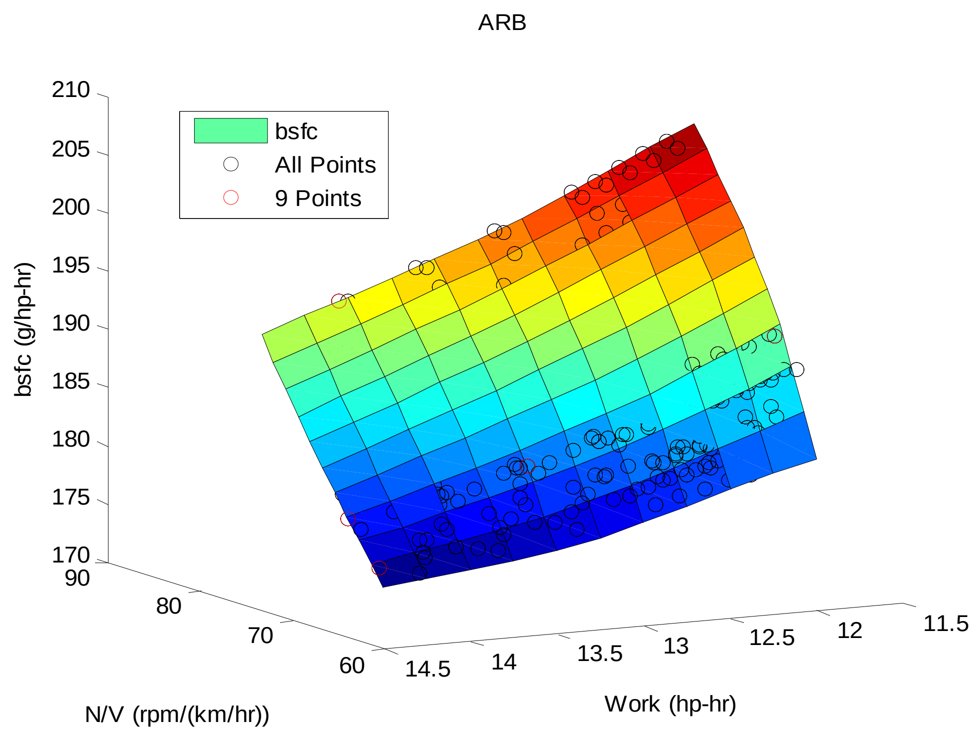

Figure 3-24 Contour plot of CO_2 with only 9 points for ABB cycle

Comparing Figure 3-19 to Figure 3-21, very similar behaviors for all three cycles are observed, and therefore, it can be said that 9 points would be acceptable at least for the engines and vehicles that are under consideration.

3.10.5 Generic Vehicle Definition

Chapter 3.10.4 shows that nine vehicle configurations for each certification cycle could be used to cover the range of the vehicles to be certified. However, it is not clear how those vehicle configurations can be defined in a generic way. This section attempts to achieve this objective.

To cover the range of vehicle configuration that the engine could be sold in the agencies are considering the vehicle configuration defined in Table 3-30 to Table 3-32. To cover the range of axles, the axle ratios would be calculated from the regulatory defined engines speeds and the maximum duty cycle speed of 65 mph. With the engine speed, tire radius, top gear ratio and vehicle speed, the axle ratio can be calculated. To cover the range of engine work the agencies are proposing a range of drag area (C_dA), coefficients of rolling resistance (C_{rr}) and vehicle masses. For Class 8 vehicles the highest mass and highest C_dA be on the same vehicle and that both C_dA and vehicle mass drop together for the lower average power vehicles. The reason for this is that, the cruise cycle's average power is most affected by the vehicle's C_dA, where mass has the largest effect on average power on the transient cycle. For Class 2b-7 vehicles mass and C_{rr} are varied to change the average power over the cycle. For these vehicles C_{rr} is varied instead of C_dA because C_dA is not an input into GEM for vocational vehicles.

In addition to defining the vehicle parameters the agencies are proposing that the transmissions be defined for each vehicle configuration. Table 3-34 defines the transmission type and gear ratios for each of these vehicles.

Table 3-34 Default Transmissions

GEAR NUMBER	TRANSMISSION TYPE AND GEAR RATIOS		
	10 speed AMT	6 speed HH AT	6 speed MH AT
1	12.8	4.6957	3.102
2	9.25	2.213	1.8107
3	6.76	1.5291	1.4063
4	4.9	1	1
5	3.58	0.7643	0.7117
6	2.61	0.6716	0.61
7	1.89	N/A	
8	1.38		
9	1		
10	0.73		

3.10.6 Certification Point Determination from Alternative

Table 3-30 to Table 3-32 define the numbers of vehicle configurations so that a well-defined map can be generated for a certain vehicle family to be certified. Section 3.10.4 shows that a surface fitting could approximate the surface for the entire vehicle applications. It indicates that the fitted surface could be well behaved only if an individual cycle is plotted. However, it can be imagined that the surface could be distorted if those mapping points shown in Table 3-30 to Table 3-32 may not be general enough to define the range of applications. As a result, an alternative to surface fitting should be considered. This section discusses a numerical scheme that is used to determine to-be-certified CO_2 of the vehicle family from the CO_2 map generated from the engine tests as well as GEM simulation. It should be pointed out that the numerical scheme discussed in this section is only the first attempt to derive a numerical scheme that can interpolate or extrapolate certification point, and many other alternatives and optimization schemes can be used as well.

In the approach, it is assumed that one map per certification cycle is considered, each consisting of 8-9 data points, but the map data does not need to be in an exact rectangular matrix or in any particular order. In order to demonstrate the concept, the generic vehicle defined in Table 3-31 is used, where there are a total of nine configurations as shown in Figure 3-25 to Figure 3-27 for three certification cycles. Shown in these figures are also a number of vehicle configurations that could be certified under this map, covering a wide range of applications including both tractor and vocational vehicles and different transmission packages.

In these figures, X axis is SN/SV defined as average engine speed over average vehicle speed in rpm/km-ph. Y axis is the cycle work in kw-hr over the individual driving cycle. The legend of "Map Points" stands for the generic class 8 nine vehicle configurations using the same engine defined in Table 3-31. In these transmission packages, the same engine as the generic vehicle is used, and vehicle variables are varied, such as tire, axle, and aerodynamic packages. Veh 1 and Veh 2 stand for class 8 vehicles for typical vocational applications using the same engine as the generic vehicle. They all have similar vehicle weight, but with different tires, axle ratios, and aerodynamic packages. The purpose of these practices is to demonstrate whether the generic vehicle points (Map Points) can be used to interpolate or extrapolate all other points under different vehicle and transmission configurations with a high confidence level.

From these figures, it can be seen that quite a few vehicle configurations are outside generic vehicle points, which are shown in "Map Points". This means that extrapolations must be used. It is hoped that whatever numerical scheme is used can offer reasonably good accuracy in terms of interpolation as well as extrapolation.

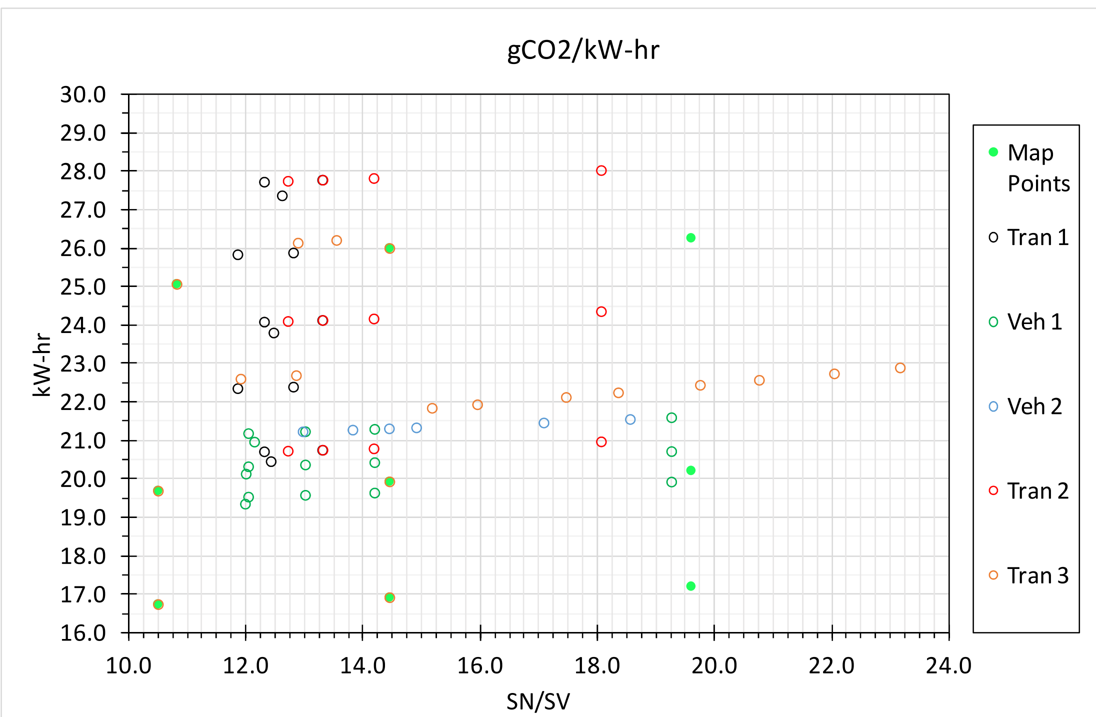

Figure 3-25 Alternative certification map for 55 mph certification cycle

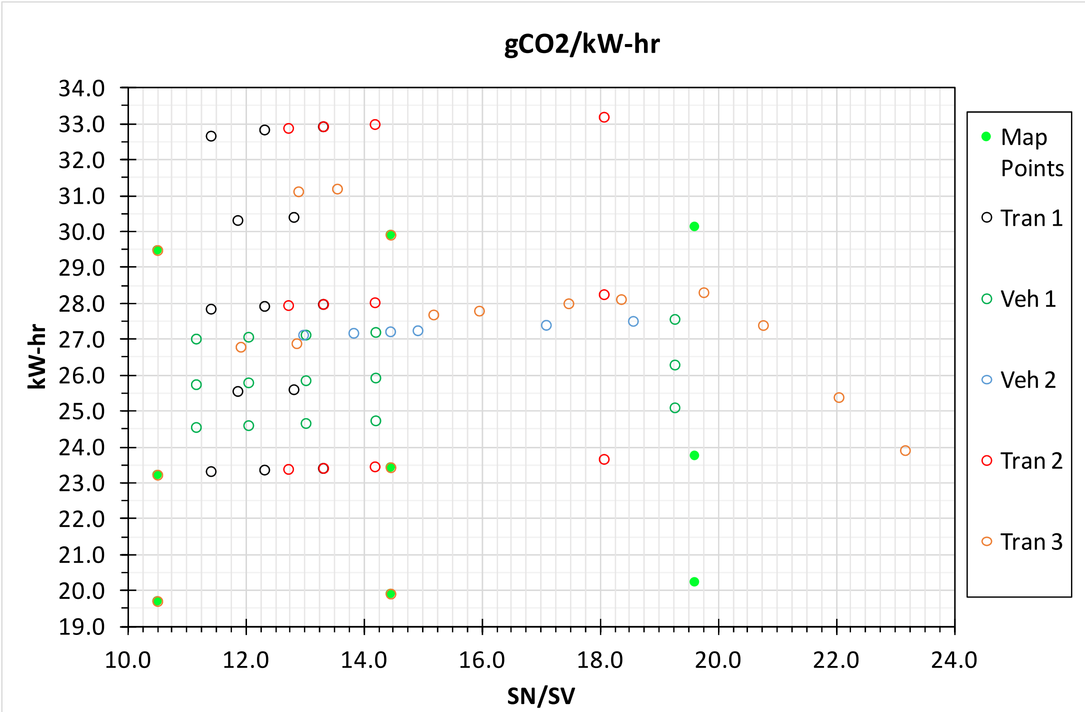

Figure 3-26 Alternative certification map for 65 mph certification cycle

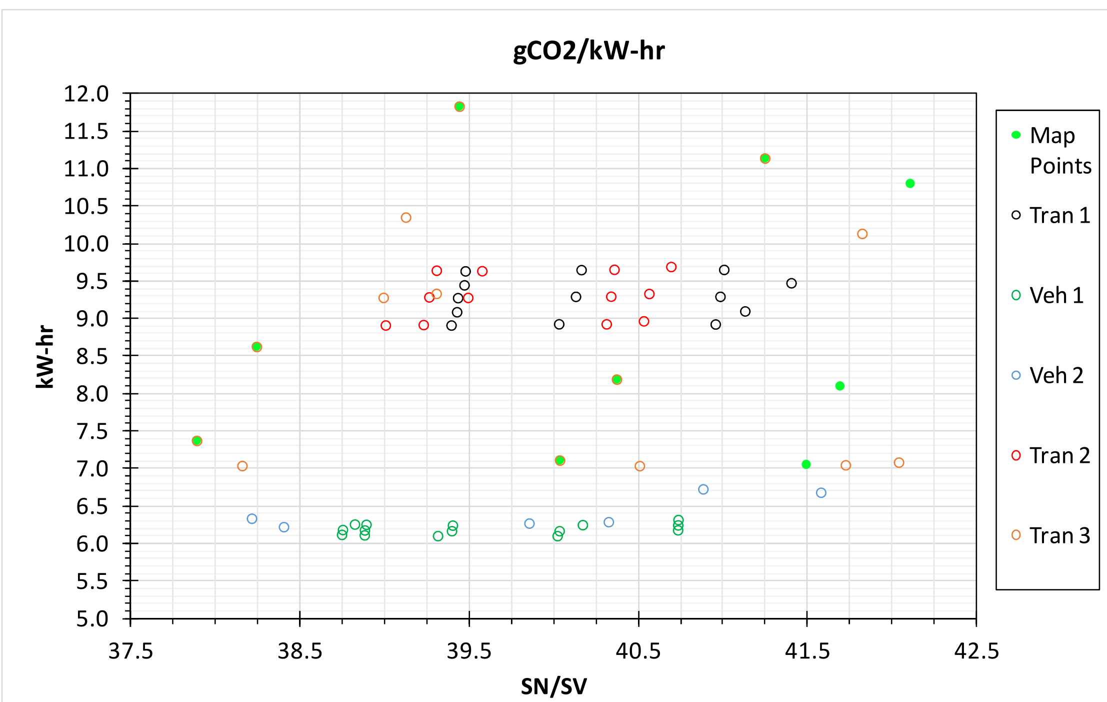

Figure 3-27 Alternative certification map for ARB certification cycle

In order to prove the concept and numerical accuracy in determining appropriate CO_2 for certification, those nine points defined by Table 3-31 as shown in "Map Points" of these three figures which are used to interpolate or extrapolate CO_2 for any other vehicle configurations points and then are compared with the actual simulation points. In the numerical scheme used in this study, within, above, and to the right of a mapped region defined by nine Map Points, interpolation and extrapolation occur in a plane defined by the interpolated point's 3-nearest mapped neighbors. Below and to the left of the mapped region extrapolation occur between the 2 nearest neighbors along the non-extrapolated axis and there is no change in the extrapolated value along any extrapolated axis. The interpolation scheme is to pick the 3 closest neighbors that have a maximum included angle less than 120 degrees, which eliminates picking the narrow triangular planes formed just outside of the mapped region. Table 3-35, Table 3-36, and Table 3-37 show the comparisons for those points.

In these tables, there are 76 vehicle configurations. Among them, nine points with green color filled are the generic vehicle defined in Table 3-31. All other points represent different vehicle configurations under the same engine family. The column with error (%) is the comparison of CO_2 g/hp-hr between the test points and interpolated or extrapolated values. For the sake of simplicity, both values of CO_2 g/hp-hr for both test and interpolated/extrapolate points are not shown in these tables. As can be seen from Table 3-35 and Table 3-36, only one point shows over 4 percent numerical accuracy, and most points are under 2.5 percent difference for cruise speed 55 mph and 65 mph cycles, even for those points located outside mapped region. On the other hand, ARB cycle shows quite a few points in the range of 4.0-4.5 percent difference, which is a concern as far as the certification is concerned. These results suggest that more work and numerical scheme development will be required moving forward.

Table 3-35 Proof of Concept and Numerical Scheme Accuracy for 55MPH Cycle

	INTERP/EXTRAP POINTS					INTERP/EXTRAP POINTS		
i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)		i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)
1	12.61	27.37	0.5%		39	12.71	24.11	1.0%
2	12.31	27.73	-0.4%		40	14.18	24.17	0.4%
3	13.30	27.78	-0.2%		41	18.06	24.36	2.3%
4	12.47	23.81	1.6%		42	13.31	24.13	0.8%
5	12.31	24.09	1.0%		43	12.71	20.74	1.2%
6	13.30	24.13	0.8%		44	14.18	20.80	0.9%
7	12.42	20.46	1.8%		45	18.06	20.98	3.0%
8	12.31	20.72	1.7%		46	13.31	20.76	1.2%
9	13.30	20.76	1.2%		47	11.0727	20.474	0.5%
10	11.85	25.84	0.2%		48	11.3574	20.298	1.5%
11	12.80	25.89	0.3%		49	11.9048	20.342	1.9%
12	11.85	22.36	1.3%		50	12.8518	20.428	1.7%
13	12.80	22.40	1.6%		51	11.1814	22.769	0.3%
14	12.14	20.97	0.2%		52	11.3602	22.55	1.0%
15	12.04	21.19	-0.3%		53	11.9048	22.609	1.5%
16	13.01	21.24	-0.6%		54	12.8518	22.7	1.6%
17	14.19	21.30	-2.1%		55	12.882	26.145	0.5%
18	19.26	21.61	-2.0%		56	15.1703	21.851	-0.7%
19	11.99	20.14	0.3%		57	17.4585	22.132	-0.8%
20	12.04	20.33	-0.2%		58	19.7468	22.449	-1.8%
21	13.01	20.38	-0.9%		59	22.0351	22.745	-3.3%
22	14.19	20.44	-1.6%		60	23.1592	22.9	-4.0%
23	19.26	20.73	-1.4%		61	18.3492	22.253	-1.1%
24	11.98	19.36	0.4%		62	20.7542	22.579	-2.8%
25	12.04	19.54	0.0%		63	15.9442	21.943	-0.2%
26	13.01	19.59	-0.3%		64	13.5392	26.215	0.4%
27	14.19	19.65	-1.2%		65	10.8136	25.072	0.0%
28	19.26	19.93	-0.9%		66	10.4952	19.698	0.0%
29	14.44	21.32	-2.3%		67	10.4952	16.748	0.0%
30	14.90	21.34	-2.9%		68	14.4455	26.005	0.0%
31	12.97	21.24	-0.6%		69	14.4455	19.938	0.0%
32	17.08	21.47	-1.4%		70	14.4455	16.927	0.0%
33	13.82	21.28	-1.8%		71	19.5963	26.267	0.0%
34	18.55	21.56	-1.7%		72	19.5963	20.22	0.0%
35	12.71	27.75	-0.2%		73	19.5963	17.21	0.0%
36	14.18	27.82	-0.5%		74	17.0015	26.129	1.5%
37	18.06	28.03	-1.3%		75	17.0015	20.072	1.8%

38	13.31	27.78	-0.2%		76	17.0015	17.061	2.0%

Table 3-36 Proof of Concept and Numerical Scheme Accuracy for 65MPH Cycle

	INTERP/EXTRAP POINTS					INTERP/EXTRAP POINTS		
i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)		i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)
1	11.40	32.68	0.6%		39	12.71	27.96	1.8%
2	12.31	32.85	-0.9%		40	14.18	28.04	0.8%
3	13.30	32.94	-1.2%		41	18.06	28.26	2.1%
4	11.40	27.86	0.9%		42	13.31	27.99	1.5%
5	12.31	27.93	1.8%		43	12.71	23.39	2.2%
6	13.30	27.99	1.5%		44	14.18	23.47	1.9%
7	11.40	23.33	1.5%		45	18.06	23.67	4.2%
8	12.31	23.38	2.1%		46	13.31	23.42	2.1%
9	13.30	23.42	2.1%		47	10.287	23.201	0.1%
10	11.85	30.33	1.1%		48	11.1382	23.307	1.3%
11	12.80	30.41	0.6%		49	11.9048	23.383	2.0%
12	11.85	25.57	1.9%		50	12.8518	23.471	2.3%
13	12.80	25.61	2.4%		51	10.4864	26.581	0.1%
14	11.15	27.02	1.1%		52	11.1382	26.689	0.9%
15	12.04	27.08	1.2%		53	11.9048	26.797	1.2%
16	13.01	27.13	1.7%		54	12.8518	26.895	2.3%
17	14.19	27.21	0.4%		55	12.882	31.126	0.1%
18	19.26	27.57	1.2%		56	15.1703	27.695	0.5%
19	11.15	25.75	1.2%		57	17.4585	28.007	1.6%
20	12.04	25.80	2.0%		58	19.7468	28.315	0.1%
21	13.01	25.86	0.7%		59	22.0351	25.395	2.3%
22	14.19	25.94	0.2%		60	23.1592	23.919	3.4%
23	19.26	26.30	1.0%		61	18.3492	28.124	2.0%
24	11.15	24.56	0.3%		62	20.7542	27.401	-0.3%
25	12.04	24.61	1.5%		63	15.9442	27.802	1.0%
26	13.01	24.67	0.4%		64	13.5392	31.201	-0.3%
27	14.19	24.75	-0.3%		65	10.4952	29.49	0.0%
28	19.26	25.11	0.4%		66	10.4953	23.234	0.0%
29	14.44	27.23	0.0%		67	10.4952	19.715	0.0%
30	14.90	27.26	-0.7%		68	14.4455	29.917	0.0%
31	12.97	27.13	1.8%		69	14.4456	23.441	0.0%
32	17.08	27.41	1.5%		70	14.4455	19.921	0.0%
33	13.82	27.18	0.8%		71	19.5963	30.142	0.0%
34	18.55	27.52	2.0%		72	19.5964	23.766	0.0%
35	12.71	32.89	-1.0%		73	19.5963	20.247	0.0%

36	14.18	33.00	-1.8%		74	17.0015	30.063	1.0%
37	18.06	33.20	-1.6%		75	17.0016	23.594	0.6%
38	13.31	32.94	-1.2%		76	17.0015	20.075	0.3%

Table 3-37 Proof Of Concept and Numerical Scheme Accuracy for ARB Cycle

	INTERP/EXTRAP POINTS					INTERP/EXTRAP POINTS		
i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)		i	$\Sigma N/\Sigma V_i$	kW-hr$_i$	Error (%)
1	41.00	9.66	-1.2%		39	39.26	9.29	-2.7%
2	40.16	9.65	-0.9%		40	40.34	9.30	-1.3%
3	39.48	9.64	-1.0%		41	40.56	9.33	-1.9%
4	40.98	9.30	-1.0%		42	39.49	9.28	-2.5%
5	40.13	9.30	-2.9%		43	39.23	8.92	-2.3%
6	39.43	9.28	-2.3%		44	40.31	8.93	-2.6%
7	40.95	8.93	-2.1%		45	40.53	8.97	-2.8%
8	40.03	8.93	-2.0%		46	39.00	8.91	-2.0%
9	39.39	8.91	-1.9%		47	39.1403	9.2227	1.0%
10	41.40	9.48	-0.7%		48	40.0123	9.2143	0.4%
11	39.47	9.45	-1.3%		49	39.2724	9.1879	0.7%
12	41.13	9.10	-1.1%		50	38.9924	9.1411	1.0%
13	39.43	9.09	-2.3%		51	39.2179	9.3688	0.4%
14	40.17	6.25	-4.1%		52	40.0236	9.3563	0.2%
15	39.40	6.25	-4.2%		53	39.3053	9.3359	0.4%
16	38.82	6.26	-4.3%		54	38.9921	9.2828	0.9%
17	38.89	6.26	-4.4%		55	39.1243	10.353	1.2%
18	40.73	6.32	-3.9%		56	38.1574	7.0408	0.2%
19	40.03	6.17	-4.5%		57	40.5059	7.0397	0.7%
20	39.40	6.17	-4.5%		58	42.0372	7.087	1.2%
21	38.75	6.19	-4.6%		59	43.4797	7.1226	1.6%
22	38.88	6.18	-4.6%		60	43.1689	7.1632	0.9%
23	40.73	6.25	-4.1%		61	44.334	7.1471	0.8%
24	40.02	6.11	-4.8%		62	44.0081	7.1626	0.0%
25	39.31	6.11	-4.7%		63	41.7231	7.0508	-2.9%
26	38.75	6.12	-4.8%		64	41.8206	10.136	1.5%
27	38.88	6.12	-4.8%		65	39.4411	11.832	0.0%
28	40.73	6.18	-4.4%		66	38.2432	8.6276	0.0%
29	39.85	6.27	-4.2%		67	37.8895	7.3752	0.0%
30	40.32	6.29	-3.9%		68	41.2466	11.14	0.0%
31	38.40	6.23	-4.5%		69	40.3708	8.1927	0.0%
32	40.88	6.73	-3.3%		70	40.0346	7.1138	0.0%
33	38.21	6.34	-4.5%		71	42.1071	10.8	0.0%

34	41.58	6.69	-2.9%		72	41.6921	8.0995	0.0%
35	39.31	9.65	-1.3%		73	41.4929	7.0552	0.0%
36	40.36	9.66	-1.3%		74	42.1548	10.83	0.2%
37	40.69	9.69	-1.8%		75	41.6017	8.0873	0.4%
38	39.57	9.64	-1.2%		76	41.4366	7.0472	0.4%

3.10.7 Preliminary Comparisons of Primary and Alternative Approaches

The main purpose of introduction of this alternative approach for vehicle certification is to integrate vehicle certification with engine certification, being able to address both GHG emissions and criteria emission in one set of tests. Chapter 3.10.4 shows the principle of this approach. However, one of the key questions remains – how this alternative certification approach is credible in terms of accuracy as opposed to the primary vehicle certification approach? In addition, there are also many other questions that still need answers, such as parent and child rating impacts, the impact of vocational sector with a large variation on the ratio of N/V (average engine speed over average vehicle speed), surface fit or interpolation scheme, and engine certification.

Shown in Figure 3-28 is the comparison between alternative approaches discussed in this Section and GEM with steady state map based approach discussed in Chapter 4 of this draft RIA. In both engine and GEM simulations, a test matrix consisting of twenty seven points is tested (3 axle ratios x 3 C_d values x 3 cycles) as shown below.

- Nine variations of the Kenworth T700 to cover the range of vehicle loads
  - Axel ratio: 2.64, 2.85, and 3.08
  - C_d: 0.41, 0.55, and 0.7
- Three certification cycles – with distance correction
  - 55 w/SwRI grade profile
  - 65mph w/SwRI grade profile
  - ARB Transient
- Eaton AMT model: 10 speed: F016E310C-LAS

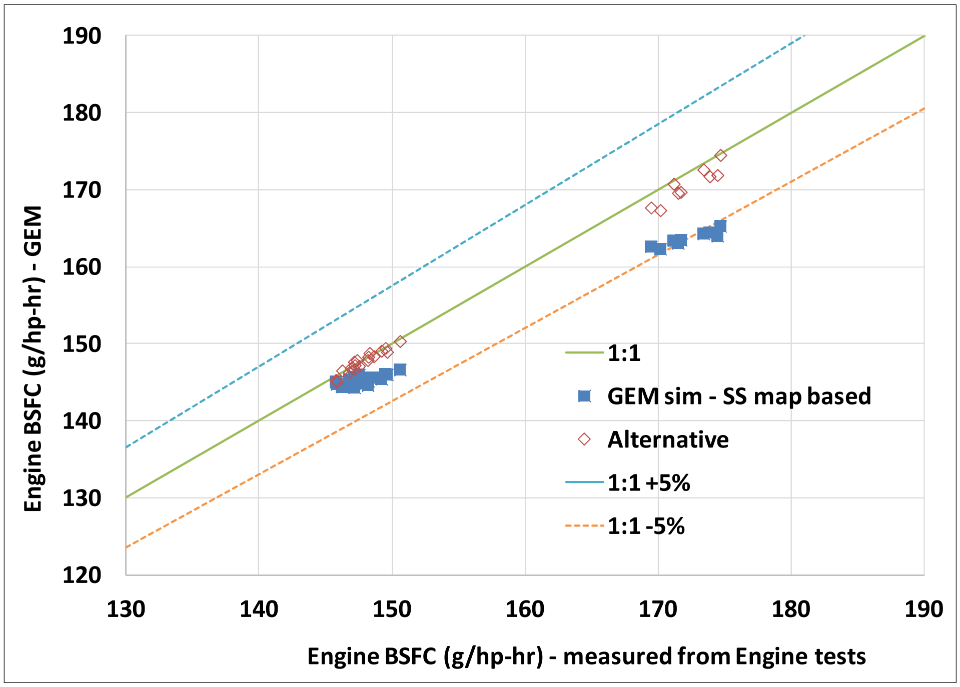

Figure 3-28 Comparisons between Alternative and GEM Based Approaches

As shown in Figure 3-28, both alternative approach and GEM based approach seem to produce similar results in 55 mph and 65 mph cruise cycles with road grade. However, it is clearly shown that the alternative approach seems to be better in the transient cycle than GEM based approach with the steady state map.

3.10.8 Remaining Questions and Future Plans

The comparison shown in Figure 3-28 only partially answers this alternative approach fidelity with one specific engine and transmission platform and because of this there are still many unanswered questions. The following questions are only a subset of the questions that need to be answered:

- How does this alternative approach address parent and child rating? Would nine points be adequate to cover the practical range of the vehicle operation on the road?
- How can this approach address those points that may be out of map ranges with much higher or lower N/V?
- What kinds of numerical schemes, interpolation or surface fitting, shall be used to interpolate those points that are located between testing points?
- What the numerical scheme shall be used to extrapolate those points outside the maps?
- How robust are these numerical schemes?
- Can what we have learned so far be applied to other engines?
- How the single engine certification point shall be selected among the number of engine tests?
- Are there potential unintended consequences?

The agencies welcome comments on these questions and on the alternative vehicle certification approach in general.

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[28] The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm

Chapter 4: Vehicle Simulation Model

4.1 Purpose and Scope

In designing a regulatory GHG emission control and fuel consumption program, it is necessary to estimate the performance of technologies, verify compliance with the regulatory standards, and estimate overall benefits of the program. The agencies developed the Greenhouse gas Emission Model (GEM) to serve these purposes for Phase 1, which was consistent with recommendations by the National Academies of Sciences (NAS) to use vehicle simulation to demonstrate compliance.[A] GEM is currently being used to certify the fuel consumption and CO_2 benefits of the Phase 1 rulemaking for all heavy duty vehicles except for HD pickups and vans, which require a chassis dynamometer test for certification. While the version of GEM used in Phase 1 contained most of the technical and mathematical features needed to run a vehicle simulation, the model was limited. For example:

- Only manual transmissions were used in the model for all tractor and vocational vehicle simulations, which is not always the case for real world applications, especially for vocational vehicle applications
- The model did not include engine torque interruption during gear shifting
- Engine control were simplified, with no fueling cut-off features
- Only the agencies' pre-specified engine fuel maps were used

The Phase 1 certification process only required up to five user inputs, and all other vehicle parameters and their inputs were pre-specified by the agencies.[1] Phase 1 GEM only recognized the benefits of aerodynamics improvement, tire rolling resistance, vehicle speed limiter, weight reduction, and idle reduction (only for high roof sleeper tractors).

Because the proposed Phase 2 standards are predicated on the performance of a broader range of technological improvements than Phase 1, including changes to transmissions and better integration of engines and transmissions, a more comprehensive vehicle simulation model is required. This chapter describes a new version of this vehicle simulation model, referred to as Phase 2 GEM. It should be noted that all changes to GEM described in this chapter remain potential, since the agency is proposing these changes, and will make a final determination as to what changes are appropriate only after considering the entire record after the close of the public comment period.

[A] National Academies of Science. "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles." 2010. Recommendation 8-4.

4.2 Model Code Description

4.2.1 Engineering Foundations of the Model

EPA developed GEM to be a forward-looking Matlab /Simulink-based model for heavy-duty (Class 2b-8) vehicle compliance in 2011.[1] A more detailed description of this model and its engineering foundation can be found in Reference 1. The underlying GEM code was originally developed to simulate a broad range of vehicle speeds over essentially any in-use duty cycle. However, the official version that is used for determining compliance with the Phase 1 standards incorporates the regulatory duty cycles into the code. In other words, manufacturers cannot run other duty cycles with the official version of GEM. We propose to continue this approach for Phase 2.

In order to meet proposed Phase 2 rulemaking requirements in recognizing most of the technologies that are measured in both engine and chassis dynamometers, GEM has been considerably enhanced. Specifically, the agencies are proposing to implement the following key technical features into Phase 2 GEM:

- An upgraded engine controller, which includes engine fuel cut-off during braking and deceleration

- An upgraded transmission model, which includes an upgraded manual transmission, along with newly developed automatic and automated manual transmissions

- An upgraded driver model with a distance-compensated driver that will drive the certification drive trace over a prescribed distance regardless of increased drive time due to vehicle under-performance, for example.

4.2.2 Model Components

The GEM architecture is comprised of four systems: Ambient, Driver, Powertrain, and Vehicle as seen in Figure 4-1. With the exception of Ambient and Driver, each system consists of one or more subcomponents. The function of each system and its respective component models, wherever applicable, is discussed in this chapter. Many changes and modifications described in this chapter have resulted from numerous constructive comments from both public comments and GEM peer reviews.[2] The model has been upgraded to improve the fidelity of the model and better match the function of the simulated vehicles, which also meets our primary goal to accurately reflect changes in technology for compliance purposes. As part of this effort, substantial effort has been put forth to accurately track and audit power flows through the model to ensure conservation of energy.

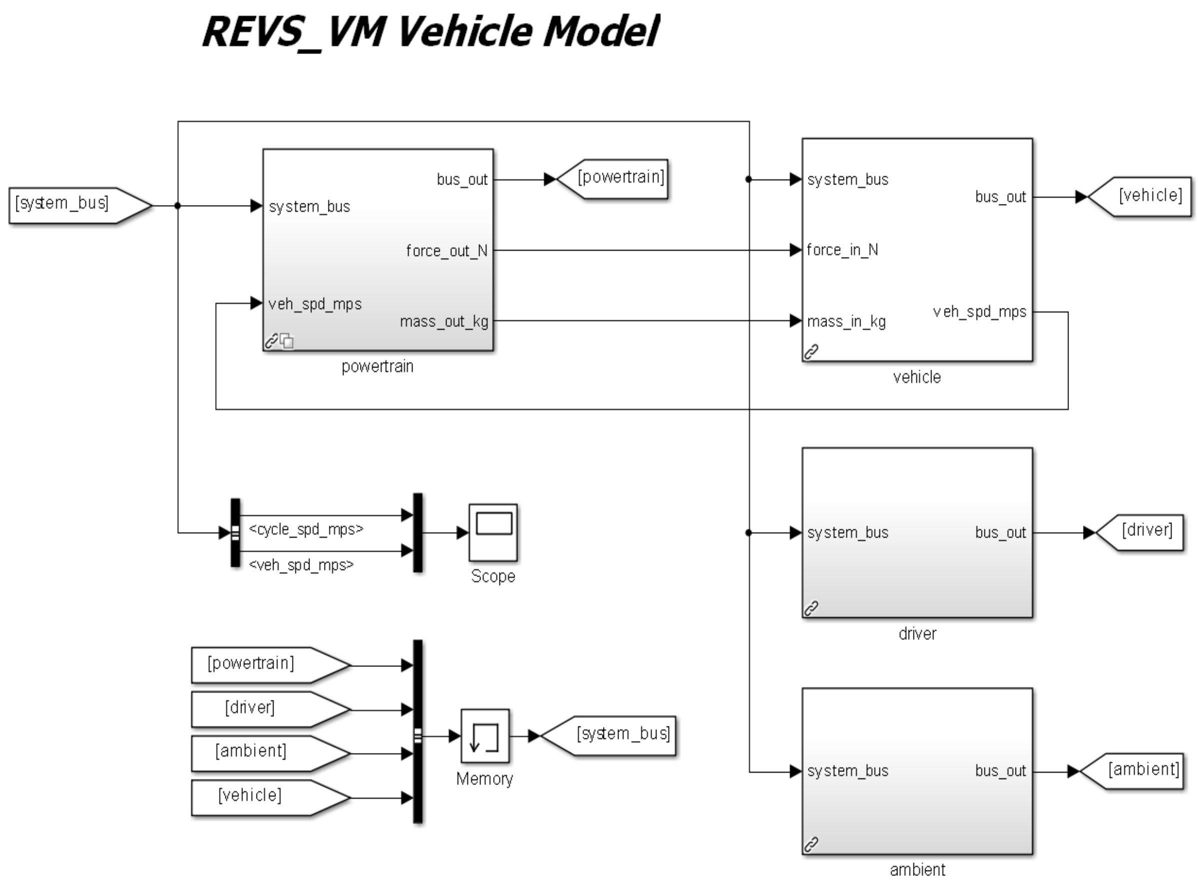

Figure 4-1 GEM model structure

4.2.2.1 Ambient Subsystem

This system defines ambient conditions such as pressure, temperature, and road gradient, where vehicle operations are simulated. Just like in Phase 1 GEM, the conditions have been maintained in accordance with standard SAE practices. The road gradient has been modified to accept a road grade that varies as a function of distance traveled.

4.2.2.2 Driver Subsystem

The driver model in Phase 2 GEM has been substantially reorganized to simplify operation and to add support for distance compensated drive cycles. The result is a purely proportional-integral control driver that features a small lookahead to anticipate the drive cycle, especially useful at launch where the vehicle response may be delayed due to the large effective inertia in low gears. The proposed target drive cycle consists of a road grade versus distance and a vehicle speed target as a function of the time required to achieve those speeds as a function of distance (i.e. desired cycle time). The drive cycle speed can be converted to a target speed versus distance travelled, however such a conversion involves the complication of tracking vehicle stop times separately since they necessarily occur over zero distance.

Because the simulation itself is time-based, we consider the driver to be distance compensated rather than distance-based. The driver always operates in the time domain. To implement the distance compensated driver, the cycle time is tracked separately from simulation time, based on the ability of the target vehicle to meet the target speed trace. If the vehicle meets the target speed trace then cycle time is equivalent to simulation time as there is no difference in the distance travelled. If the vehicle under-performs the drive cycle then cycle time proceeds more slowly than simulation time, forcing the vehicle to drive for a longer amount of time in order to cover an equivalent distance.

In terms of implementation, to apply distance compensation at each time step, the current model vehicle speed is divided by the target speed from the drive cycle. This value is integrated to produce the current cycle time and an updated speed target. The result is that if a simulated vehicle is traveling at half the drive cycle speed the simulation will progress through the drive cycle at half the rate. This behavior is disabled at speeds below 1 meter per second to provide reasonable launch behavior (which necessarily occurs over short distances), division by zero and to maintain vehicle stop times independent of small discrepancies in total distance travelled.

The addition of distance compensation allows all simulated vehicles to complete an equivalent trip such as traveling from point A to point B. Without distance compensation, under-powered vehicles might complete the drive cycle by time but not distance and would have done less work than higher powered vehicles as measured in ton-miles. Distance compensation also allows for the variation in road grade to be kept in synchronization with the drive cycle speed trace.

4.2.2.3 Powertrain Subsystem

The engine, transmission, electric accessories, and portions of the vehicle models from Phase 1 GEM have been upgraded and merged into a conventional vehicle powertrain system as shown in Figure 4-2. The conventional powertrain system contains sub-models representing the engine, transmission, electric accessories, and driveline. Only conventional powertrains are modeled in Phase 2 GEM, and no hybrid power systems are modeled and certified with GEM. Rather, hybrid powertrains would be certified through powertrain dynamometer tests as described in Chapter 3 of the draft RIA.

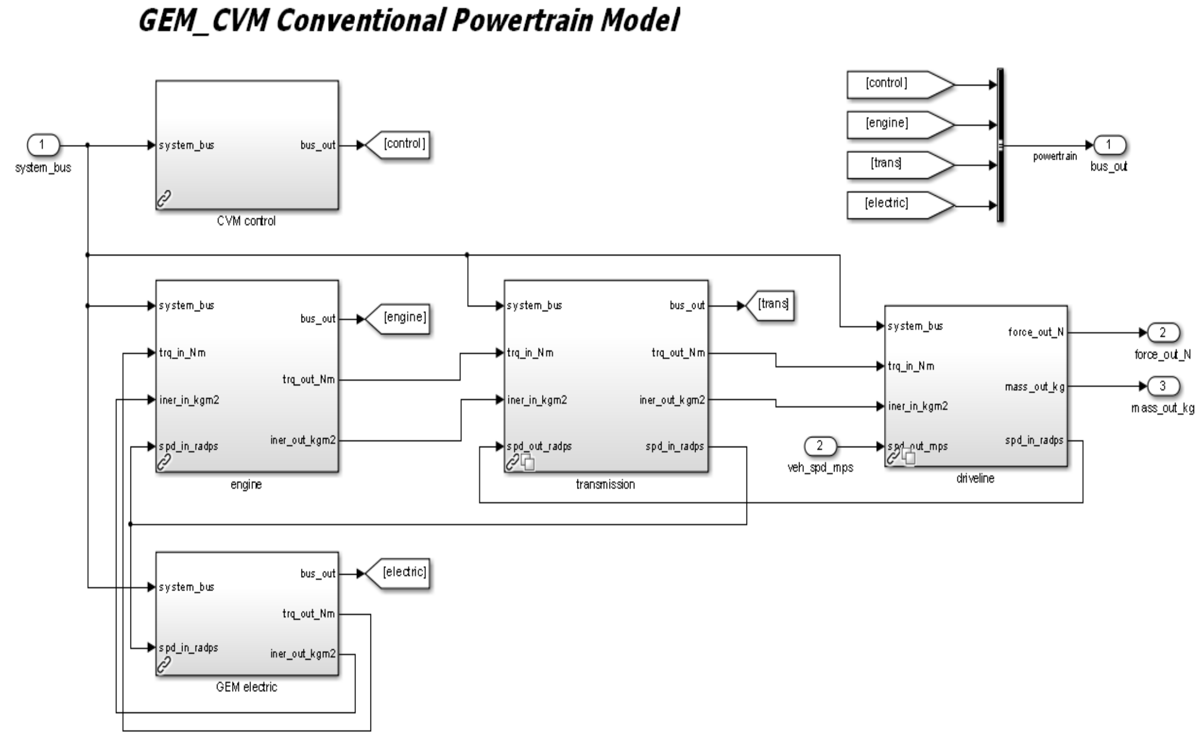

Figure 4-2 GEM Powertrain Model

4.2.2.3.1 Engine Subsystem

The engine model is based on a steady-state fuel map covering all engine speed and torque conditions with torque curves for wide open throttle (full load) and closed throttle (no load). The engine fuel map in Phase 2 is the input provided by users. The engine fuel map features three sets of data: engine speed, torque, and fueling rate at pre-specified engine speed and torque intervals. In-cylinder combustion processes are not modelled. The engine speed at a given point in the drive cycle is calculated from the physics of the downstream speeds. The quantity of torque required is calculated from the driver model accelerator demand, an idle speed governor, and requests from the transmission during shifts. The torque request is then limited by the maximum torque curve. The engine torque and speed are used to interpolate a fuel rate from the fuel map. The engine model also includes a constant power loss to simulate mechanical accessories. Most vehicles run a number of accessories that are driven *via* mechanical power from the engine. Some of these accessories are necessary for the vehicle to run, like the engine coolant pump or power steering, while others are only used occasionally and at the operator's discretion, such as the air conditioning compressor. Some heavy-duty vehicles also use Power Take Off (PTO) to operate auxiliary equipment, such as refuse compactors or lift forks. These would also be modeled as a mechanical accessory. The mechanical accessory load is proposed to be fixed for all vehicles based on regulatory subcategory, as shown below in Table 4-6, Table 4-7, and Table 4-8. The actual power consumed for this loss would differ for actual vehicle configurations, but the agencies do not propose to allow users to change this value in GEM. If a manufacturer uses a hybrid powertrain for power take-off devices, it may make use of the hybrid-PTO test procedure. See, 40 CFR 1037.525.

4.2.2.3.2 Electric Subsystem

The electric subsystem is modeled as a constant power loss. The power consumed for this loss is based on the vehicle subcategory. It represents the power loss associated with the starter, electric energy system, alternator and the electrically driven accessories. The simplification has a negligible impact on the fuel consumption and CO_2 emissions results. The power losses for different vehicles are shown in tables from Table 4-5 to Table 4-10.

4.2.2.3.3 Transmission Subsystem

The transmission subsystem features three different variants representing the three major types of transmissions that are currently in use in the heavy-duty sector, which are the transmission types on whose performance the various proposed standards are predicated. The variants are manual transmission (MT), automated manual transmission (AMT), and automatic transmission (AT) (planetary gear set with torque converter). The different transmission models are built from similar components, but each features a unique control algorithm matching behaviors observed during vehicle testing3.

4.2.2.3.3.1 Transmission Gear Selection

All of the transmission models use a dynamic shift algorithm to determine the operating gear over the cycle3. This employs a rule based approach utilizing the engine torque curve and fuel map to select gears that optimize efficient engine operation and provide a torque reserve as a traditional transmission calibration would.

4.2.2.3.3.2 Clutch

The clutch model in Phase 2 GEM replaces the simplified model found in Phase 1 GEM. The original clutch model had no transition between the fully engaged and fully disengaged states and provided no commensurate torque impulse to the driveline. In the new clutch model, engagement and disengagement occur over time, torque is conserved across the clutch and the inertial effects of accelerating and decelerating the upstream inertias are captured.

4.2.2.3.3.3 Gearbox

The gearbox model has also been substantially revised in Phase 2 GEM to provide more realistic operation. The gearbox contains gear ratios and efficiencies for each gear. Each gear also has spin (churning) loss torques that can vary by current gear number and input speed. GEM assumes higher efficiency for direct drive than any other gear for manual and automated manual transmissions. Shifting behavior is more realistic than in Phase 1 GEM with appropriate delays provided by a synchronizer clutch model. This layout is most similar to a manual transmission, but the application for a planetary gearbox is a reasonable approximation as this type of gearbox can utilize a variety of topologies. A detailed description on the shifting strategy can be seen in reference[3]. The gearbox rotational inertias are split between a common input inertia, common output inertia and a gear specific inertia. The common inertias represent rotational inertia always coupled to the input or output shafts. The gear specific inertias are added or removed as gears are engaged or disengaged and incur additional losses.

4.2.2.3.3.4 Hydrodynamic Torque Converter

The torque converter model in Phase 2 GEM simulates a lockup-type torque converter. The torque multiplication and resulting engine load are calculated via torque ratio and K-factor curves that vary as a function of speed ratio. A base torque ratio curve is used for all simulations and the K-factor curve is scaled based on the engine torque curve to provide a good match between the torque converter stall speed and the engine's speed at maximum torque. This approximation could result in some simulation differences for highly specialized vehicles equipped with torque converters matched to their specialized duty cycle, but for the vast majority of vehicles, the effect of this approximation on simulated CO_2 emissions is negligible. The lockup behavior of the torque converter is accomplished by integrating a clutch model similar to the one discussed in Chapter 4.2.2.3.3.2. The torque converter model also contains a pump loss torque that varies with input speed to simulate the power required to operate the pump on an automatic transmission.

4.2.2.3.3.5 Manual Transmission & Control

The manual transmission (MT) is composed of the clutch and gearbox systems discussed above. The gearbox spin losses for a particular simulation are scaled with the vehicle class. The manual transmission features minimal gear specific inertia. Control of the MT is accomplished via a low speed clutch engagement model that gets the vehicle moving by feathering the clutch during launch. Shifts are accomplished by reducing the requested engine load, disengaging the clutch, shifting the gearbox to the new gear and reengaging the clutch. In heavier vehicles shifting is accomplished by double-clutching to match transmission input speeds rather than relying purely on the gearbox synchronizers.

4.2.2.3.3.6 Automatic Transmission & Control

The automatic transmission (AT) is composed of the torque converter and gearbox systems discussed above. The gearbox gear specific inertias and spin loss torques are higher as would be expected from a conventional planetary automatic transmission gearbox. The AT is allowed to shift under load. During upshifts and torque converter lockup the engine output torque is slightly reduced to minimize the resultant torque pulse encountered by decelerating the engine inertia.

Torque converter lockup will be controlled by a predetermined lookup table or lockup strategy algorithm and at this time is not expected to be among the available user inputs with the possible exception of indicating the lowest gear in which lockup may occur.

4.2.2.3.3.7 Automated Manual Transmission & Control

The automated manual transmission (AMT) features the same clutch and gearbox models as the manual transmission with the addition of an inertia brake to slow the gearbox input inertia during upshifts. Control of the AMT during launch features a clutch feathering routine similar to the MT. Upshifts are handled by limiting the engine load, disengaging the clutch and shifting the gearbox to neutral. The inertia brake is then applied to slow the transmission input inertia before the gearbox engages the new gear. With the new gear engaged the clutch is reengaged and the engine is again allowed to operate at full load. Downshifts are handled by shifting the gearbox to neutral and accelerating the gearbox input up to a speed matching the desired gear using the engine.

4.2.2.3.4 Driveline

The driveline system contains all of the components that convert the torque at the transmission output to force at the wheels. This includes drive shafts as well as driven axles, consisting of a differential, brakes and tires. Except as specified below, we are not proposing to change the Phase 1 GEM approach to driveline modeling. For example, both Phase 1 and Phase 2 GEM can model all axles individually, or a single composite axle can be substituted to reduce simulation time.

4.2.2.3.4.1 Driveshaft

The driveshaft is a simple component for transferring torque while adding additional rotational inertia.

4.2.2.3.4.2 Final Drive

The final drive is modeled as a gear ratio change and an associated fixed efficiency. Various combinations of spin loss and efficiency, including a look-up table as a function of wheel speed and axle output torque, were considered. Table 4-1 below shows the comparisons between single value and look-up table efficiency approaches for a Class 6 box truck simulation.

Table 4-1 Axle Efficiency Modeling and Comparisons

Axle Study Results (Box Truck) **Fixed Efficiency v. Look-up Table**		**Fuel Economy (MPG)**	
Drive Cycle	**Look-up Table MPG**	**Fixed 95.5% Efficiency MPG**	**Difference**
55 mph	**11.19**	**11.15**	**0.36%**
65 mph	**9.13**	**9.06**	**0.77%**
CARB HHDDT	**8.43**	**8.29**	**1.67%**

In this table, 95.5 percent is a fixed efficiency, which is intended to be used as the GEM predefined value. As can be seen, the difference between these two approaches is fairly small, and the fuel economy with the fixed efficiency is more conservative (lower) than the look-up table approach as far as certifications are concerned. We are open to the approach of using a look-up table and request comment on its use. At this time, however, a single efficiency value was selected to simplify simulation and model inputs. The final drive model also adds some rotational inertia to the system.

4.2.2.3.4.3 Brakes

The brake system on each axle applies a torque to the axle proportional to the brake pedal position from the driver model. The scaling factor to determine this force is based on engine maximum torque, transmission multiplication and final drive ratio.

4.2.2.3.4.4 Tires

The tire component model transfers the torques and rotational inertias from upstream components to a force and equivalent mass that is passed to the vehicle model. This conversion uses the loaded tire radius and adds the tire's rotational inertia. The force associated with the tire rolling resistance is also applied when the vehicle is moving. The magnitude of this force is determined by the coefficient of rolling resistance, vehicle static mass and current grade.

The proposed new version of GEM would make tire size a manufacturer-specified input rather than use a predefined value as was done for Phase 1. Manufacturers would specify tire size in terms of loaded radius or perhaps tire revolutions per mile. Other than this, tires are being modeled the same as in Phase 1.

4.2.2.4 Vehicle

The vehicle system consists of the chassis, its mass and forces associated with aerodynamic drag, rolling resistance, and changes in road grade. The aerodynamic force is calculated from the air density, vehicle speed, frontal area and drag coefficient. The vehicle system also contains the vehicle speed integrator that computes acceleration from the input force and equivalent mass which is integrated to generate vehicle speed and distance traveled.

4.2.3 Capability, Features, and Computer Resources

GEM is a flexible simulation platform that can model a wide variety of vehicles with conventional powertrains from Class 2b to Class 8. The key to this flexibility is the component description files that can be modified or adjusted to accommodate vehicle-specific information. Parameters such as vehicle weight, engine fuel map, transmission gear ratios, tire radius, or axle ratio can all be changed as inputs by the user in this fashion. The proposed Phase 2 GEM predefines all drive cycles (the Transient mode, as defined by the California Air Resources Board (CARB) in their Highway Heavy-Duty Diesel Transient (HHDDT) cycle, and EPA GEM constant speed cycles at 65 mph and 55 mph, each with varying road grade). The agencies also pre-defined many key parameters, since those parameters are either hard to quantify due to lack of certified testing procedures or difficult to obtain due to proprietary barriers. Examples of these parameters include transmission shifting strategies, transmission gear mechanical efficiency, and transmission spin and pumping loss. The values selected for these parameters are a result of substantial testing found in the Southwest Research Institute Report[4], as well as confidential discussions with engine, chassis and component manufacturers.

During simulation the GEM tracks the status of many components and the status of all of the modeled losses. This information provides an energy audit to ensure the model conserves energy. The fuel consumed and vehicle speed traces are immediately available in the generated report, while the larger data set is available in a Matlab .mat file or a comma-separated values (CSV) file.

4.2.3.1 GEM Executable

The agencies propose to require that vehicle manufacturers use the Phase 2 GEM executable version, which does not require the use of Matlab or Simulink software, for demonstrating compliance with the proposed CO_2 and fuel consumption standards. In this form, a precompiled executable format is used for certification. Its computational requirements are minimal. When using the minimum recommended 2 GHz processor and 4 GB of RAM, a single simulation should complete in 10 seconds and generate 100 MB output files. Inputs from the manufacturers are provided in a text file, and the results are available in a generated report.

4.2.3.2 GEM Matlab /Simulink Model

The Matlab/Simulink version of the GEM source code will be released for users that desire a more detailed look at the inner workings of the model. The system requirements for the Matlab /Simulink version of GEM include Matlab, Simulink and StateFlow software from Mathworks (version 2014a or later) and a compatible compiler.[5] The recommended hardware for the Matlab release of GEM is 2+ GHz processor and 4 GB of RAM. The output data from a GEM simulation into Matlab is approximately 500 MB, depending on the simulation configuration and outputs selected. Simulations inside Matlab /Simulink using the source code take approximately 2 to 3 minutes. Although the source code is available to users, all of the component initialization files, control strategies and the underlying Matlab /Simulink/Stateflow-based models may not be used for determining compliance. Only the executable version can be used when producing official truck certification results. Also, it should be pointed out that EPA will not provide any technical support for the use of the GEM source code because it is beyond the scope of the agency's responsibilities and resources.

4.2.4 Peer Review of Phase 2 GEM

The agencies conducted a peer review of Phase 2 GEM which has been submitted for public review in this NPRM. The peer review was conducted by an independent contractor and includes four reviewers. Additional details regarding the peer review and EPA's responses to the peer review comments can be found in the docket2.

The agencies also met with and received comments from the Engine Manufacturers Association, along with other industry stakeholders, during the development of Phase 2 GEM, which identified some areas of concern with GEM. In response, the agencies made changes as necessary.

4.3 Validation of Phase 2 GEM Simulations

This chapter presents the results of an engineering evaluation of the ability of the computer model in GEM to accurately simulate actual engine and vehicle performance. Note that this version differs from the compliance version in that it was possible to use actual values for vehicle parameters that are locked in the compliance version of GEM. For example, validations used actual vehicle curb weights. They also incorporated actual shift strategies where available. This is appropriate because the purpose of the validations was to evaluate the engineering basis of the model, rather than to evaluate whether the policy of locking certain parameters is appropriate.

4.3.1 Experimental Tests for GEM Validation

Working with Southwest Research Institute (SwRI), EPA has invested significantly in various truck tests in order to collect data to validate Phase 2 GEM. The technical research workshop held at SwRI, San Antonio, TX, December 10-11 details all of these tests[6]. The following truck tests were carried out by SwRI for the purpose of model validation:

- Class 6 Kenworth T270 vocational box truck with AT
- Class 6 Ford F-650 vocational tow truck with AT
- Class 8 Kenworth T700 line haul truck with AMT
- Class 8 New Flyer refuse truck with AT

The key specifications for those trucks are listed in Table 4-2.

Table 4-2 Vehicle Specifications of Heavy-Duty Trucks Tested at Southwest Research Institute

Truck	2013 Kenworth T700	2012 Kenworth T270	2011 Ford F-650 Tow truck	2012 New Flyer Refuse
Engine /Rated Power (hp)	Cummins ISX 455	Cummins ISB 240	Cummins ISB 270	Cummins ISL 345
Transmission	Eaton F016E310C-LAS	Allison 2100	Allison 2200 RDS	Eaton FO16E310C-LA

In order to fully validate the model, each truck was tested over six different driving cycles including regulatory cycles and non-regulatory cycles. They are the EPA GEM 55mph (with and without grade), EPA GEM 65mph (with and without grade), the transient portion of the CARB Heavy-Duty Diesel Truck (HDDT) cycle, the World Harmonized Vehicle Cycle (WHVC), the High-efficiency Truck Users Forum (HTUF) Class 6 Parcel Delivery Cycle, and the National Renewable Energy Laboratory (NREL) Combined International Local and Commuter Cycle (CILCC) cycle (which is a utility vehicle cycle). The inclusion of driving cycles in addition to those used for Phase 1 certification was done to expand the range of operation. Some of the cycles are very aggressive (especially for Class 8 trucks), such as the CILCC and Parcel Delivery cycles, with many stops and rapid accelerations. EPA evaluated the results from these additional cycles to improve the modeling capability and its response to highly transient conditions, thus providing additional confidence in model fidelity. All trucks were tested on a chassis dynamometer. In addition, the engine and transmission from the F-650 tow truck were tested in a powertrain dynamometer cell. More information on the vehicle chassis and powertrain dynamometer setups and tests can found in the Southwest Research Institute Report[7].

Considering that procurement of trucks for model validations would be time consuming and expensive, EPA developed a comprehensive approach to quantify variants of vehicles in order to maximize testing efficiency. This was done by varying aerodynamic drag and tire rolling resistance, as well as using weights to simulate different trucks, affording coverage of a wide range of vehicles. For tractors, varying these parameters also reflects the effects of pulling different types of trailers, which would impact the combined drag, rolling resistance, and weight of the vehicle. In this sense, this simultaneously provides validation data for both tractors and trailers.

Three vehicles were selected for this portion of the test program and they are: the Kenworth T270 box truck, the Kenworth T700 truck with a 53 foot box trailer, and the F-650 tow truck. The first two trucks were tested on a chassis dynamometer, while the third one was tested on a powertrain system dynamometer. A total of six drive cycles were tested: EPA GEM 55 mph, EPA GEM 65 mph, CARB HHDDT, WHVC, NREL CILCC, and HTUF Parcel Delivery cycle. An additional set of six tests were run for each driving cycle listed above to evaluate the impact of various vehicle characteristics on CO_2 emissions and fuel efficiency. The characteristics of the six test modifications are listed below:

1. Adding 800 to 1,000 pounds to the vehicle's tare weight depending on the vehicle class

2. Adding 15 percent to the vehicle-specific constant value representing the vehicle's frictional load to simulate higher rolling resistance tires

3. Reducing the vehicle-specific constant value representing the vehicle's frictional load by 15 percent to simulate lower rolling resistance tires

4. Increasing the vehicle-specific coefficient representing aerodynamic effects by 15 percent to simulate a higher aerodynamic drag vehicle

5. Decreasing the vehicle-specific coefficient representing aerodynamic effects by 15 percent to simulate a lower aerodynamic drag vehicle

6. Running a new set of road load coefficients, to represent a vehicle configuration optimized for fuel efficiency for each vehicle that was tested, which consists of the lowest rolling resistance as well as the lowest aerodynamic drag coefficient

Three valid replicate tests were conducted for each vehicle and characteristic over each driving cycle. A valid replicate was defined as a successful test run in which all data was collected without regeneration of the diesel particulate filter. The following parameters were measured or recorded during all tests:

- Vehicle speed as a function of time
- Engine fuel rate as a function of time
- Engine speed as a function of time
- Gear number as a function of time
- Engine load (Nm) as a function of time
- Emissions (NO_X, HC, CO, CO_2, N_2O, CH_4) as a function of time in g/s
- Measured cycle fuel economy (MPG) and emissions (NO_X, HC, CO, CO_2, PM, N_2O, CH_4)
- Grade as function of time for the cycle with road grade if tested

4.3.2 Results of the GEM Validations

Taking into account all of the vehicles and test configurations mentioned above, more than 130 vehicle variants were tested, allowing GEM to be comprehensively validated against a very well-defined and robust set of test data.

The results displayed in through Figure 4-3 through Figure 4-6 show the of comparison between the GEM simulations and testing data of the Class 8 Kenworth T700 truck, Class 6 Ford F-650 tow truck, Class 6 Kenworth T270 box truck, and New Flyer refuse truck respectively. In all figures shown here for 55 and 65mph cycles, road grade is not included.

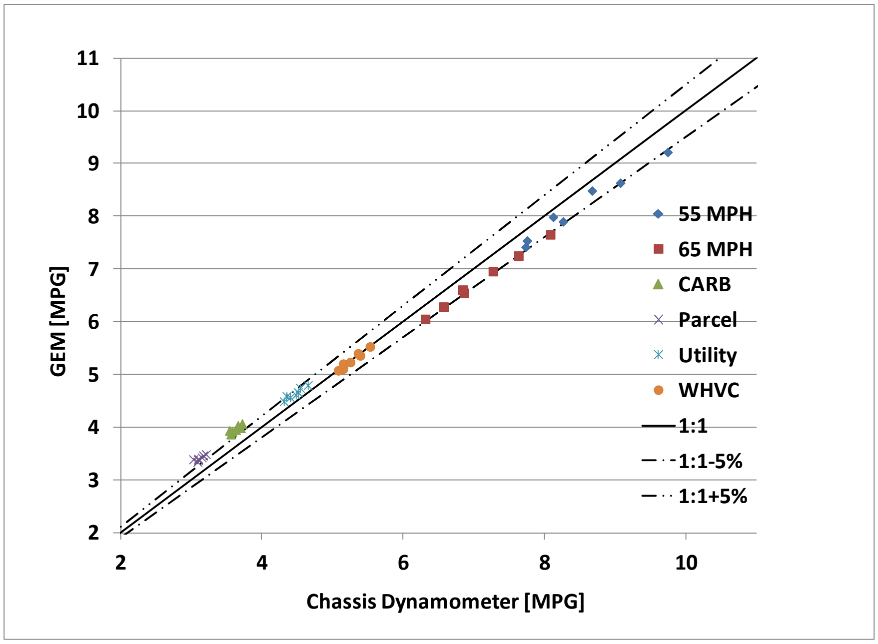

Figure 4-3 GEM Validation against Class 8 Kenworth T700 Truck chassis tests

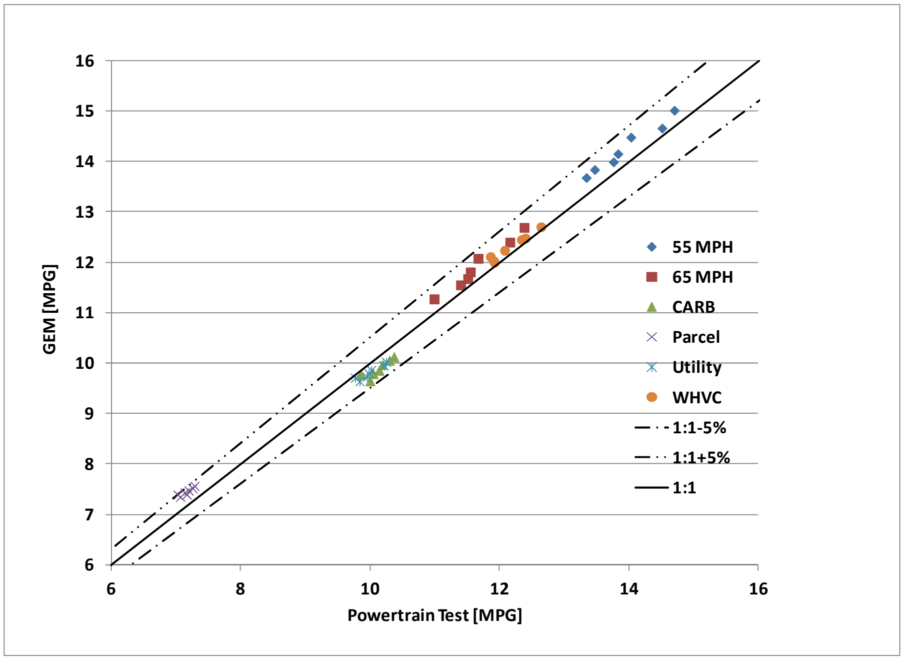

Figure 4-4 GEM validation against Class 6 Ford F-650 tow truck powertrain tests

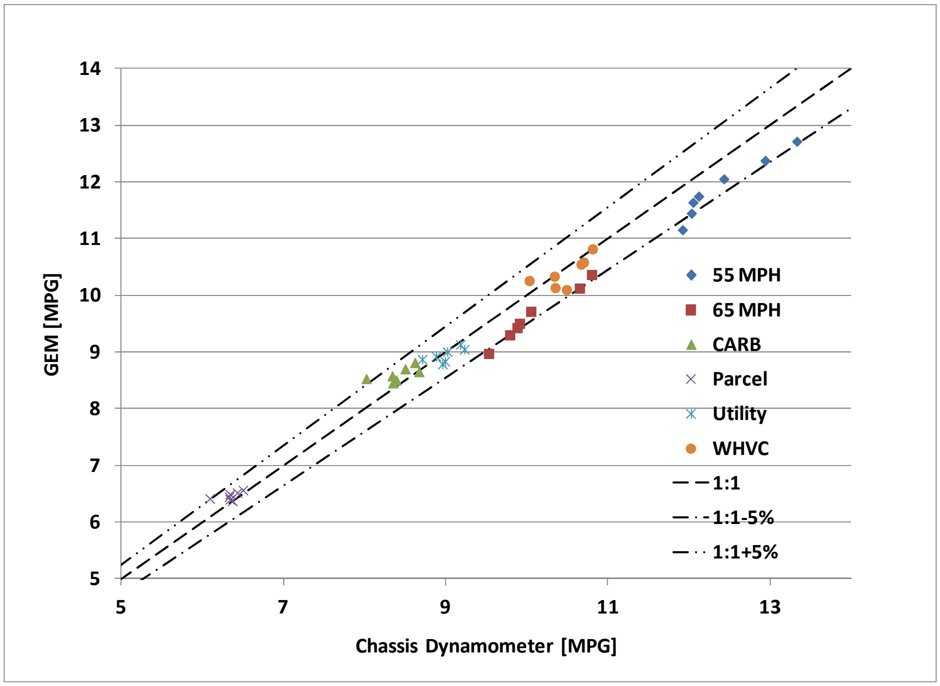

Figure 4-5 GEM validation against Class 6 Kenworth T270 box truck chassis tests

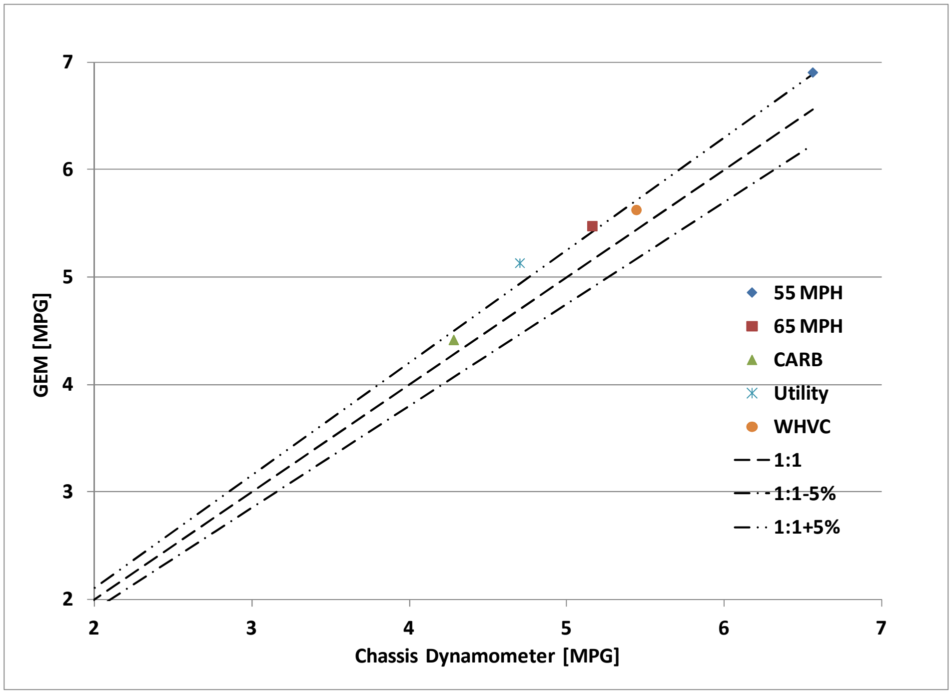

Figure 4-6 GEM validation against New Flyer refuse truck chassis tests

A review of the data indicates that there is good agreement between the GEM simulations and testing data obtained over the wide range of vehicles and conditions. In general, the accuracy of the model simulations against the testing data is very well controlled with an error of less than ±5 percent, although there are a few outliers of the transient simulation cases for Class 8 trucks due to the nature of the high variability of chassis dynamometer tests. The range of vehicles tested and simulated included vehicles that varied in terms of all of the proposed regulatory inputs. Thus, the agencies believe that the accuracy of GEM is sufficient to simulate the benefits of the range technologies that form the basis of the proposed standards.

Figure 4-7 shows the overall comparison between the simulation and test results when combining all of the testing and simulation into one figure. Overall, the simulation and test result correlate well.

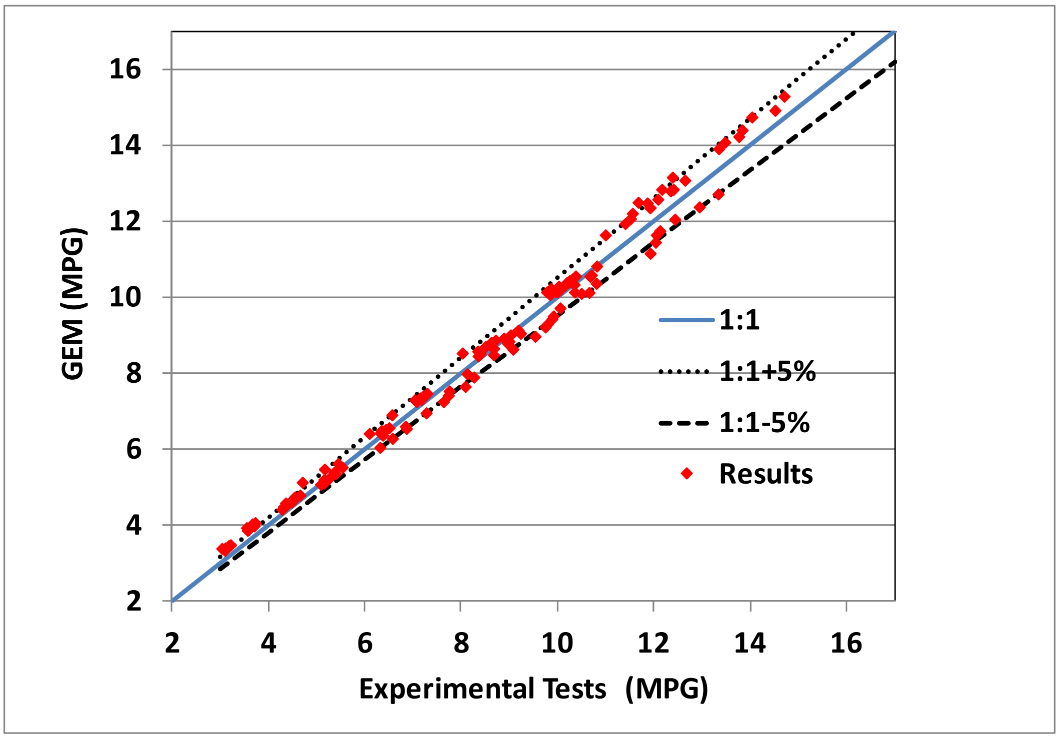

Figure 4-7 Comparison of model simulations and chassis test results for the 130 vehicle test configurations

While it is encouraging that GEM accurately simulates overall vehicle performance in an absolute sense, it is actually more important that GEM is accurate in relative comparisons. This is because the agencies used the same version of GEM to calculate the stringency of the proposed standards as was used to evaluate baseline performance for this rulemaking. The ultimate purpose of this new version of GEM will be to evaluate *changes* or *additions* in technology, and compliance is demonstrated on a relative basis to the numerical standards that were also derived from GEM. The importance of relative comparisons can be further explained with the following simplified example.

Assume you have two simulation models: one that says a baseline vehicle with Bin 3 aerodynamics and a conventional automatic transmission would be 90 g/ton-mile, and another that said the same vehicle would be 95 g/ton-mile. Assume also that there was a similar vehicle that was the basis of the new standards that had Bin 4 aerodynamics and a dual-clutch transmission. If both models simulated the second vehicle as being 10 g/ton-mile better than the baseline vehicle, then the models would work equally well for compliance as long as they were also used to set the standards. With the first model, we would set the standard at 80 g/ton-mile. And with the second, we would set the standard at 85 g/ton-mile. In both cases, manufacturers adding Bin 4 aerodynamics and dual-clutch transmissions would meet the standard. In other words, the two models would be equivalent in terms of measuring the effect of *the change* in technology on emissions, even though the absolute values were significantly different.

As is shown below, GEM indeed performs better in this relative sense. The results from the T700 and T270 trucks, and powertrain tests for the F-650 tow truck shown in Figure 4-3 through Figure 4-5, can also be presented in a format to evaluate GEM's ability to measure the relative impact of a technology. Table 4-3 shows an example of relative comparisons to illustrate how the relative comparison is done with the T700 truck. For simplicity, only the results from the Class 8 T700 tractor on the 65mph cycle are shown in this table. The column labeled as Chassis Test Fuel Economy Result (MPG) shows the testing results, while the column with GEM Fuel Economy Result (MPG) shows the GEM simulation results. Each row represents a single change to the vehicle configuration, relative to the baseline case. The "Delta" in the last column is the difference between the impact of the vehicle configuration change as measured on the chassis dynamometer and simulated in GEM (which sometimes differs from the apparent delta due to rounding). For example, the row with the "+15 percent Crr" variable compares GEM results to chassis test results for a vehicle that is the same as the baseline vehicle except that it has tires with a coefficient of rolling resistance 15 percent higher than the baseline vehicle. For this example, chassis testing indicates the change in rolling resistance increases fuel consumption for this cycle by 3.9 percent, while GEM predicts it would increase by 4.9 percent, but the delta difference is only 1.0 percent as shown in the last column.

Table 4-3 Sample of Relative Comparisons for T700 Truck

Drive Cycle	Vehicle Attribute Variables	Chassis Test Fuel Economy Result (MPG)	GEM Fuel Economy Result (MPG)	Impact of Variable on Chassis Test Result	Impact of Variable on GEM Simulation Result	Delta
65 mph	Baseline	6.84	6.61	0.0%	0.0%	0.0%
65 mph	+907 kg	6.86	6.55	-0.3%	0.9%	-1.2%
65 mph	+15% Crr	6.57	6.28	3.9%	4.9%	-1.0%
65 mph	-15% Crr	7.27	6.96	-6.3%	-5.3%	-1.0%
65 mph	+15% Cd	6.31	6.05	7.7%	8.4%	-0.7%
65 mph	-15% Cd	7.63	7.25	-11.5%	-9.8%	-1.8%
65 mph	Optimized Package	8.08	7.65	-18.1%	-15.8%	-2.3%

The same methodology was applied to all other cases including three different trucks, and six driving cycles and six vehicle variables. The differences between the chassis test and GEM results from all of these comparisons are plotted in Figure 4-8.

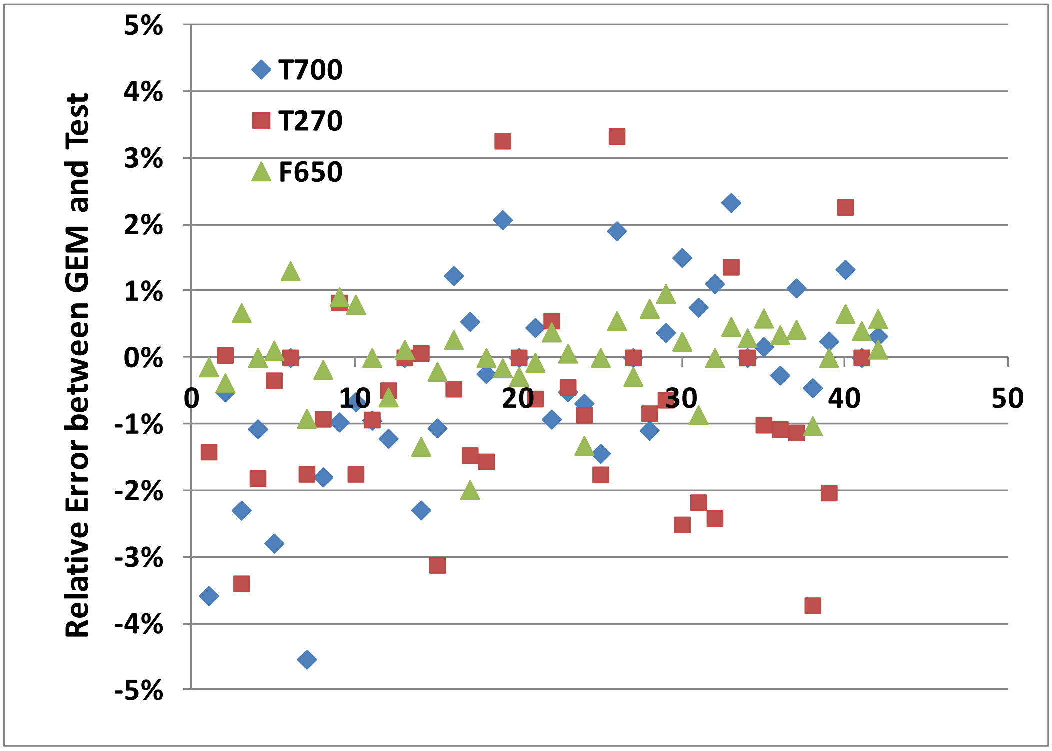

Figure 4-8 Relative comparisons between tests and GEM results

In Figure 4-8, the horizontal axis represents the test number of each truck. It can be seen that the majority of cases have less than ±2-3 percent difference. Excellent correlation was obtained between the F-650 tow truck powertrain test data and GEM results, where all of the comparisons had an error less than ±2 percent. However, a few outliers with an error greater than 3 percent can be found in the Class 8 T700 and Class 6 T270 data. This is not unexpected since all the tests for both T700 and T270 trucks were conducted on the chassis dynamometer, while the tests for F-650 tow truck were conducted in the powertrain dynamometer cell[8]. The recent findings from the SwRI program sponsored by EPA show that chassis dynamometer tests have higher variability than powertrain tests, as discussed below[9].

The driver behavior in the chassis dynamometer is one of the biggest contributors to the variability. This becomes even more an issue when a driver drives a very heavy vehicle like a Class 8 truck to follow a targeted vehicle speed trace in the chassis dynamometer cell, specifically for those highly transient cycles, such as CARB HHDDT, NREL CILCC, and HTUF Class 6 Parcel Delivery cycles. In contrast, a robot driver is used in the powertrain test for F-650 truck tests, thus removing this major source of variability. In addition, many other testing conditions, such as air temperature and coolant temperature, can be more stably controlled during powertrain than in chassis dynamometer tests. The findings also include many other sources of variability in the chassis dynamometer tests, such as tire temperature, thermal management during idle, and transmission oil temperature.9[,10] Because of the many uncertainties due to the variability of chassis dynamometer testing, it has been very challenging to match GEM results with chassis dynamometer test results in the same range of accuracy as the comparisons against the powertrain tests, specifically for those highly transient cycles. In some cases, it is hard to quantify which method, vehicle simulation or chassis dynamometer test, is more accurate. Therefore, considering the favorable comparison between the powertrain tests and GEM simulation results, it is fair to say that the overall accuracy of the GEM to represent the relative changes in fuel economy of a real world vehicle should be in the range of ±2-3 percent.

Figure 4-7 and Figure 4-8, respectively, show the GEM accuracy against over 130 vehicle variants on an absolute and a relative basis. All are done in a total vehicle configuration, which includes all vehicle components, such as engine, transmission, and driveline. Since certification would be done in a total vehicle form for CO_2 emissions and fuel efficiency, these types of comparisons are the most important because they demonstrate that GEM is capable of capturing the impact on the total vehicle CO_2 emissions and fuel consumption due to technology improvement of individual components. In order to show the fidelity of GEM in modeling individual components in a more detailed level, the comparisons for the key components must be demonstrated as well. Displayed in Figure 4-9 through Figure 4-11 are the comparisons of engine speed, fuel rate, and transmission gear numbers as function of time over the CARB HHDDT cycle for Class 8 T700 truck.

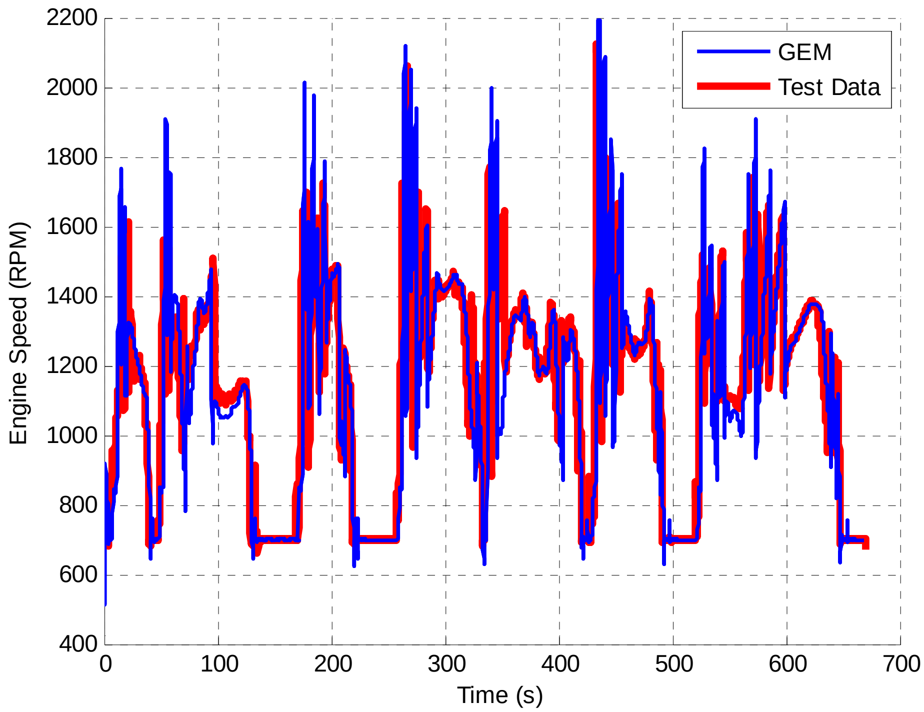

Figure 4-9 Engine speed comparisons over the WHVC for a Class 8 T700 truck

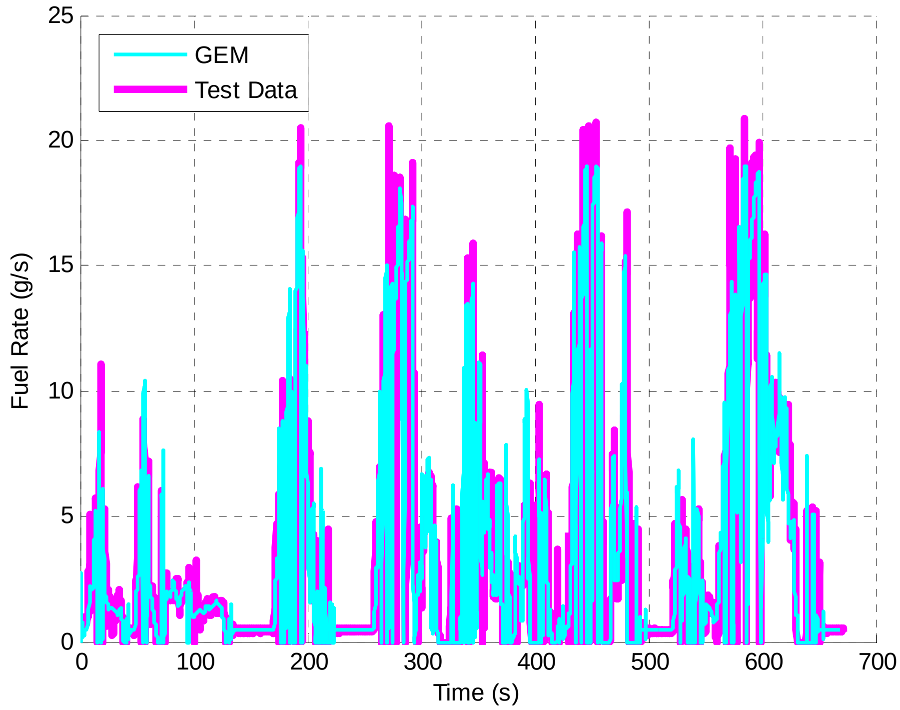

Figure 4-10 Engine fuel rate comparisons over the WHVC for a Class 8 T700 truck

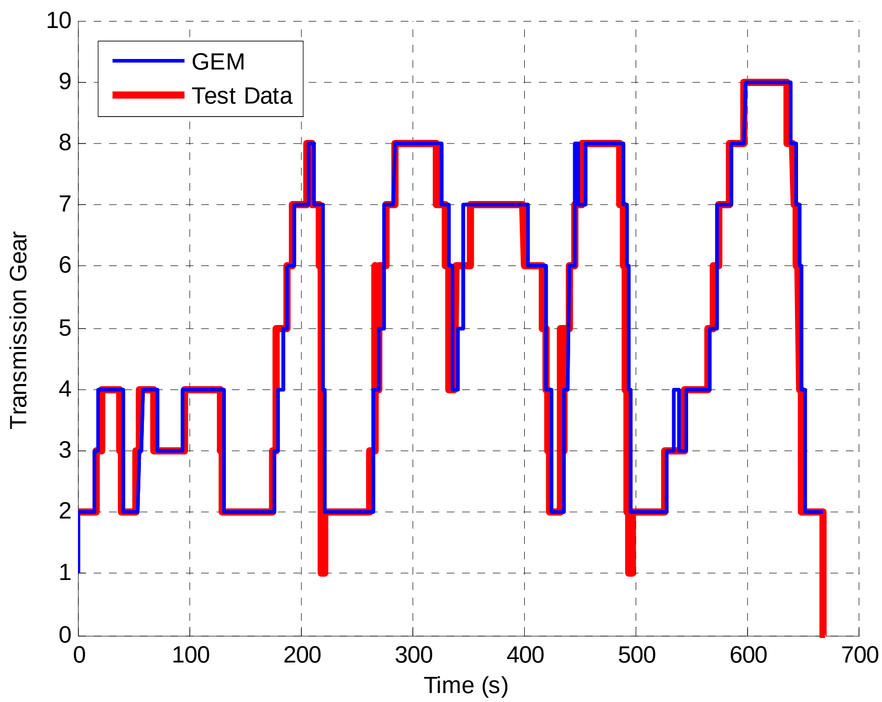

Figure 4-11 Transmission gear comparisons over the WHVC for a Class 8 T700 truck

As shown in Figure 4-9 through Figure 4-11, reasonably good comparisons between GEM simulations and tests are obtained. GEM basically can capture detailed behaviors of the engine and transmission. To further provide more complete picture on the GEM validations, Figure 4-12 and Figure 4-13 show another set of examples for an F-650 tow truck. Shown in these two figures are the comparisons of engine speed and transmission output shaft torque over the World Harmonized Vehicle Cycle (WHVC) between powertrain dynamometer tests and GEM results. As can be seen from these two figures, reasonable comparisons are again obtained between GEM and actual test results.

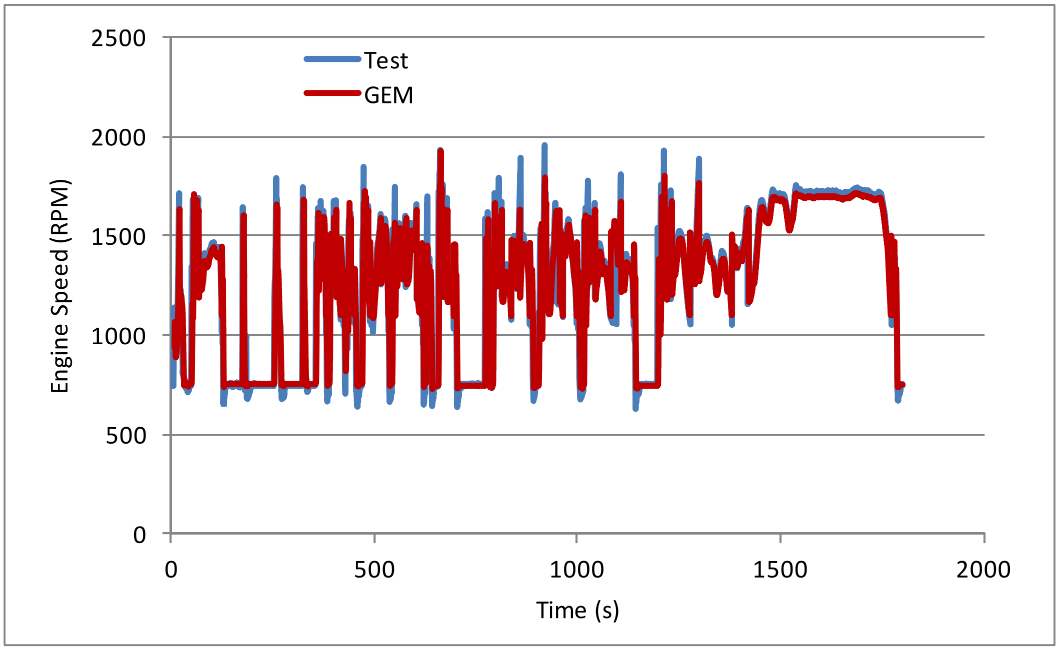

Figure 4-12 Engine speed comparisons over the WHVC for an F-650 tow truck

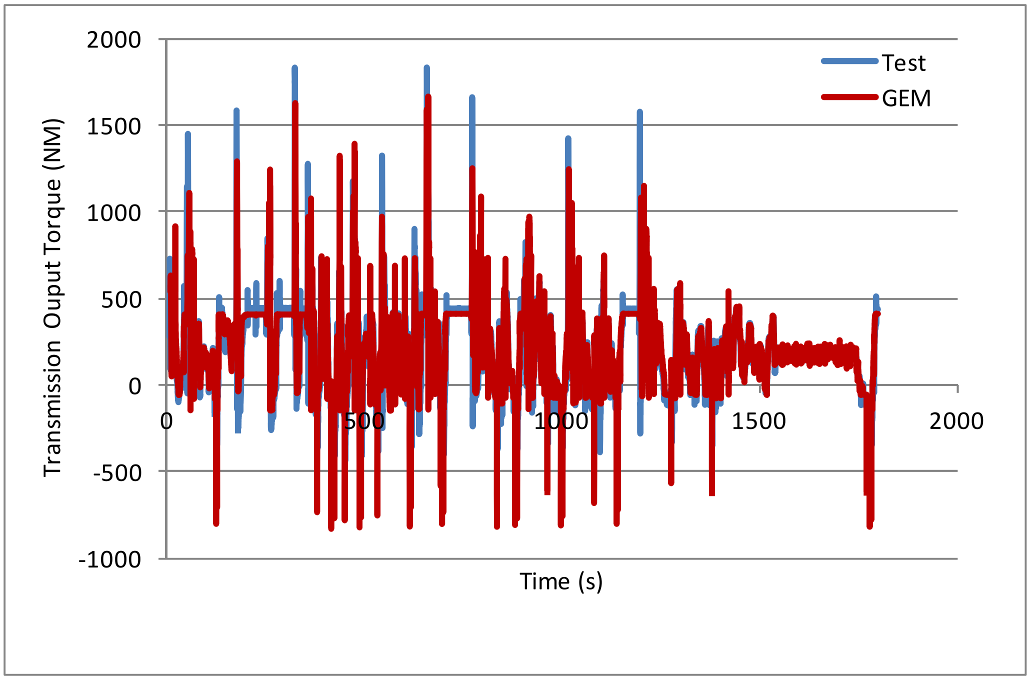

Figure 4-13 Transmission output torque comparisons over the WHVC for an F-650 tow truck

4.4 EPA and NHTSA HD Vehicle Compliance Model

As described earlier, GEM is a computer model that simulates vehicle operation to predict CO_2 emissions and fuel consumption for a wide variety of heavy-duty vehicles. This section describes how that computer model is used as a compliance tool to evaluate vehicle performance relative to the applicable standards. The engineering evaluation of GEM discussed in Chapter 4.3 was not limited by computing time and presumes all inputs to be accurate. However, using GEM as a compliance tool requires some simplification of the model. It also requires the elimination of user inputs that cannot be verified by the agencies. As discussed below, such simplifications are being proposed for Phase 2, but to a lesser degree than was done for Phase 1.

The Phase 2 GEM of EPA and NHTSA's vehicle compliance simulation model is similar to Phase 1 GEM in many respects. However, it differs from the Phase 1 version in two major aspects. The first involves the significant improvements described in Chapter of 4.2.1. Second, Phase 2 GEM provides users the opportunity to enter additional vehicle and engine parameters for the actual vehicle being simulated. As noted above, Phase 1 GEM only allows a maximum of five user defined inputs for tractors. These are: the aerodynamic drag coefficient, tire rolling resistance, vehicle speed limiter, weight reduction, and idle reduction. For vocational vehicles there is only one user defined input: tire rolling resistance. In contrast, the proposed Phase 2 GEM allows the user to input many more engine and vehicle parameters, including most of those that have the biggest impact on emissions. In particular, it allows vehicle manufacturers to input their own engine fuel maps. Key driveline parameters, such as transmission gear number versus gear ratio, axle ratio, and tire rolling radius, are also part of the manufacturer inputs.

There are still some GEM input parameters that are proposed to be pre-defined by the agencies. For some, such as shifting strategy, this is due to the fact that the parameters are hard to measure and quantify due to the lack of well-defined test procedures. For others, the manufacturers consider the parameter values to be proprietary and are reluctant to share the information with other parties. Examples of those items include the transmission gear shifting strategy table and gear mechanical efficiency. The modeling parameters associated with torque converters for automatic transmission would be also pre-defined by the agencies. The inertias of all rotational parts, vehicle weights and accessory power losses are also default parameters defined by the agencies. Finally, in order to have a consistent basis for the standards, the vehicle weights and payloads are predefined by vehicle class and duty cycle.

Table 4-6 and Table 4-7 list all of the proposed GEM input parameters for tractors and Table 4-8 through Table 4-10 list the predefined parameters for vocational vehicles. These tables also include weighting factors for each driving cycle for the determination of composite CO_2 in g/ton-mile.

It is important to note that, for many of these parameters, publicly available information on the values for current and future vehicles is limited. Manufacturers have provided values to the agencies, but have generally identified them as confidential business information. Nevertheless, we have used this information to inform our estimation of appropriate default values.

4.4.1 Predefined GEM Values

4.4.1.1 Transmissions

One of the major changes in Phase 2 GEM is to allow manufacturers to enter their transmission gear ratio versus gear number. When entering this information, manufacturers also have an option to select the type of transmission, which is either manual, automated manual or automatic with a torque converter. Mechanical efficiency for each gear is pre-defined by the agencies as shown in Table 4-5 through Table 4-10. Pre-specification was required due to the lack of a reliable, repeatable, and cost-effective test procedure.

One of the areas that required significant development work was the transmission shift strategy for use in the compliance tool. This was required because transmission suppliers have been reluctant to provide their shifting strategies to vehicle manufacturers for vehicle certification due to their concern over protecting intellectual property. The shifting strategy in the proposed Phase 2 GEM includes the agencies' internally developed automatic shift algorithm3. The impact of the use of the agencies' default transmission shifting as opposed to using manufacturers' shifting strategies has been evaluated and the results are presented in Table 4-4.

Table 4-4 Impact of the Agencies' Default Shifting Strategy Compared to Transmission Manufacturers' Strategies

Truck	Cycle	Manufacturer Shift Strategy Fuel Economy (MPG)	EPA Defined Shift Strategy Fuel Economy (MPG)	Difference (%)
T270 Box Truck	GEM 55 mph	11.36	11.36	0
T270 Box Truck	GEM 65 mph	9.24	9.24	0
T270 Box Truck	CARB HHDDT	8.39	8.44	0.60
F-650 Tow Truck	GEM 55 mph	14.49	14.57	0.55
F-650 Tow Truck	GEM 65 mph	12.03	12.14	0.91
F-650 Tow Truck	CARB HHDDT	10.32	10.72	3.88
T700 Class 8 Truck	GEM 55 mph	7.96	7.96	0
T700 Class 8 Truck	GEM 65 mph	6.59	6.59	0
T700 Class 8 Truck	CARB HHDDT	3.9	3.94	1.02

The Manufacturer column in Table 4-4 represents the simulation results using the shifting tables and strategies provided by the transmission manufacturer, while the EPA column represents the results using EPA's default shift algorithm. The transmission manufacturer and EPA fuel economy results are essentially the same despite the different shifting strategies. There is a noticeable difference in fuel economy results for the CARB HHDDT cycle, but it is still relatively small. It should be pointed out that in the case of 55 and 65 mph cruise speed cycles, there are few, if any, shifts.

Phase 2 GEM includes three types of transmissions as discussed in Chapter 4.2.2.3.3. They are manual transmissions (MT), automated manual transmissions (AMT) and automatic transmissions (AT). Due to lack of test data for other types of transmissions, GEM was not able to be validated in time against these three cases:

1. Dual clutch transmission (DCT)
2. Dual clutch transmission with a torque converter
3. Allison TC-10 automatic transmission

The agencies are proposing use of AMT to model case 1; use of AT to model case 2, and use of AT to model case 3. The manufacturers would still have the option to use powertrain dynamometer tests to quantify the benefits of these or any other special transmissions, rather than use the pre-defined values. The detailed test procedure of the powertrain dynamometer tests are described in Chapter 3 of the draft RIA

4.4.1.2 Axles

Axle ratios for all model sub-categories would be user defined. Default axle mechanical efficiency is pre-defined by the agencies. Based on comments that the agencies receive related to this NPRM, we may adopt provisions in the final rule that would allow manufacturers to override the default mechanical efficiency and input their own values; however, the inputs would be determined by using the prescribed test procedure described by Chapter 3.8 of the draft RIA.

Typical base Class 8 tractors have one steer and two drive axles, while typical base Class 7 tractors have one steer and one drive axle. The trailer used for both Class 7 and Class 8 tractors in simulation modeling has two axles. All HHD vocational vehicle categories have 3 axles, while all others only have two.

4.4.1.3 Weights

It is assumed that the vehicle unloaded weight will vary by vehicle subcategory. Taking tractors as an example, the total weight ranges from 65,500 to 70,500 lbs, while for Class 7 tractors weight ranges from 46,500 to 50,000 lbs. The payload capacity varies as shown in Table 4-5 through Table 4-10. The development of these weights is discussed in Chapter 3 of the draft RIA.

4.4.1.4 Inertia

All of the inertias for rotational parts, including engine, transmission and axle, are pre-defined based on a combination of the agencies' engineering judgment and confidential business information from OEMs. The default inertia values were used during GEM validation against respective trucks and they will be used as the default values for all of the vehicles certified using GEM. Thus, the vehicle OEM will not have flexibility to enter their own inertias.

4.4.1.5 Accessory Load

The agencies are assuming that all trucks, including tractors and vocational vehicles, carry a constant electrical load as well as mechanical load when operated over the agencies' certification drive cycles. Those agency derived values were used when GEM validations were carried out against experimentally derived data from SwRI. All of the default, pre-specified values are shown in Table 4-5 through Table 4-10, and would be used as the default values for all vehicle certification.

4.4.1.6 Tires

Tire radius is a user defined input; however, the agencies do provide default values for all vehicle sub-categories. Static loaded tire radius is used in GEM for all simulations for every combination tractor and the default value can be overridden by the vehicle OEM.

The trailer tire coefficient of rolling resistance (Crr, trailer tires) assumes a constant value for all trailer tires. This value was developed through tire testing performed by the SmartWay Transport Partnership.[11]

4.4.1.7 Idle Cycle and Its Modeling

As described in Chapter 3.4.2 of this draft RIA, we are proposing the addition of an idle-only cycle to determine both fuel consumption and CO_2 emissions when a vocational vehicle is idling, and to recognize technologies that either reduce the fuel consumption rate or shut the engine off (and restart) during short-term idle events during the workday. Based on user inputs, GEM would calculate CO_2 emissions and fuel consumption at both zero torque (neutral idle) and with torque set to Curb-Idle Transmission Torque (as defined in 40 CFR 1065.510(f)(4) for variable speed engines) for use in the CO_2 emission calculation in 40 CFR 1037.510(b). We are also proposing that GEM would calculate reduced CO_2 and fueling for stop-start systems, based on an assumption that the effectiveness would represent a 90 percent reduction of the emissions that would occur if the vehicle had operated at Curb-Idle Transmission Torque over this cycle. This cycle is proposed to be applicable for all subcategories of vocational vehicles (HHD, MHD and LHD) using any of the proposed composite duty cycles (Regional, Multi-Purpose, or Urban composite duty cycles). More can be seen in Chapter 3.4.2.3 about the idle cycle. Chapter 4.5 discusses how these idle technologies are modeled as part of technology improvements that are recognized in GEM.

4.4.1.8 Transient Adjustment Factor

As described in Chapter 2, fuel consumption during transient engine operation typically is higher than during steady-state operation. The difference can vary significantly, but the trend is generally consistent. Because the GEM simulation relies on steady-state fuel maps to predict emissions for all the cycles, including the transient cycle, the agencies are proposing to apply a transient adjustment to GEM results for the transient cycle.

4.4.1.8.1 Transient Engine Testing

To evaluate the need for a transient adjustment factor, we compared the results from 28 individual engine dynamometer tests. Three different engines were used to generate this data, and these engines were produced by two different engine manufacturers. One engine was tested at three different power ratings (13 liters at 410, 450 & 475 hp) and the other engines ranged from medium heavy-duty (6.7 liters, 300 hp) to heavy heavy-duty (15 liters, 455 hp) service classes. For each engine and rating our proposed steady-state engine dynamometer test procedure was conducted to generate the data table to represent that particular engine in GEM. Next, GEM simulated various vehicles in which the engine could be installed. For each of the GEM duty cycles we are proposing, namely the urban local (CARB HHDDT), urban highway with road grade (GEM 55 mph), and rural highway with road grade (GEM 65 mph) duty cycles, we determined the GEM result for each vehicle configuration, and we saved the engine output shaft speed and torque information that GEM utilized to interpolate the steady-state engine data table for each vehicle configuration We then had this same engine output shaft speed and torque information programmed into the engine dynamometer controller, and we had each engine perform the same duty cycles that GEM demanded of the simulated version of the engine. We then compared the GEM interpolated results to the measured engine dynamometer results. We concluded that for the 55 mph and 65 mph duty cycles, GEM's interpolation of the steady-state data tables was sufficiently accurate versus the measured results. This is reasonable because even with changes in road grade, the 55 mph and 65 mph duty cycles do not demand rapid changes in engine speed or load. They are nearly steady-state, just like the data tables themselves. However, for the CARB HHDDT cycle, we observed a consistent bias, where GEM consistently under-predicted fuel consumption and CO_2 emissions. This low bias over the 28 engine tests ranged from 4.2 percent low to 7.8 percent low. When we aggregated these results by engine, the results were between 5 and 6 percent. We understand that use of an engine dynamometer test with GEM inputs of torque and speed to quantify the impact of using a steady state engine fuel map would not be perfect, since this approach would not consider the interaction of the driver model of GEM in response to individual vehicle component dynamics. Also, the input torque and speed values calculated in GEM and input into the engine dynamometer are only targeted values and they are not the real measured engine torque and speed. Since the engine may not be able to follow the targeted speed trace, there may be some discrepancy compared to the vehicle performance obtained from GEM. Accessory loads between the engine test and GEM simulation are also different. In spite of these differences, it is a common fact that steady state operation is different from transient operation, specifically in a diesel engine.

The most significant difference between steady state and transient behavior is the smoke control during acceleration. Diesel engines must limit the fueling in order to prevent smoke during rapid acceleration. In contrast, there is no such issue during steady state mapping. Furthermore, all modern diesel engines use a fueling cut-off technique to shut off the fueling during deceleration based on a manufacturer-defined set of conditions. In addition, thermal management is another major factor to that may create a difference between steady state and transient fueling. The aftertreatment system is very sensitive to exhaust temperature in order to maintain optimal performance of selective catalytic reduction devices. Post fueling must be injected into the exhaust stream once the exhaust temperature is below certain criteria, typically in the range of 200 degrees Celsius. In steady state fueling mapping, the engine always follows the defined testing procedure; thus, the engine runs hotter even at light loads than in a transient condition at the same speed and torque, thus thermal management may not even kick in. Because of these differences, engine manufacturers typically include at least two distinguished engine calibrations into the engine control unit – one for typically on-highway operation, and the other for transient operation, such as urban and mountainous areas.

We are confident that this low bias in GEM results using a steady state fuel map would continue to exist well into the future if we were to test additional engines. However, with the range of the results that we have generated so far we are somewhat less confident in proposing a single numerical value to correct for this bias over the CARB HHDDT drive cycle. The procedure used to derive this proposed correction adjustment factor, although reasonable, may still need more refinement.

4.4.1.8.2 Proposed Value for the Transient Adjustment Factor

Based on the limited testing that was performed for this analysis, the agencies are proposing a transient adjustment factor of 1.05. This means that the simulated transient cycle GEM results (that are generated based on steady-state fuel maps) would be multiplied by 1.05 before being output from the GEM compliance tool. The higher output value would be the official GEM result.

This 1.05 factor reflects the engine at the lower end of the range for the three engines, with the other two engines indicating values of 1.06 or 1.07 might be appropriate. The agencies are proposing the lower value because we do not want to allow manufacturers to gain an advantage from powertrain testing without making some improvement to the powertrain. The test results indicate that an adjustment of 1.07 would allow the ISX engine (which showed a lower transient difference) to show a 2 percent improvement without making any improvements. The agencies recognize that there is significant uncertainty in the proposed value and will continue to evaluate the adjustment. The agencies would likely consider values in the range of 1.00 to 1.07.

4.4.1.9 Tractor Tables

Table 4-5 through Table 4-7 display the predefined GEM parameters proposed for the Phase 2 tractor compliance model. The predefined parameters were developed using the same methodology used in Phase 1. Many of the parameters are based on the vehicles EPA selected to test at SwRI and are considered to reasonably represent the fleet in their respective categories. For example, the transmission gear ratio, axle ratio, tire diameters, and all accessory losses used for all tractors shown in these three tables are from the Kenworth T700 truck tested at SwRI. All of the other predefined parameters, such as the engine power rating, vehicle weight, payload, follow the Phase 1 structure. The gear mechanical efficiency as well as axle mechanical efficiency was developed based on several verbal communications from stakeholders. For further detail regarding how these parameters are chosen and used in GEM see Chapters 4.4.3 to 4.4.9.

Table 4-5 Class 8 Combination Tractor Sleeper Cab Predefined Modeling Parameters

Regulatory Class	Class 8 Combination	Class 8 Combination	Class 8 Combination
	Sleeper Cab - High Roof	Sleeper Cab - Mid Roof	Sleeper Cab - Low Roof
Gearbox Efficiency	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	31978	30277	30390
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental Air Temperature (°C)	25	25	25
Payload (tons)	19	19	19
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.05	0.05	0.05
GEM 55 mph	0.09	0.09	0.09
GEM 65 mph	0.86	0.86	0.86

Table 4-6 Class 8 Combination Tractor Day Cab Predefined Modeling Parameters

Regulatory Subcategory	Class 8 Combination Day Cab - High Roof	Class 8 Combination Day Cab - Mid Roof	Class 8 Combination Day Cab - Low Roof
Gearbox Efficiency	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	31297	29529	29710
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental air temperature (°C)	25	25	25
Payload (tons)	19	19	19
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.19	0.19	0.19
GEM 55 mph	0.17	0.17	0.17
GEM 65 mph	0.64	0.64	0.64

Table 4-7 Class 7 Combination Tractor Predefined Modeling Parameters

Regulatory Subcategory	Class 7 Combination	Class 7 Combination	Class 7 Combination
	Day Cab - High Roof	Day Cab - Mid Roof	Day Cab - Low Roof
Gearbox Efficiency	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for the gear with a 1:1 gear ratio, and 96% for all other gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	22679	20910	21091
Axle Base	4	4	4
Default Axle Configuration	4x2	4x2	4x2
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental air temperature (°C)	25	25	25
Payload (tons)	12.5	12.5	12.5
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.19	0.19	0.19
GEM 55 mph	0.17	0.17	0.17
GEM 65 mph	0.64	0.64	0.64

4.4.1.10 Vocational Tables

Table 4-8 through Table 4-10 display the predefined GEM parameters proposed for use for the vocational vehicle compliance model. Many of the parameters are based on the vehicles EPA selected to test at SwRI and are considered to reasonably represent the fleet in their respective categories. For example, the Kenworth T270 truck and Ford F-650 tow truck are used as vehicles to represent the MHD and LHD vocational vehicle fleet, while the Kenworth T700 and New Flyer refuse trucks are used to represent the fleet of HHD vocational vehicles. With those vehicles as reference, it helps to determine the type of transmission and its gear ratio, tire diameters, and all accessory losses used for all vocational vehicles shown in these three tables. Tire radius and axle ratios were selected, using good engineering judgment and stakeholder input, to reflect reasonable final drive ratios to match with our modeled transmissions. With the exception of the Multi-purpose and Urban HHD vehicles, the engine power rating is the same as in Phase 1. For these two subcategories, the agencies selected 11L-345 hp engines because this is a more typical power rating for vehicles that are not long haul. Other parameters, such as the engine power rating, vehicle weight, payload, weight reduction, tire rolling resistance, frontal area, and axle base, etc. follow the Phase 1 structure. The gear mechanical efficiency as well as axle mechanical efficiency is selected based on the inputs from stakeholders. The weighting of steer tire Crr and drive tire Crr is different than in Phase 1 to better reflect the weight distribution over the steer and drive axles. The assignment of 50 percent of reduced weight back to payload is different than in Phase 1 and not the same as for tractors. See the draft RIA Chapter 2 for details. Chapter 4.4.3 to 4.4.9 explains how these parameters are used in GEM.

The agencies propose to expand the number of vocational subcategories from three (in Phase 1) to nine (in Phase 2). It can be seen from Table 4-8 through Table 4-10, the agencies are also proposing to add an idle cycle for vocational vehicles to the duty cycles used in Phase 1 certification.

Table 4-8 Vocational HHD Vehicle Predefined Modeling Parameters

Regulatory Subcategory	HHD Regional Duty Cycle	HHD Multi-Purpose Duty Cycle	HHD Urban Duty Cycle
Gearbox Efficiency	98% for the gear with a 1:1 gear ratio, and 96% for all other gears	98% for all gears	98% for all gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	19051	19051	19051
Number of Axles	3	3	3
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	6.86	6.86	6.86
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	7.50	7.50	7.50
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.50	0.82	0.94
GEM 55 mph	0.28	0.15	0.06
GEM 65 mph	0.22	0.03	0.00
Idle cycle	0.10	0.15	0.20

Table 4-9 Vocational MHD Vehicle Predefined Modeling Parameters

Regulatory Subcategory	MHD	MHD	MHD
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Gearbox Efficiency	98% for all gears	98% for all gears	98% for all gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	11408	11408	11408
Number of Axles	2	2	2
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	5.40	5.40	5.40
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	5.60	5.60	5.60
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.50	0.82	0.94
GEM 55 mph	0.28	0.15	0.06
GEM 65 mph	0.22	0.03	0.00
Idle cycle	0.10	0.15	0.20

Table 4-10 Vocational LHD Vehicle Predefined Modeling Parameters

Regulatory Subcategory	LHD Regional Duty Cycle	LHD Multi-Purpose Duty Cycle	LHD Urban Duty Cycle
Gearbox Efficiency	98% for all gears	98% for all gears	98% for all gears
Axle Mechanical Efficiency	95.5%	95.5%	95.5%
Total weight (kg)	7257	7257	7257
Number of Axles	2	2	2
Electrical Accessory Power (W)	300	300	300
Mechanical Accessory Power (W)	1000	1000	1000
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	5.40	5.40	5.40
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	2.85	2.85	2.85
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.50	0.82	0.94
GEM 55 mph	0.28	0.15	0.06
GEM 65 mph	0.22	0.03	0.00
Idle cycle	0.10	0.15	0.20

4.4.1.11 Trailer Tables

Trailers are simulated using the same GEM models as the tractor program. There are only minor differences between the trailer and tractor modeling parameters and inputs. Table 4-11 lists all of the predefined vehicle parameters of trailer baseline models. The predefined modeling parameters for the long box dry van trailer subcategory are identical to the Class 8 high-roof sleeper cab tractor subcategory. The other trailer subcategories differ in tractor cab type, total weight, aerodynamic characteristics, number of axles, payload, and drive cycle. For example, the refrigerated trailers include a refrigeration unit which adds weight and slightly improves aerodynamic performance (reduces CdA). Short box vans are half the length, have a single axle, and are pulled by a day cab tractor which reduces total weight and the total payload carrying capacity. The drive cycle weightings are consistent with the tractor program. Long box trailers are simulated as being pulled by sleeper cabs, and therefore have the long-haul drive cycle weightings. The short box trailers are pulled by day cabs and have the short-haul weightings.

Similar to the tractor program, trailer manufacturers can provide aerodynamic drag, tire rolling resistance and weight reduction inputs to the model. The key differences between the trailer and tractor options are that aerodynamic drag is submitted as a *change* in drag (delta CdA) for trailers, which is compared to the baseline CdA values shown in Table 4-11 within GEM, and only adjustments to *trailer* tire rolling resistance are allowed. A list of weight reduction options is available in 40 CFR 1037.520 and manufacturers have the option to indicate that their trailers use Automatic Tire Inflation Systems (ATIS) for a predefined additional performance improvement. Additional information about each trailer subcategory is found in Chapter 2.10 of this draft RIA.

Table 4-11 Predefined Modeling Parameters for Box Trailers

Regulatory Subcategory	Long Box Dry Van	Long Box Refrigerated Van	Short Box Dry Van	Short Box Refrigerated Van
Tractor Type	C8 Sleeper Cab - High Roof		C8 Day Cab - High Roof	
Engine Fuel Map	15L - 455 HP			
Gear ratio	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1, 0.73			
Gearbox Efficiency	98% for 1:1 gear ratio, and 96 for all other gears			
Axle Mechanical Efficiency	95.5%			
Total weight (kg)	31978	33778	15191	16991
Baseline CdA Values (m^2)	6.2	6.1	6.1	6.0
Number of Axles	5		4	
Payload (tons)	19		10	
Default Axle Configuration	6x4			
Electrical Accessory Power (W)	300			
Mechanical Accessory Power (W)	1000			
Steer Tire RR	6.54			
Drive Tire RR	6.92			
Tire Radius (m)	0.5			
Axle Drive Ratio	3.7			
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr			
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons			
Drive Cycles & Weightings:				
CARB HHDDT	0.05		0.19	
GEM 55 mph	0.09		0.17	
GEM 65 mph	0.86		0.64	
Payload (tons)	19		7	

4.5 Technology Improvements that Are Recognized in GEM without Simulation

The development of GEM as a compliance tool has required the agencies to balance the need for simplicity against the rigor of the model. As part of that process, the agencies have identified several technologies and technological improvements that would be difficult to accurately simulate, but that should be recognized during certification. These would be recognized in the proposed Phase 2 GEM through post-simulation adjustments to the results. This is similar to what was done in Phase 1, where the GEM interface included pull-down menus for manufacturers to select these adjustments. For this reason, these adjustments have come to be known as pull-down technologies.

Phase 2 GEM would continue to recognize those technologies that would be difficult to model accurately. In addition to those recognized in Phase 1, the technology list is expanded to a much wider range as discussed in the next few paragraphs of this Chapter. In contrast to the Phase 1 approach, Phase 2 GEM uses a different approach in recognizing these technologies. First of all, all technology improvements are built into GEM. Default improvement values for each of these technologies, developed by the agencies after consulting various stakeholders and searching for literature values, are implemented into GEM. The user can only select either "Y" or "N" in the GEM input file, where Y means that the technology is included, while N means the vehicle does not have this technology. This means that users have no flexibility to enter their own values.

For some of these technologies, such as predictive cruise control and Automatic Tire Inflation Systems (ATIS), the actual benefit is dependent on how operators behave in the real world. For example, ATIS would be of very little benefit where a driver made sure on a daily basis that the tires were properly inflated, but would have large benefits where a driver never checked the tires. For other technologies, the benefits of the technology are small relative to the difficulty of rigorously simulating it. The agencies believe the technology improvement approach is an appropriate compromise that will achieve the regulatory goal of incentivizing the use of the technology.

In this proposed approach, the GEM software would adjust the simulation results to decrease the g/ton-mile results that are output by the model. For example, with a technology that is assigned a 1 percent benefit, the official result for a vehicle that was simulated as having 500 g/ton-mile CO_2 emissions would be reported as having an emission rate of 495 g/ton-mile.

The technology improvement values used for tractors are shown in Table 4-12. These values represent the agencies' best judgment about the appropriate value for each of these technologies. We are generally assigning minimum values to be conservative and not overestimate the actual in-use benefits. These values were developed based on all available information, including information from stakeholders.

Table 4-12 Tractor Technology Improvement Values

Technology Improvement	Class 8 Sleeper Cabs	Class 8 Day Cabs	Class 7 Day Cabs	Class 8 Heavy Haul Tractors
Single Drive Axle (6x2 or 4x2) Configuration	2.5%	2.5%	N/A	2.5%
Part-time Single Drive Axle 6x2 Configuration[a]	2.5%	2.5%	N/A	2.5%
Low Friction Axle Lubricant	0.5%	0.5%	0.5%	0.5%
Automated Manual, Automatic, and Dual Clutch Transmissions	2%	2%	2%	2%
Predictive Cruise control	2%	2%	2%	2%
High Efficiency Air Conditioning Compressor	0.5%	0.5%	0.5%	0.5%
Electric Accessories	1%	1%	1%	1%
Extended Idle Reduction	5%	N/A	N/A	N/A
Automatic Tire Inflation System (ATIS)	1%	1%	1%	1%

Note:
[a] A 2.5% reduction over the 55 mph and 65 mph cycles and no reduction over the CARB HHDDT cycle

For vocational vehicles, the technologies in Table 4-13 would be considered.

Table 4-13 Vocational Vehicle Technology Improvement Values

Technology Improvement	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
HHD Single Drive Axle (6x2 or 4x2) Configuration	2.5%	2.5%	2.5%
HHD Part-time Single Drive Axle 6x2 Configuration[a]	1.0%	0.3%	0.1%
Low Friction Axle Lubricant	0.5%	0.5%	0.5%
HHD Automated Manual or Dual Clutch Transmissions	2.3%	N/A	N/A
PTO Delta Fuel (g/ton-mile)	0 to 30	0 to 30	0 to 30
Neutral Idle	Emissions during idle cycle calculated using torque and speed values from idle fuel map with the transmission in drive and neutral, 10% and 90% of the cycle time, respectively[b]		
Stop-Start Idle Reduction	90 percent reduction of idle-cycle emissions calculated using torque and speed values from idle fuel map with the transmission in drive[b]		

Notes:
[a] Based on 2.5% reduction over the 55 mph and 65 mph cycles and no reduction over the CARB HHDDT cycle
[b] See idle fuel consumption test procedure at 40 CFR 1036.535(d).

For trailers, the following technologies in Table 4-14 would be considered.

Table 4-14 Trailer Technology Improvement Values

Technology Improvement	Effectiveness
Automatic Tire Inflation Systems	1.5%

If a manufacturer believes that the CO_2 reduction benefits assigned by the agencies are an underestimate, they have the option to perform powertrain testing or request (and demonstrate) credit in the off-cycle technology process.

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Chapter 5: Impacts on Emissions and Fuel Consumption

5.1 Executive Summary

Climate change is widely viewed as the most significant long-term threat to the global environment. According to the IPCC, it is extremely likely (>95 percent probability) that human influence was the dominant cause of the observed warming since the mid-20th century. The primary GHGs of concern are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride.[1] Mobile sources emitted 28 percent of all U.S. GHGs in 2012 when considering all upstream and downstream emissions, and the transportation-related GHGs alone have grown 18 percent between 1990 and 2012.[2] Mobile sources addressed in the recent endangerment finding under CAA Section 202(a) – highway vehicles including passenger cars, light-duty trucks, heavy-duty trucks, buses, and motorcycles – accounted for 24 percent of all U.S. GHGs in 2012.[3] Heavy-duty vehicles emit CO_2, methane, nitrous oxide, and hydrofluorocarbons and are responsible for almost 22 percent of all mobile source GHGs (over 6 percent of all U.S. GHGs) and about 26 percent of CAA Section 202(a) mobile source GHGs. For heavy-duty vehicles in 2007, CO_2 emissions represented nearly 97 percent of all GHG emissions (including HFCs).[4]

This chapter provides the anticipated emissions impacts from the proposed standards. In addition, the emissions impacts of Alternative 4 are presented because the agencies are carefully considering it along with the preferred alternative. The reductions in emissions are expected for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs). In addition to reducing the emissions of greenhouse gases, this program would also affect the emissions of "criteria" air pollutants and their precursors, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), oxides of sulfur (SO_X), volatile organic compounds (VOC) and oxides of nitrogen (NO_X), and several air toxics, such as benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

The proposed standards will affect both diesel- and gasoline-fueled heavy-duty vehicles, as well as those running on natural gases. The analyses account for both vehicle emissions ("downstream" emissions) and emissions from fuel production and distribution ("upstream" emissions). The agencies conducted coordinated and complementary analyses by employing both DOT's CAFE model and EPA's Motor Vehicle Emission Simulator (MOVES2014)[5], relative to different reference cases (i.e., different baselines). The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed complementary analyses, using the CAFE model ("Method A") and the MOVES model ("Method B"), to estimate fuel consumption and emissions from these vehicles. See Section 5.3 for additional details. The changes in upstream emissions result from decreased fuel consumption. The emission factors from GREET[6] were used to estimate the changes in upstream emissions. In some cases, the GREET values were modified or updated by the agencies to be consistent with the EPA's National Emission Inventory (NEI) and emission factors from MOVES.

Table 5-1 through Table 5-3 summarize the impact of the proposed program on GHG emissions from the heavy-duty sector in calendar years 2025, 2035 and 2050, using Method A and B, relative to two reference cases – more dynamic and less dynamic. Table 5-4 through Table 5-6 summarize the projected fuel savings from the proposed program in calendar years 2025, 2035 and 2050, using Method A and B, relative to the two reference cases. The comparable analyses for Alternative 4 are summarized in Table 5-7 through Table 5-12.

Table 5-1 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	27.2	86.9	123.0
Upstream	9.3	29.7	42.0
HFC	0.09	0.25	0.3
Total	36.6	116.9	165.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-2 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	28.1	94.6	134.9
Upstream	9.6	32.3	46.1
HFC	0.09	0.25	0.3
Total	37.8	127.2	181.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-3 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	27.4	94.7	136.5
Upstream	9.3	32.2	46.5
HFC	0.1	0.25	0.3
Total	36.8	127.2	183.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-4 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	2.5	5.1%	7.6	14.3%	10.8	17.0%
Gasoline	0.2	2.4%	0.9	11.0%	1.2	13.2%
Total	2.7	4.7%	8.5	13.8%	12.0	16.5%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-5 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	2.5	5.2%	8.3	15.4%	11.9	18.4%
Gasoline	0.2	2.6%	1.0	11.5%	1.3	13.7%
Total	2.7	4.8%	9.3	14.8%	13.2	17.8%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-6 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	2.5	5.1%	8.5	15.6%	12.3	18.7%
Gasoline	0.2	2.1%	0.8	10.4%	1.1	12.8%
Total	2.7	4.7%	9.3	14.9%	13.4	18.0%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-7 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	33.5	90.9	124.0
Upstream	11.5	31.0	42.3
HFC	0.09	0.25	0.3
Total	45.1	122.2	166.6

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-8 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	34.6	98.7	136.0
Upstream	11.8	33.7	46.5
HFC	0.09	0.25	0.3
Total	46.5	132.7	182.8

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-9 Annual Total Reductions of Heavy-Duty GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	33.7	98.3	136.9
Upstream	11.5	33.4	46.6
HFC	0.1	0.25	0.3
Total	45.3	132.0	183.8

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-10 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	3.0	6.1%	7.9	14.8%	10.8	17.0%
Gasoline	0.3	3.9%	1.0	12.1%	1.3	13.8%
Total	3.3	5.8%	8.9	14.4%	12.1	16.6%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-11 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	3.1	6.3%	8.6	16.0%	12.0	18.5%
Gasoline	0.3	4.3%	1.1	12.5%	1.3	14.3%
Total	3.4	6.0%	9.7	15.5%	13.3	18.0%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-12 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

	CY2025		CY2035		CY2050	
	Billion Gallons	% Reduction	Billion Gallons	% Reduction	Billion Gallons	% Reduction
Diesel	3.1	6.2%	8.8	16.1%	12.3	18.7%
Gasoline	0.3	3.4%	0.9	11.1%	1.1	12.9%
Total	3.4	5.9%	9.7	15.5%	13.4	18.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

The non-GHG impacts of the proposed rulemaking are largely driven by three factors. The largest contributor is from the projected increased use of auxiliary power units (APUs), which provide power, heat and cooling for trucks during extended engine idling. Reduced emissions from upstream fuel production and distribution also contribute significantly to the emissions benefits. Emissions of certain pollutants, such as NO_X and $PM_{2.5}$ are further reduced through improved engine efficiency, aerodynamics and tire rolling resistance and absolute changes in average total running weight of the vehicles. To a smaller extent, a rebound of vehicle miles traveled (VMT) would increase the emissions of all pollutants proportional to the VMT rebound amount. The emissions impacts of non-GHGs on both downstream and upstream from the heavy-duty sector in calendar years 2025, 2035 and 2050 are summarized in Table 5-13 through Table 5-15, using Method A and B, relative to the two reference cases. The comparable analyses for Alternative 4 are summarized in Table 5-16 through Table 5-18.

Table 5-13 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	3%	25	13%	34	16%
Acetaldehyde	672	10%	1,893	30%	2,682	36%
Acrolein	97	10%	273	31%	387	37%
Benzene	145	5%	421	18%	595	22%
CO	30,282	3%	87,286	8%	123,876	10%
Formaldehyde	2,119	11%	5,969	32%	8,460	37%
NO_X	101,916	7%	291,282	26%	413,501	31%
$PM_{2.5}$	376	1%	1,535	3%	2,199	4%
SO_X	6,213	5%	19,905	14%	28,101	17%
VOC	16,227	6%	49,080	18%	69,525	22%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-14 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	3%	25	13%	35	16%
Acetaldehyde	672	10%	1,891	30%	2,680	36%
Acrolein	97	10%	273	31%	386	37%
Benzene	145	5%	425	18%	603	22%
CO	30,487	3%	88,724	8%	126,081	10%
Formaldehyde	2,119	11%	5,969	32%	8,461	37%
NO_X	102,983	7%	299,911	26%	427,332	32%
$PM_{2.5}$	419	1%	1,910	4%	2,791	5%
SO_X	6,421	5%	21,672	15%	30,850	18%
VOC	16,403	6%	50,812	19%	72,253	23%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-15 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	2.7%	25	15.1%	36	19.4%
Acetaldehyde	674	10.1%	1,902	30.5%	2,697	36.0%
Acrolein	97	9.8%	274	31.3%	388	36.9%
Benzene	149	5.4%	445	18.8%	633	22.9%
CO	29,622	1.9%	85,961	6.6%	122,659	8.4%
Formaldehyde	2,121	11.4%	5,978	31.7%	8,475	37.0%
NO_X	102,502	7.2%	298,907	26.6%	426,610	32.1%
SO_X	386	0.6%	1,883	4.2%	2,815	5.4%
$PM_{2.5}$	6,070	4.9%	20,777	15.3%	30,000	18.4%
VOC	16,724	5.6%	52,872	18.8%	75,521	22.7%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-16 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Alternative 4 vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	3%	25	13%	34	16%
Acetaldehyde	673	10%	1,893	30%	2,682	36%
Acrolein	97	10%	273	31%	387	37%
Benzene	152	6%	426	18%	595	22%
CO	31,383	3%	88,047	8%	124,137	10%
Formaldehyde	2,123	11%	5,970	32%	8,460	37%
NO_X	105,693	7%	293,918	26%	413,967	31%
$PM_{2.5}$	639	1%	1,703	4%	2,237	4%
SO_X	7,682	6%	20,849	15%	28,385	17%
VOC	18,006	6%	50,189	19%	69,796	22%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-17 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Alternative 4 vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	3%	25	13%	35	16%
Acetaldehyde	672	10%	1,891	30%	2,679	36%
Acrolein	97	10%	273	31%	386	37%
Benzene	153	6%	430	18%	603	22%
CO	31,637	3%	89,514	8%	126,360	10%
Formaldehyde	2,123	11%	5,969	32%	8,460	37%
NO_X	106,822	7%	302,575	26%	427,805	32%
$PM_{2.5}$	689	1%	2,082	5%	2,833	5%
SO_X	7,941	6%	22,646	16%	31,151	18%
VOC	18,222	6%	51,924	19%	72,509	23%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-18 Annual Total Reductions (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions – Alternative 4 vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	9	2.8%	26	15.2%	36	19.4%
Acetaldehyde	676	10.1%	1,903	30.6%	2,697	36.0%
Acrolein	97	9.8%	274	31.3%	388	36.9%
Benzene	157	5.7%	450	18.9%	634	22.9%
CO	30,580	1.9%	86,526	6.6%	122,703	8.4%
Formaldehyde	2,125	11.4%	5,980	31.7%	8,476	37.0%
NO_X	106,180	7.4%	301,339	26.8%	426,796	32.1%
SO_X	646	1.1%	2,036	4.6%	2,827	5.4%
$PM_{2.5}$	7,450	6.1%	21,550	15.9%	30,364	18.4%
VOC	18,652	6.2%	53,966	19.2%	75,621	22.7%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.2 Introduction

5.2.1 Downstream (Tailpipe) Emissions

As described in more detail in this chapter, the downstream reductions in emissions due to the proposed program are anticipated to be achieved through improvements in engine efficiency, road load reduction, and APU use during extended idling, with the exception of $PM_{2.5}$.[A] Absolute reductions in tailpipe emissions are projected to grow over time as the fleet turns over to vehicles affected by the proposed standards, meaning that the emissions benefits of the program would continue to grow as older vehicles in the fleet are replaced by newer vehicles that emit less CO_2.

The effect of the regulations on the timing of fleet turnover and total VMT can have an impact on downstream GHG and other emissions, as discussed in Section IX of the preamble. If the regulations spur firms to increase their purchase of new vehicles before efficiency standards are in place (“pre-buy”) or to delay their purchases once the standards are in place then there would be a delay in achieving the full GHG and other emission reductions from improved fuel economy across the fleet. If the lower per-mile costs associated with higher fuel economy lead to an increase in VMT (the “rebound effect”), then the total emission reductions would also be reduced. Chapter 8 of the draft RIA provides more detail on how the rebound effect was calculated in the agencies’ analysis. The analysis discussed in this chapter incorporates the rebound effect into the estimates. However, the impacts of any delayed fleet turnover are not estimated.

[A] The projected increased use of APUs would lead to higher $PM_{2.5}$ emissions since engines powering APUs are currently required to meet less stringent PM standards than on-road engines.

5.2.2 Upstream Emissions

In addition to downstream emission reductions, reductions are expected in the emissions associated with the processes involved in getting fuel to the pump, including the extraction and transportation of crude oil, the production and distribution of finished gasoline and diesel, and the production and transportation of renewable fuels. Changes are anticipated in upstream emissions due to the expected reduction in the overall volume of gasoline and diesel consumed. Less fuel consumed means less fuel transported, less fuel refined, and less crude oil extracted and transported to refineries. Thus, there would be reductions in the emissions associated with each of these steps in the fuel production and distribution processes. In addition, any changes in downstream reductions associated with changes in fleet turnover, and VMT are reflected in a corresponding change in upstream emissions associated with fuel processing and distribution.

The agencies recognize that the proposed standards could lower the world price of oil (the "monopsony" effect, further discussed in Chapter 8 of the draft RIA). Lowering oil prices could lead to an uptick in oil consumption globally, resulting in a corresponding increase in GHG emissions in other countries. This global increase in emissions could slightly offset some of the emission reductions achieved domestically as a result of the regulation. EPA does not provide quantitative estimates of the impact of the proposed regulation on global petroleum consumption and GHG emissions in this draft RIA.

5.2.3 Global Warming Potentials

Throughout this document, in order to refer to the four inventoried greenhouse gases on an equivalent basis, Global Warming Potentials (GWPs) are used. In simple terms, GWPs provide a common basis with which to combine several gases with different heat trapping abilities into a single inventory (Table 5-19). When expressed in CO_2eq terms, each gas is weighted by its heat trapping ability relative to that of CO_2. The GWPs used in this analysis are consistent with the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) on a 100-year timescale.[7]

Table 5-19 Global Warming Potentials of GHGs

GAS	GLOBAL WARMING POTENTIAL (CO_2EQ)
CO_2	1
CH_4	25
N_2O	298
HFC134a	1,430

5.3 Program Analysis and Modeling Methods

5.3.1 Models Used

Different tools exist for estimating potential fuel consumption and emissions impacts associated with fuel efficiency and GHG emissions standards. One such tool is EPA's official mobile source emissions inventory model named Motor Vehicle Emissions Simulator (MOVES).[8] The agencies used the most current version of the model, MOVES2014, to quantify the impacts of these proposed standards on GHG emissions, fuel consumption, as well as criteria pollutants and air toxics emissions. In MOVES, vehicle types are categorized by their use and represented by combination tractors, single unit trucks, refuse trucks, motor homes, transit buses, intercity buses, school buses, and light commercial trucks. The agencies ran MOVES with user input databases that reflected the projected technological improvements resulting from the proposed rules, such as the improvements in engine and vehicle efficiency, aerodynamic drag, and tire rolling resistance. The changes made to the default MOVES database are described below in Section 5.3.2. All the input data, MOVES runspec files, and the scripts used for the analysis, as well as the version of MOVES used to generate the emissions inventories, can be found in the docket.[9]

Another such tool is DOT's CAFE model. For this analysis, the model was reconfigured to use the work based attribute metric of "work factor" established in the Phase 1 rule for heavy-duty pickups and vans, instead of the light-duty "footprint" attribute metric. The CAFE model takes user-specified inputs on, among other things, vehicles that will be produced in a given model year, technologies available to improve fuel efficiency on those vehicles, potential regulatory standards that would drive improvements in fuel efficiency, and economic assumptions. The CAFE model takes every vehicle in each manufacturer's fleet and decides what technologies to add to those vehicles in order to allow each manufacturer to comply with the standards in the most cost-effective way and uses a representation of the HD pickup and van fleet that captures heterogeneity at the manufacturer, model year, and powertrain (and other technology) level. Based on the resulting improved vehicle fleet, the CAFE model then calculates total fuel consumption and GHG, criteria, and toxics emissions impacts based on those inputs, along with economic costs and benefits. The CAFE model is discussed in greater detail in Chapter 10 of the draft RIA.

For this rule, the agencies conducted coordinated and complementary analyses by employing both DOT's CAFE model and EPA's MOVES model. These models were used to project the impacts resulting from the proposed standards on fuel consumption, GHG emissions, as well as criteria pollutants and air toxics emissions. As described in Section 5.3.2, the agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed complementary analyses using the CAFE model ("Method A") and the MOVES model ("Method B") to estimate fuel consumption and emissions from these vehicles. For both methods, the agencies analyzed the impact of the proposed rules, relative to two different reference cases – less dynamic and more dynamic. The less dynamic baseline projects very little improvement in new vehicles in the absence of new Phase 2 standards. In contrast, the more dynamic baseline projects more improvements in vehicle fuel efficiency. The agencies considered both reference cases, reaching corroborative conclusions. The results for all of the regulatory alternatives relative to both reference cases, derived via the same methodologies discussed in this Chapter, are presented in Chapter 11 of the draft RIA and these different analyses all support the reasonableness of the proposed standards.

For brevity, a subset of these analyses are presented in this section, and the reader is referred to both the Chapter 11 of the draft RIA and NHTSA's DEIS Chapters 3 and 5 for complete sets of these analyses. In this Chapter, Method A is presented for both the proposed standards (i.e., Alternative 3 – the agencies' preferred alternative) and for the standards the agencies considered in Alternative 4. Method A is presented relative to both the more dynamic baseline (Alternative 1b) and the less dynamic baseline (Alternative 1a). Method B is presented also for the proposed standards and Alternative 4, but relative only to the less dynamic baseline. The agencies' intention for presenting both of these complementary and coordinated analyses is to offer interested readers the opportunity to compare the regulatory alternatives considered for Phase 2 in both the context of our HD Phase 1 analytical approaches and our light-duty vehicle analytical approaches. The agencies view these analyses as corroborative and reinforcing: both support agencies' conclusion that the proposed standards are appropriate and at the maximum feasible levels.

Because reducing fuel consumption also affects emissions that occur as a result of fuel production and distribution (including renewable fuels), the agencies also calculated those "upstream" changes using the "downstream" fuel consumption reductions predicted by the MOVES model for vocational vehicles and tractor-trailers. As described earlier, for HD pickups and vans, parallel and complementary analyses of estimating the emissions from upstream processes were conducted using the fuel consumption estimates from both DOT's CAFE model (Method A) and EPA's MOVES model (Method B), relative to the two reference cases. Method A used the CAFE model to estimate vehicular fuel consumption and emissions impacts for HD pickups and vans and to calculate upstream impacts. For vocational vehicles and combination tractor-trailers, both Method A and Method B estimated the projected corresponding changes in upstream emissions using the same tools originally created for the Renewable Fuel Standard 2 (RFS2) rulemaking analysis,[10] used in the LD GHG rulemakings,[11] HD GHG Phase 1,[12] and updated for the current analysis. The estimate of emissions associated with production and distribution of gasoline and diesel from crude oil is based on emission factors in the "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" model (GREET) developed by DOE's Argonne National Lab. In some cases, the GREET values were modified or updated by the agencies to be consistent with the National Emission Inventory (NEI) and emission factors from MOVES. Method B used the same tool described above to estimate the upstream impacts for HD pickups and vans.

Updates and enhancements to the GREET model assumptions include updated crude oil and gasoline transport emission factors that account for recent EPA emission standards and modeling, such as accounting for impacts of fuel requirements on vapor emissions from storage and transport. In addition, GREET does not include air toxics. Thus, emission factors for the following air toxics were added: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. These upstream toxics emission factors were calculated from the 2005 National Emissions Inventory (NEI), a risk and technology review for petroleum refineries, speciated emission profiles in EPA's SPECIATE database, or the Mobile Source Air Toxics rulemaking (MSAT) inventory for benzene; these pollutant tons were divided by refinery energy use or gasoline distribution quantities published by the DOE Energy Information Administration (EIA) to get emission factors in terms of grams per million BTU of finished gasoline and diesel. These updates are consistent with those used for the upstream analysis included in the LD GHG rulemaking and HD GHG Phase 1. The actual calculation of the emission inventory impacts of the decreased gasoline and diesel production is done in EPA's tool for upstream emission impacts.[13]

5.3.2 Calculation of Downstream Emissions

5.3.2.1 Model inputs and Assumptions for the Less Dynamic Reference Case

The less dynamic reference case (identified as Alternative 1a in Section X of the preamble and Chapter 11 of the draft RIA), a "no action" alternative, functions as one the baselines against which the impacts of the proposed standards can be evaluated and includes the impact of HD GHG Phase 1, but generally assumes that fuel efficiency and GHG emission standards are not improved beyond the required 2018 model year levels. However, the less dynamic reference case projects some improvements in the efficiency of the box trailers pulled by combination tractors due to increased penetration of aerodynamic technologies and low rolling resistance tires attributed to both EPA's SmartWay Transport Partnership and California Air Resources Board's Tractor-Trailer Greenhouse Gas regulation, as described in Section IV of the preamble. For other HD vehicle sectors, no market-driven improvement in fuel efficiency was assumed. For HD pickups and vans, the CAFE model was applied in a manner that assumes manufacturers would only add fuel-saving technology as needed to continue complying with Phase 1 standards. MOVES2014 defaults were used for all other parameters to estimate the less dynamic reference case emissions inventories. For the aerodynamic drag and tire rolling resistance coefficients of combination tractor-trailers and vocational vehicles, default MOVES values for each MOVES source/vehicle type were used that represent a fleet-wide adoption of HD GHG Phase 1.

The less dynamic reference case assumed the MOVES2014 default vehicle population and vehicle miles traveled (VMT).[14] The growth in vehicle populations and miles traveled in MOVES2014 is based on the relative annual VMT growth from AEO2014 Early Release for model years 2012 and later.[15] For extended idling emission inventories, the MOVES2014 default auxiliary power unit (APU) penetration rates were used. These rates assume that 30 percent of all combination long-haul tractors model year 2010 and later use an APU during extended idling.[B]

5.3.2.2 Model inputs and Assumptions for the More Dynamic Reference Case

The more dynamic reference case (identified as Alternative 1b in Section X of the preamble and Chapter 11 of the draft RIA), also includes the impact of Phase 1 and generally assumes that fuel efficiency and GHG emission standards are not improved beyond the required 2018 model year levels. However, for this case, the agencies assume market forces would lead to additional fuel efficiency improvements for tractors and trailers. These additional assumed improvements are described in Section X of the preamble. No additional fuel efficiency improvements due to market forces were assumed for vocational vehicles. For HD pickups and vans, the agencies applied the CAFE model using the input assumption that manufacturers having achieved compliance with Phase 1 standards would continue to apply technologies for

[B] The agencies assessed the current level of automatic engine shutdown and idle reduction technologies used by the tractor manufacturers to comply with the 2014 model year CO_2 and fuel consumption standards. To date, the manufacturers are meeting the 2014 model year standards without the use of this technology. Therefore, the agencies are reverting the baseline APU adoption rate back to 30 percent, the value used in the HD GHG Phase 1 baseline.

which increased purchase costs would be "paid back" through corresponding fuel savings within the first six months of vehicle operation. The agencies conducted the MOVES analysis of this case in the same manner as for the less dynamic reference case.

5.3.2.3 Model Inputs and Assumptions for the Control Case

The control case (identified as Alternative 3 in Chapter 11 of the draft RIA) represents the agencies' proposed fuel efficiency and GHG standards for HD engines, HD pickup trucks and vans, Class 2b through Class 8 vocational vehicles, Class 7 and 8 combination tractors, and trailers. To account for improvements of engine and vehicle efficiency in vocational vehicles and combination tractor-trailers, EPA developed additional user input data for MOVES runs to estimate the control case inventories.

The agencies used the percent reduction in aerodynamic drag and tire rolling resistance coefficients and absolute changes in average total running weight (gross combined weight) expected from the proposed rules to develop the road load inputs for the control case. For running emissions, the key concept underlying the definition of operating mode in MOVES is scaled tractive power (STP), vehicle speed and vehicle acceleration.[16] STP represents the vehicle's tractive power scaled by a constant factor. It is calculated using mass of the vehicle and road load factors that include tire rolling resistance, aerodynamic drag, and friction losses in the drivetrain. STP is estimated using the equation below:

$$STP_t = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{f_{scale}} \qquad \textbf{Equation 5-1}$$

Where:

A = the rolling resistance coefficient [kW·sec/m],
B = the rotational resistance coefficient [$kW \cdot sec^2/m^2$],
C = the aerodynamic drag coefficient [$kW \cdot sec^3/m^3$],
m = mass of individual vehicle [metric ton],
f_{scale} = fixed mass factor,
v_t = instantaneous vehicle velocity at time t [m/s],
a_t = instantaneous vehicle acceleration [m/s^2]

The proposed improvements in road load factors would reduce the tractive power exerted by a vehicle to move itself and its cargo. The emissions emitted by heavy-duty trucks are a function of STP as determined from a variety of data sources. Thus, a reduction in road load factors are expected to result in reduced GHG and non-GHG emissions. The improvements in tire rolling resistance, aerodynamic drag, and absolute changes in average vehicle weight expected from the technologies which could be used to meet the proposed standards were modified in the "sourceusetypephysics" table.[C]

For vocational vehicles and tractor-trailers, the agencies also used the percent reduction in CO_2 emissions expected from the powertrain and other vehicle technologies not accounted for in the aerodynamic drag and tire rolling resistance in the proposed rules to develop energy inputs for the control case runs. In contrast, for HD pickup trucks and vans, the proposed standards were evaluated only in terms of the total vehicle reductions in fuel use and CO_2 emissions, since nearly all of these vehicles would be certified on a chassis dynamometer. Finally, EPA used an assumed percent penetration of APU use during extended idling, based on the expectation that manufacturers will use APUs to meet the vehicle GHG standard for combination long-haul tractors, as discussed in Section III.D of the preamble.

5.3.2.3.1 Emission Rate and Road Load Inputs

Both the stringency and the form of the proposed fuel consumption and CO_2 emission standards vary by vehicle category. Accordingly, the modeling of the proposed standards in MOVES varies by the vehicle category. For the vocational vehicles and combination tractor-trailers, EPA has analyzed the impacts of the proposed standards by evaluating the technologies applied to the energy rates as well as to the road load inputs. However, the impacts on the HD pickup trucks and vans were estimated only in terms of reduction in energy rates.

5.3.2.3.1.1 Tractor-Trailers

Similar to the approach used in the HD GHG Phase 1 analysis, EPA aggregated the nine tractor subcategories into the two MOVES combination tractor-trailer categories – short-haul and long-haul. The agencies used sales distribution data from the HD GHG Phase 1 analysis and determined the long-haul reductions in energy rates and road load factors, based on a sales mix assumption of 80 percent high roof, 15 percent mid roof, and 5 percent low roof sleeper cabs. The short-haul combination tractors were evaluated using a day cab sales distribution assumption of 7 percent Class 7 low roof, 10 percent Class 7 high roof, 40 percent Class 8 low roof, 35 percent Class 8 high roof, and 8 percent vocational tractors, based on the information used in the HD GHG Phase 1 analysis. The details of the analyses aggregating the tractor subcategories into MOVES categories using the sales mix assumption described above can be found in the docket.[17]

The trailer category encompasses many types of trailers. As with the tractor category, EPA aggregated the trailer subcategories into two MOVES combination tractor-trailer categories. EPA used a combination of ACT Research's 2013 factory shipment data[18] for trailer distribution by type and "primary trip length" information from the U.S. Census' 2002 Vehicle Inventory and Use Survey[19] to distribute each trailer type into long- and short-haul categories. EPA applied the trailer market percentages as shown in Table 5-20 to determine the trailer impact on the MOVES long- and short-haul combination tractor-trailer categories.

[C] Class 2b and 3 trucks do not use the STP metric and are regulated, for non-GHG emissions, based on chassis testing (gram per mile basis) rather than engine testing (gram per brake horsepower-hour basis), therefore road load reductions are not necessarily expected to result in reduced non-GHG emissions.

Table 5-20 Aggregation of Trailer Types into MOVES Combination Tractor-Trailer Categories

TRAILER TYPE	Combination Long-Haul Tractor-Trailers	Combination Short-Haul Tractor-Trailers
Long Dry Van	55.5%	20.3%
Short Dry Van	12.3%	20.2%
Long Refrigerated Van	18.2%	2.6%
Short Refrigerated Van	5.2%	3.8%
Special Purpose Van	0.0%	6.4%
Container Chassis	0.2%	1.8%
Flatbed	6.9%	10.9%
Tank	0.4%	1.5%
Other On-Highway Trailers	1.2%	2.7%
Off-Road Trailers	0.0%	29.9%

Table 5-21 describes the improvements in the energy rate expected from the heavy-duty engine, transmission, and driveline technologies which could be applied to meet the proposed tractor standards. The percentage reductions from the reference case were applied to the default MOVES energy rates in the appropriate source bins within MOVES "emissionrate" table.

Table 5-21 Estimated Reductions in Energy Rates for the Proposed Standards for Tractor-Trailers

VEHICLE TYPE	FUEL	MODEL YEARS	REDUCTION FROM REFERENCE CASE
Long-haul Tractor-Trailers	Diesel	2018-2020	1.3%
		2021-2023	5.2%
		2024-2026	9.7%
		2027+	10.4%
Short-haul Tractor-Trailers[D]	Diesel	2018-2020	0.9%
		2021-2023	5.0%
		2024-2026	9.5%
		2027+	10.4%

Table 5-22 contains the improvements in tire rolling resistance, coefficient of drag, and weight reductions expected from the technologies which could be used to meet the proposed standards for combination tractor-trailers. The percentage reductions in tire rolling resistance and drag coefficients and the absolute changes in average vehicle weight were modified in the "sourceusetypephysics" table.

[D] Vocational tractors are included in the short-haul tractor segment.

Table 5-22 Estimated Reductions in Road Load Factors for the Proposed Standards for Tractor-Trailers

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[A]
Combination Long-haul Tractor-Trailers	2018-2020	5.5%	5.1%	-131
	2021-2023	9.8%	15.3%	-199
	2024-2026	15.7%	20.5%	-246
	2027+	17.9%	26.9%	-304
Combination Short-haul Tractor-Trailers[E]	2018-2020	4.0%	1.6%	-41
	2021-2023	10.5%	9.3%	-79
	2024-2026	13.9%	12.3%	-100
	2027+	17.6%	15.9%	-127

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

In addition, the projected use of auxiliary power units (APU) during extended idling, shown below in Table 5-23, was included in the modeling for the long-haul combination tractor-trailers by modifying the "hotellingactivitydistribution" table in MOVES.

Table 5-23 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Trucks[a]	2010-2020	30%
	2021-2023	80%
	2024+	90%

Note:
[a] The assumed APU penetration remains constant for model years 2024 and later.

5.3.2.3.1.2 Vocational Vehicles

Similar to the approach for tractor-trailers, EPA aggregated the nine vocational vehicle subcategories into each of the seven MOVES vehicle types.[F] The energy rate inputs were derived by applying the anticipated levels of engine, axle, transmission, and idle reduction technologies equally across all weight classes and vehicle types. Each of these technology packages is described in Chapter 2 of the draft RIA. The differences between gasoline and diesel vocational vehicles in energy rate reduction from the reference cases, shown in Table 5-24, are due to the differences in anticipated engine-level technology packages, as described in Chapter 2 of the draft RIA.

[E] Vocational tractors are included in the short-haul tractor segment.
[F] Seven MOVES vehicle types for vocational vehicles are intercity bus, transit bus, school bus, refuse truck, single-unit short-haul truck, single-unit long-haul truck, and motor home.

The percentage reductions from the reference case were applied to the default MOVES energy rates in the appropriate source bins within MOVES “emissionrate" table.

Table 5-24 Estimated Reductions in Energy Rates for the Proposed Standards for Vocational Vehicles

VEHICLE TYPE	FUEL	MODEL YEARS	REDUCTION FROM REFERENCE CASE
Single-Frame Vocational[G]	Diesel & CNG	2021-2023	5.3%
		2024-2026	8.9%
		2027+	13.3%
	Gasoline	2021-2023	3.3%
		2024-2026	5.4%
		2027+	10.3%

The agencies used MOVES population data for new vehicles expected to be sold in 2018 for each weight class, as well as assumptions about their distribution among the three new vocational vehicle duty cycles. This population allocation is shown in Table 5-25.

Table 5-25 Vocational Vehicle Types and Population Allocation

VEHICLE TYPE	RURAL	MULTI-PURPOSE	URBAN
Short Haul Straight Truck	35%	60%	5%
Long Haul Straight Truck, Motor Home, Intercity Bus	100%	0%	0%
School Bus	0%	100%	0%
Transit Bus	0%	75%	25%
Refuse	0%	0%	100%
All Class 4-5	23%	21%	2%
All Class 6-7	15%	19%	1%
All Class 8	7%	8%	4%

Using these population distribution estimates and the technology application rates described in Chapter 2 of the draft RIA, EPA derived the levels of improvements in tire rolling resistance and weight reduction.

Table 5-26 contains the improvements in tire rolling resistance, coefficient of drag, and weight reductions expected from the technologies which could be used to meet the proposed standards for vocational vehicles. The percentage reductions in tire rolling resistance and drag coefficients and the absolute changes in average vehicle weight were modified in the

[G] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

"sourceusetypephysics" table in MOVES. The analyses used to develop the MOVES inputs for vocational vehicles, described above, can be found in the docket.[20]

Table 5-26 Estimated Reductions in Road Load Factors for the Proposed Standards for Vocational Vehicles

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)
Intercity Buses	2021-2023	6.5%	0%	0
	2024-2026	9.2%	0%	0
	2027+	16.5%	0%	0
Transit Buses	2021-2023	0%	0%	0
	2024-2026	2.9%	0%	0
	2027+	3.0%	0%	0
School Buses	2021-2023	0%	0%	0
	2024-2026	2.9%	0%	0
	2027+	4.0%	0%	0
Refuse Trucks	2021-2023	0%	0%	20
	2024-2026	2.9%	0%	20
	2027+	3.0%	0%	25
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	5.8
	2024-2026	8.3%	0%	5.8
	2027+	13.0%	0%	7
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	20
	2024-2026	9.2%	0%	20
	2027+	16.5%	0%	25
Motor Homes	2021-2023	3.0%	0%	0
	2024-2026	6.2%	0%	0
	2027+	7.4%	0%	0

5.3.2.3.1.3   Heavy-Duty Pickup Trucks and Vans

As explained above, the agencies used both DOT's CAFE model and EPA's MOVES model, using analytical Method A and B, respectively, to project fuel consumption, GHG and non-GHG emissions impacts resulting from the proposed standards for HD pickups and vans, including downstream vehicular emissions as well as emissions from upstream processes related to fuel production, distribution, and delivery.

5.3.2.3.1.3.1   Method A for HD Pickups and Vans

For Method A, the CAFE model calculated fuel consumption rates, then calculated vehicular CO_2 emissions from the fuel consumption based on fuel properties (density and carbon content). It also applies per-mile emission factors from MOVES to estimated VMT (for each regulatory alternative, adjusted to account for the rebound effect) in order to calculate vehicular CH_4 and N_2O emissions (as well, as discussed below, of non-GHG pollutants), and applies per-gallon upstream emission factors from GREET in order to calculate upstream GHG (and non-GHG) emissions.

Consistent with HD GHG Phase 1 approach, the proposed standards for HD pickups and vans are established as a function of the vehicle work factor, a metric unique to this segment which is calculated based on the vehicle capabilities (i.e., payload, towing and four-wheel drive). As proposed, the work-factor-based standards would increase in stringency by 2.5 percent per year, starting in MY 2021 until they reach the final level of the proposed standards in MY 2027. The standards define targets specific to each vehicle model, but no vehicle is required to meet its target; instead, the production-weighted averages of the vehicle-specific targets define average fuel consumption and CO_2 emission rates that a given manufacturer's overall fleet of produced vehicles is required to achieve. The standards are specified separately for gasoline and diesel vehicles, and vary with work factor. Work factors could change, and today's analysis assumes that some applications of mass reduction could enable increased work factor in cases where manufacturers could increase a vehicle's rated payload and/or towing capacity. Therefore, average required levels will depend on the mix of vehicles and work factors of the vehicles produced for sale in the U.S., and since these can only be estimated at this time, average required and achieved fuel consumption and CO_2 emission rates are subject to uncertainty. Between today's notice and issuance of the ensuing final rule, the agencies intend to update the market forecast (and other inputs) used to analyze HD pickup and van standards, and expect that doing so will lead to different estimates of required and achieved fuel consumption and CO_2 emission rates (as well as different estimates of impacts, costs, and benefits).

The following four tables present stringency increases and estimated required and achieved fuel consumption and CO_2 emission rates for the two No Action Alternatives (Alternative 1a and 1b) and the proposed standards defining the Preferred Alternative. Stringency increases are shown relative to standards applicable in model year 2018 (and through model year 2020). As mathematical functions, the standards themselves are not subject to uncertainty. By 2027, they are 16.2 percent more stringent (i.e., lower) than those applicable during 2018-2020. The DOT's CAFE model estimate that, by model 2027, the proposed standards could reduce average required fuel consumption and CO_2 emission rates to about 4.86 gallons/100 miles and about 458 grams/mile, respectively. The model further estimate that average achieved fuel consumption and CO_2 emission rates could correspondingly be reduced to about the same levels. If, as represented by Alternative 1b, manufacturers would, even absent today's proposed standards, voluntarily make improvements that pay back within six months, these model year 2027 levels are about 13.5 percent lower than the agencies estimate could be achieved under the Phase 1 standards defining the No Action Alternative. If, as represented by Alternative 1a, manufacturers would, absent today's proposed standards, only apply technology as required to achieve compliance, these model year 2027 levels are about 15 percent lower than the agencies estimate could be achieved under the Phase 1 standards. As indicated below, the agencies estimate that these improvements in fuel consumption and CO_2 emission rates would build from model year to model year, beginning as soon as model year 2017 (insofar as manufacturers may make anticipatory improvements if warranted given planned produce cadence).

Table 5-27 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved Fuel Consumption Rates for Method A, Relative to Alternative 1b [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED FUEL CONS. (GAL./100 MI.)			AVE. ACHIEVED FUEL CONS. (GAL./100 MI.)		
		No Action	Proposed	Reduction	No Action	Proposed	Reduction
2014	MYs 2014-2020 Subject to Phase 1 Standards	6.41	6.41	0.0%	6.21	6.21	0.0%
2015		6.41	6.41	0.0%	6.12	6.12	0.0%
2016		6.27	6.27	0.0%	6.15	6.15	0.0%
2017		6.11	6.11	0.0%	5.89	5.88	0.2%
2018		5.80	5.80	0.0%	5.75	5.70	0.8%
2019		5.78	5.78	0.0%	5.72	5.68	0.7%
2020		5.78	5.78	0.0%	5.69	5.64	0.8%
2021	2.5%	5.77	5.64	2.2%	5.63	5.42	3.8%
2022	4.9%	5.77	5.50	4.7%	5.63	5.42	3.8%
2023	7.3%	5.77	5.38	6.8%	5.63	5.28	6.3%
2024	9.6%	5.77	5.25	9.0%	5.63	5.23	7.1%
2025	11.9%	5.77	5.12	11.4%	5.63	4.99	11.5%
2026	14.1%	5.77	4.98	13.7%	5.63	4.93	12.5%
2027	16.2%	5.77	4.86	15.8%	5.62	4.86	13.7%
2028*	16.2%	5.77	4.86	15.8%	5.62	4.86	13.7%
2029*	16.2%	5.77	4.86	15.8%	5.62	4.85	13.7%
2030*	16.2%	5.77	4.86	15.8%	5.62	4.85	13.7%

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
*Absent further action, standards assumed to continue unchanged after model year 2027.

Table 5-28 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved CO_2 Emission Rates for Method A, Relative to Alternative 1b [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED CO_2 RATE (G./MI.)			AVE. ACHIEVED CO_2 RATE (G./MI.)		
		No	Proposed	Reduction	No	Proposed	Reduction
2014	MYs 2014-2020 Subject to Phase 1 Standards	602	602	0.0%	581	581	0.0%
2015		608	608	0.0%	578	578	0.0%
2016		593	593	0.0%	580	580	0.0%
2017		578	578	0.0%	556	554	0.2%
2018		548	548	0.0%	543	538	0.8%
2019		545	545	0.0%	539	535	0.7%
2020		545	545	0.0%	536	532	0.8%
2021	2.5%	544	532	2.2%	530	510	3.8%
2022	4.9%	544	519	4.7%	530	510	3.8%
2023	7.3%	544	507	6.8%	530	496	6.4%
2024	9.6%	544	495	9.1%	530	492	7.2%
2025	11.9%	544	482	11.3%	530	470	11.3%
2026	14.1%	544	470	13.6%	530	465	12.3%
2027	16.2%	544	458	15.8%	529	458	13.4%
2028*	16.2%	544	458	15.8%	529	458	13.4%
2029*	16.2%	544	458	15.8%	529	458	13.5%
2030*	16.2%	544	458	15.8%	529	458	13.5%

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

*Absent further action, standards assumed to continue unchanged after model year 2027.

Table 5-29 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved Fuel Consumption Rates for Method A, Relative to Alternative 1a [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED FUEL CONS. (GAL./100 MI.)			AVE. ACHIEVED FUEL CONS. (GAL./100 MI.)		
		No Action	Proposed	Reduction	No Action	Proposed	Reduction
2014	MYs 2014-2020 Subject to Phase 1 Standards	6.41	6.41	0.0%	6.21	6.21	0.0%
2015		6.41	6.41	0.0%	6.12	6.12	0.0%
2016		6.27	6.27	0.0%	6.15	6.15	0.0%
2017		6.11	6.11	0.0%	5.89	5.87	0.3%
2018		5.80	5.80	-0.1%**	5.75	5.70	0.9%
2019		5.78	5.78	0.0%	5.73	5.68	0.8%
2020		5.78	5.78	0.0%	5.73	5.68	0.8%
2021	2.5%	5.77	5.64	2.3%	5.72	5.44	4.8%
2022	4.9%	5.77	5.50	4.7%	5.72	5.44	4.8%
2023	7.3%	5.77	5.38	6.8%	5.72	5.29	7.6%
2024	9.6%	5.77	5.25	9.1%	5.72	5.23	8.5%
2025	11.9%	5.77	5.12	11.4%	5.72	4.98	12.9%
2026	14.1%	5.77	4.98	13.7%	5.72	4.94	13.6%
2027	16.2%	5.77	4.86	15.8%	5.72	4.87	14.9%
2028*	16.2%	5.77	4.86	15.8%	5.72	4.87	14.9%
2029*	16.2%	5.77	4.86	15.8%	5.72	4.86	15.0%
2030*	16.2%	5.77	4.86	15.8%	5.72	4.86	15.0%

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
*Absent further action, standards assumed to continue unchanged after model year 2027.
**Increased work factor for some vehicles produces a slight increase in average required fuel consumption.

Table 5-30 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved CO_2 Emission Rates for Method A, Relative to Alternative 1a [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED CO_2 RATE (G./MI.)			AVE. ACHIEVED CO_2 RATE (G./MI.)		
		No	Proposed	Reduction	No	Proposed	Reduction
2014	MYs 2014-2020 Subject to Phase 1 Standards	602	602	0.0%	581	581	0.0%
2015		608	608	0.0%	578	578	0.0%
2016		593	593	0.0%	580	580	0.0%
2017		578	578	0.0%	556	554	0.3%
2018		548	548	-0.1%**	543	538	0.9%
2019		545	546	-0.1%**	539	535	0.8%
2020		545	545	-0.1%**	539	535	0.8%
2021	2.5%	544	532	2.2%	538	512	4.9%
2022	4.9%	544	519	4.7%	538	512	4.9%
2023	7.3%	544	507	6.8%	538	497	7.7%
2024	9.6%	544	495	9.1%	538	492	8.6%
2025	11.9%	544	482	11.4%	538	470	12.7%
2026	14.1%	544	470	13.6%	538	466	13.4%
2027	16.2%	544	458	15.8%	538	459	14.7%
2028*	16.2%	544	458	15.8%	538	459	14.7%
2029*	16.2%	544	458	15.8%	538	459	14.8%
2030*	16.2%	544	458	15.8%	538	459	14.8%

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
*Absent further action, standards assumed to continue unchanged after model year 2027.
**Increased work factor for some vehicles produces a slight increase in the average required CO_2 emission rate.

While the above tables show the agencies' estimates of average fuel consumption and CO_2 emission rates manufacturers might achieve under today's proposed standards, total U.S. fuel consumption and GHG emissions from HD pickups and vans will also depend on how many of these vehicles are produced, and how they are operated over their useful lives. Relevant to estimating these outcomes, the CAFE model applies vintage-specific estimates of vehicle survival and mileage accumulation, and adjusts the latter to account for the rebound effect. This impact of the rebound effect is specific to each model year (and, underlying, to each vehicle model in each model year), varying with changes in achieved fuel consumption rates. For additional details, see Chapter 2 of the draft RIA.

5.3.2.3.1.3.2 Method B for HD Pickups and Vans

For Method B, MOVES model was used to estimate fuel consumption and GHG emissions for HD pickups and vans. MOVES evaluated the proposed standards for HD pickup trucks and vans in terms of grams of CO_2 per mile or gallons of fuel per 100 miles. Since nearly all HD pickup trucks and vans are certified on a chassis dynamometer, the CO_2 reductions for these vehicles were not represented as engine and road load reduction components, but rather as total vehicle CO_2 reductions. The stringency increases relative to the Phase 1 standards for HD pickup trucks and vans (Table 5-32) were modified in the "emissionrate" table in MOVES.

Table 5-31 Estimated Total Vehicle CO_2 Reductions for the Proposed Standards and In-Use Emissions for HD Pickup Trucks and Vans in Method B [a]

VEHICLE TYPE	FUEL	MODEL YEAR	CO_2 REDUCTION FROM REFERENCE CASE
HD Pickup Trucks and Vans	Gasoline and Diesel	2021	2.50%
		2022	4.94%
		2023	7.31%
		2024	9.63%
		2025	11.89%
		2026	14.09%
		2027+	16.24%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.3.2.3.2 VMT Inputs

The "HPMSVtype" table in MOVES was modified to reflect the VMT rebound (VMT rebound is described in more detail in Chapter 8.3 of the draft RIA). This table estimated VMT values for all calendar years. For the control case, the absolute VMT for vocational vehicle and combination tractor-trailer were increased from the reference cases by 1.83 percent, and 0.79 percent, respectively, to reflect the VMT rebound. Since VMT is applied by calendar year and not by model year, post-processing of the results were performed to ensure that only the model years affected by the program experienced VMT rebound – the results from the reference cases were used in the control case inventories for model years not affected by the proposed rules.

For HD pickups and vans, Method A used the CAFE model which simulates VMT in a dynamic fashion that responds to changes in vehicle fuel economy and fuel prices and adjusts the marginal VMT of each vehicle model, at every age (so in each calendar year). In general, the more stringent alternatives considered lead to larger improvements in fuel economy and, thus, a greater number of vehicle miles traveled as a result of the rebound effect. In the CAFE model, the rebound effect represents a symmetric driver of changes to VMT; if the per-mile price of driving declines relative to today (either from improvements in vehicle fuel economy or declines in fuel prices), VMT increases by the amount of the rebound effect, conversely, if the per-mile price of driving increases relative to today (due to increases in the price of fuel), VMT will decline by the amount of the rebound effect. In Method B, the VMT rebound effect was modeled using the MOVES model which assumed an increase in VMT from the reference levels by 1.18 percent.

5.3.3 Calculation of Upstream Emissions

The term "upstream emissions" refers to air pollutant emissions generated from all crude oil extraction, transport, refining, and finished fuel transport, storage, and distribution; this includes all stages prior to the final filling of vehicle fuel tanks at retail service stations. Additionally, it includes the production of renewable fuels and transportation of such fuel, either separately or mixed with conventional fuels.

As described in Section 5.3.1, the decreased volumes of the crude based fuels and the various crude production and transport emission factors from GREET were used to estimate the net impact of fuel use changes on upstream emissions. The analysis for this proposed rulemaking assumes that all changes in volumes of fuel used affect only gasoline and diesel, with no effects on use of ethanol, biodiesel or other renewable fuels. The production and transport of these renewable fuels, although unchanged in volume for this analysis, are still accounted for in the total inventory in this proposed rulemaking. Although impacts to agriculture related to renewable fuels and the associated transport of these feedstocks were originally included in the RFS2 rulemaking, the effects to these sectors from the proposed regulations would be minimal and have therefore excluded them from this analysis.

The agencies recognize the unique GHG emission characteristics associated with biofuels, and specifically that in the context of biofuels, "upstream emissions" include not only GHG emissions, but also any net biological sequestration that takes place. When considered on a lifecycle basis (including both tailpipe and upstream emissions), the net GHG emission impact of individual biofuels can vary significantly from both petroleum-based fuels and from one biofuel to another. EPA's Renewable Fuel Standard (RFS) program, as modified by EISA, examined these differences in lifecycle emissions in detail. For example, EPA found that with respect to aggregate lifecycle emissions including non-tailpipe GHG emissions (such as feedstock growth, transportation, fuel production, and land use), lifecycle GHG emissions in 2022 for biodiesel from soy, using certain advanced production technologies, are about 50 percent less than diesel from petroleum.

Non-GHG fuel production and distribution emission impacts of the program were estimated in conjunction with the development of lifecycle GHG emission impacts, and the GHG emission inventories discussed above. The basic calculation is a function of fuel volumes in the analysis year and the emission factors associated with each process or subprocess. It relies partially on the GREET model, but takes advantage of additional information and models to significantly strengthen and expand on the GREET analysis, as discussed in Section 5.3.1. The details of the assumptions, data sources, and calculations that were used to estimate the emission impacts presented here can be found in the docket memo, "Calculation of Upstream Emissions for the GHG Vehicle Rule," initially created for use in the LD GHG rulemaking.[21] The agencies note that to the extent future policy decisions involve upstream emissions, the agencies will need to consider the unique emission characteristics associated with biofuels. More broadly, the agencies recognize that biofuels, including biodiesel, will play an important role in reducing the nation's dependence on foreign oil, thereby increasing domestic energy security. The volumes of renewable fuels are defined by the RFS2 standards as well as the Annual RFS rulemakings, and are projected using AEO2014. The volumes of renewable fuel for these standards remain in place regardless of overall volume of fuel affected by this proposed rulemaking. Therefore, we have assumed that the effect of this proposal on biofuels agriculture and transportation of raw agricultural goods would be minimal and excluded it from this analysis.

As described earlier, the agencies estimated the impact of the proposed rules on upstream using the downstream fuel consumption reductions predicted by MOVES for vocational vehicles and tractor-trailers. For HD pickups and vans, parallel and complementary analyses of estimating the emissions from upstream processes were conducted using the fuel consumption estimates from DOT's CAFE model and EPA's MOVES model, using Method A and B, respectively. As noted previously, these analyses corroborate each other's results.

5.3.4 Calculation of HFC Emissions[H]

EPA is proposing new air conditioning (A/C) leakage standards for vocational vehicles to reduce HFC emissions. The Vintaging Model, developed by EPA Office of Atmospheric programs, produces HFC inventories for several categories of stationary and mobiles sources. However, it does not include air conditioning systems in medium and heavy-duty trucks within its inventory calculations. For this proposal, we conducted an analysis based on the inputs to the Vintaging Model and the inputs to the MOVES analysis discussed in Chapter 5.3.2 above.

The general equation for calculating HFC emissions follows:

$$\text{HFC emissions}_{\text{Year x}} = \text{A/C Systems}_{\text{Year x}} \text{ x Average Charge Size x HFC loss rate}$$

We determined the number of functioning A/C systems in each year based on the projected sales of vehicles, the fraction of vehicles with A/C systems, and the average lifetime of an A/C system. Sales were drawn from the MOVES analysis and we assumed that every vehicle had a functioning A/C system when sold. The Vintaging Model assumes that all light-duty passenger vehicle A/C systems (in the U.S.) last exactly 12 years.[I] In the absence of other information, we assumed that heavy-duty vehicles A/C systems last for the same period of time as light-duty vehicles. Light, medium and heavy-duty vehicles use largely the same components in their air conditioning systems (sometimes from the same suppliers), which would indicate similar periods of durability.

The charge size was determined using the Minnesota refrigerant leakage database.[22] EPA sorted the data based on A/C charge size and evaluated only the largest 25 percent of A/C systems to be more representative of HD systems. The average charge size is 1,025 grams of refrigerant.

Due to the similarity in system design, we assumed that the light-duty vehicle emission rate in the Vintaging Model was applicable to the current analysis, as shown in Table 5-32. The Vintaging Model assumes that losses occur from three events: leak, service, and disposal. Although vehicle A/C systems are serviced during discrete events and not usually every year, emissions from those events are averaged over the lifetime of the A/C system in the Vintaging

[H] The U.S. has submitted a proposal to the Montreal Protocol which, if adopted, would phase-down production and consumption of HFCs.

[I] This is in agreement with the IPCC report IPCC/TEAP 2005 *Safeguarding the Ozone Layer and the Global Climate System – Issues Related to Hydrofluorocarbons and Perfluorocarbons,* which indicates lifetimes (worldwide) of 9 to 12 years.

model. Leak and service emissions are considered "annual losses" and are applied every year; disposal is considered an "end of life loss" and is applied only once for each vintage of vehicles.[J]

Table 5-32 Annual In-use Vehicle HFC134a Emission Rate from Vintaging Model

KIND OF LOSS	LOSS FRACTION
Leakage	8%
Maintenance /Servicing	10%
End of Life	43%

The Vintaging Model assumes that charge loss is replaced every year; i.e., assuming an 18 percent rate of charge loss, a vehicle with a charge of 1,000 grams would lose a constant rate of 180 grams per year. While this loss rate is not representative of any single given vehicle, it is assumed accurate for the fleet as a whole. Other emissions, such as fugitive emissions at a production facility, leaks from cylinders in storage, etc., are not explicitly modeled, but such emissions are accounted for within the average annual loss rate.

EPA's analysis of the Minnesota database of MY 2010 vehicles suggests that many of the modeled vehicles likely contain some of the technology required to meet the leakage standard, and as a consequence are leaking less. We assume that these improvements are independent of EPA regulation, rather than a preemptive response to regulation. Consequently, this rulemaking does not take credit for these emission reductions.

Based on the Minnesota database, we determined that it is possible to reduce the HFC emissions from these vehicles on average by 13 percent. EPA calculated this based on the assumption that vehicles currently in the fleet which meet the MY 2014 standard would not make any additional improvements to reduce leakage. We also assumed that the systems which currently have leakage rates above the standard will reduce their leakage to the level of the standard. We then applied the 13 percent reduction to the baseline 18 percent leakage rate to develop a 15.6 percent leakage rate for MY 2014 and later vehicles to determine the reduction in emission rate which should be credited to this rulemaking.[K]

We calculated our emission reductions based on the difference between the baseline case of 2010 vehicle technology (discussed above) and the control scenario where the loss prevention technology has been applied to 100 percent of the new vocational vehicles starting in 2021 model year, as would be required by the proposed standards.

[J] The U.S. EPA has reclamation requirements for refrigerants in place under Title VI of the Clean Air Act.

[K] Using 18 percent as the base emission rate may overstate the net emission reductions. However, recent number from the ERG Report to CARB studying the leakage rate of heavy-duty vehicles are actually much larger (range of near 0 to 150 percent annually), and places an 18 percent annual loss rate well within the literature. However, (a) the net impact is very small, (b) these numbers have significant uncertainty, and (c) it is unclear what the appropriate modification would be.

Total HFC reductions are 177 metric tons over the MY 2021 baseline A/C system in 2035 and 210 metric tons in 2050. This is equivalent to a reduction of 253,118 metric tons of CO_2eq emissions in 2035; and 299,590 metric tons CO_2eq in 2050.[L]

EPA reviewed a study conducted by the Eastern Research Group (ERG) of R134a leaks in heavy-duty vehicles to California Air Resources Board.[23] The study included a total of 70 medium- and heavy-duty vehicles and off-road equipment; of which 18 of the samples were HD tractors ranging between 1990 and 2008 model years. The mobile air conditioning capacity in the tractors ranged between 1,080 grams to 1,950 grams. The study measured HFC leakage during sample times which ranged between 0.3 and 0.6 years. ERG then calculated an annualized in-use leakage rate with an assumed linear projection of measured leak rates to annual leak rates, which may be an over-estimate. The annualize leakage rate for tractors ranged between nearly 0 to nearly 1.5 grams leakage per gram of MAC capacity. These leakage rates did not include other leakage sources such as maintenance or end of life recovery. ERG found that the average of all MD and HD trucks and equipment which were 2006 MY or newer had an average leakage of 103 grams of R134a per year. Based on these results, the agency believes that our estimates for HFC reductions may understate the benefits of the proposed program. The agency will continue to analyze this and other studies that may be conducted in the future.

5.4 Greenhouse Gas Emission and Fuel Consumption Impacts

The following subsections summarize two slightly different analyses of the annual GHG emissions and fuel consumption reductions expected from the proposed standards, as well as the reductions in GHG emissions and fuel consumption expected over the lifetime of each heavy-duty vehicle categories. In addition, because the agencies are carefully considering Alternative 4 along with Alternative 3, the preferred alternative, the results from both are presented here for the reader's reference. Section 5.4.1 shows the impacts of the proposed rules and Alternative 4 on fuel consumption and GHG emissions using the MOVES model for tractor-trailers and vocational vehicles, and the DOT's CAFE model for HD pickups and vans (Method A), relative to two different reference cases – less dynamic and more dynamic. Section 5.4.2 shows the impacts of the proposed standards and Alternative 4, relative to the less dynamic reference case only, using the MOVES model for all heavy-duty vehicle categories.

5.4.1 Impacts of the Proposed Rules and Alternative 4 using Analysis Method A

5.4.1.1 Calendar Year Analysis

5.4.1.1.1 Downstream Impacts

The following two tables summarize the agencies' estimates of HD pickup and van fuel consumption and GHG emissions under the current and proposed standards defining the No-Action and Preferred alternatives, respectively. The first shows results assuming manufacturers would voluntarily make improvements that pay back within six months (i.e., Alternative 1b). The second shows results assuming manufacturers would only make improvements as needed to

[L] Using a Global Warming Potential of 1,430 for HFC-134a.

achieve compliance with standards (i.e., Alternative 1a). While underlying calculations are all performed for each calendar year during each vehicle's useful life, presentation of outcomes on a model year basis aligns more clearly with consideration of cost impacts in each model year, and with consideration of standards specified on a model year basis. In addition, the agencies performed explicit analysis of manufacturers' potential responses to HD pickup and van standards on a model year basis through 2030, and any longer-term costs presented in today's notice represent extrapolation of these results absent any underlying analysis of longer-term technology prospects and manufacturers' longer-term product offerings.

Table 5-33 Estimated Fuel Consumption and GHG Emissions over Useful Life of HD Pickups and Vans Produced in Each Model year for Method A, Relative to Alternative 1b [a]

MODEL YEAR	FUEL CONSUMPTION (B. GAL.) OVER FLEET'S USEFUL LIFE			GHG EMISSIONS (MMT CO_2EQ) OVER FLEET'S USEFUL LIFE		
	No Action	Proposed	Reduction	No Action	Proposed	Reduction
2014	9.41	9.41	0.0%	115	115	0.0%
2015	9.53	9.53	0.0%	117	117	0.0%
2016	9.72	9.72	0.0%	119	119	0.0%
2017	9.49	9.47	0.2%	116	116	0.2%
2018	9.26	9.19	0.7%	113	113	0.7%
2019	9.20	9.14	0.7%	113	112	0.7%
2020	9.19	9.12	0.7%	112	112	0.7%
2021	9.10	8.79	3.4%	111	107	3.4%
2022	9.13	8.82	3.4%	112	108	3.4%
2023	9.11	8.59	5.7%	111	105	5.7%
2024	9.32	8.72	6.4%	114	107	6.4%
2025	9.49	8.49	10.5%	116	104	10.4%
2026	9.67	8.56	11.5%	118	105	11.3%
2027	9.78	8.55	12.6%	120	105	12.3%
2028	9.90	8.66	12.6%	121	106	12.3%
2029	10.02	8.75	12.6%	122	107	12.4%
2030	10.03	8.76	12.6%	123	107	12.4%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-34 Estimated Fuel Consumption and GHG Emissions over Useful Life of HD Pickups and Vans Produced in Each Model year for Method A, Relative to Alternative 1a [a]

MODEL YEAR	FUEL CONSUMPTION (B. GAL.) OVER FLEET'S USEFUL LIFE			GHG EMISSIONS (MMT CO_2EQ) OVER FLEET'S USEFUL LIFE		
	No Action	Proposed	Reduction	No Action	Proposed	Reduction
2014	9.41	9.41	0.0%	115	115	0.0%
2015	9.53	9.53	0.0%	117	117	0.0%
2016	9.72	9.72	0.0%	119	119	0.0%
2017	9.49	9.46	0.3%	116	116	0.3%
2018	9.27	9.19	0.8%	114	113	0.8%
2019	9.20	9.14	0.7%	113	112	0.7%
2020	9.25	9.18	0.7%	113	112	0.8%
2021	9.23	8.82	4.4%	113	108	4.4%
2022	9.26	8.85	4.4%	113	108	4.4%
2023	9.23	8.60	6.9%	113	105	6.9%
2024	9.45	8.72	7.7%	116	107	7.7%
2025	9.62	8.48	11.8%	118	104	11.7%
2026	9.81	8.58	12.5%	120	105	12.3%
2027	9.93	8.57	13.7%	121	105	13.5%
2028	10.05	8.68	13.7%	123	106	13.5%
2029	10.17	8.77	13.7%	124	108	13.5%
2030	10.18	8.78	13.7%	124	108	13.5%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

To more clearly communicate these trends visually, the following two charts present the above results graphically for Method A, relative to Alternative 1b. As shown, fuel consumption and GHG emissions follow parallel though not precisely identical paths. Though not presented, charts for analysis relative to Alternative 1a would appear sufficiently similar that differences between Alternative 1a and Alternative 1b remain best communicated by comparing values in the above tables.

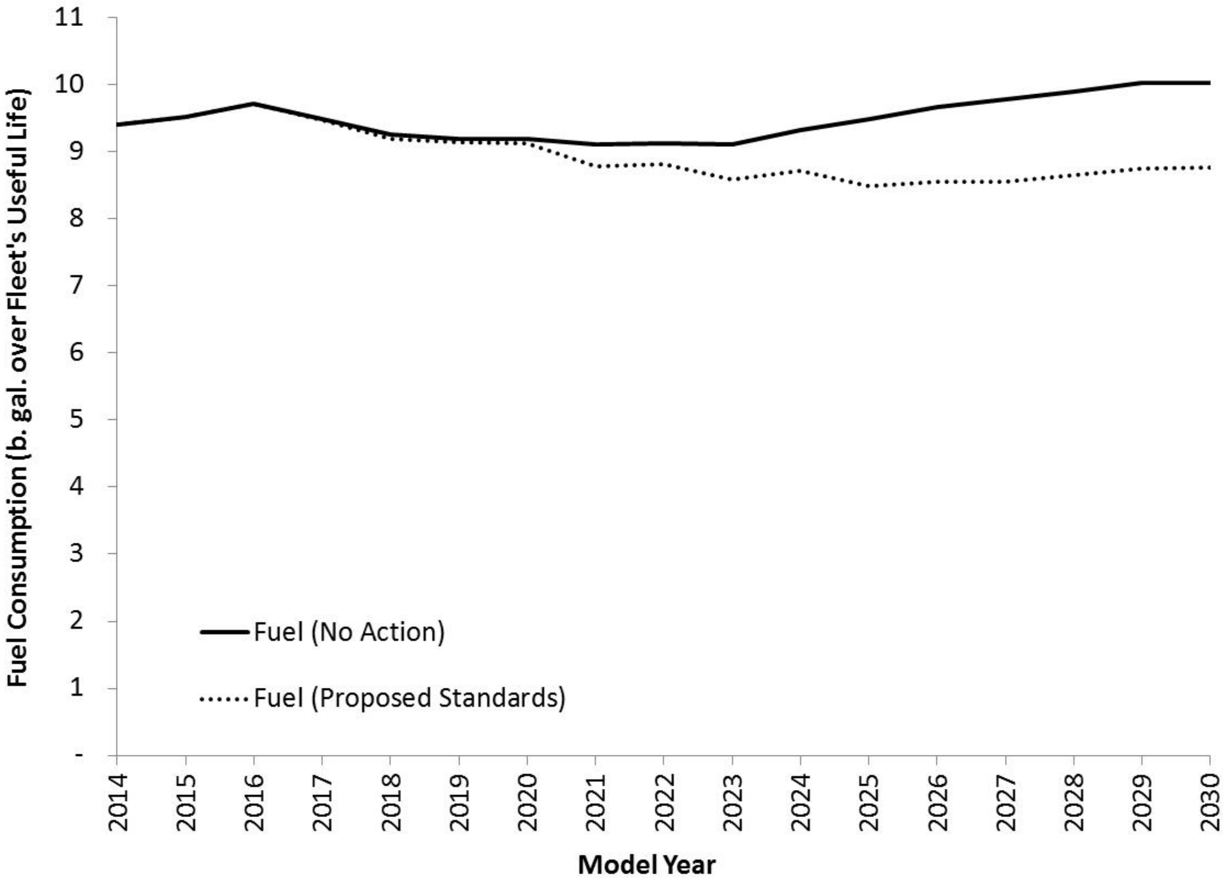

Figure 5-1 Fuel Consumption (b. gal.) over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A

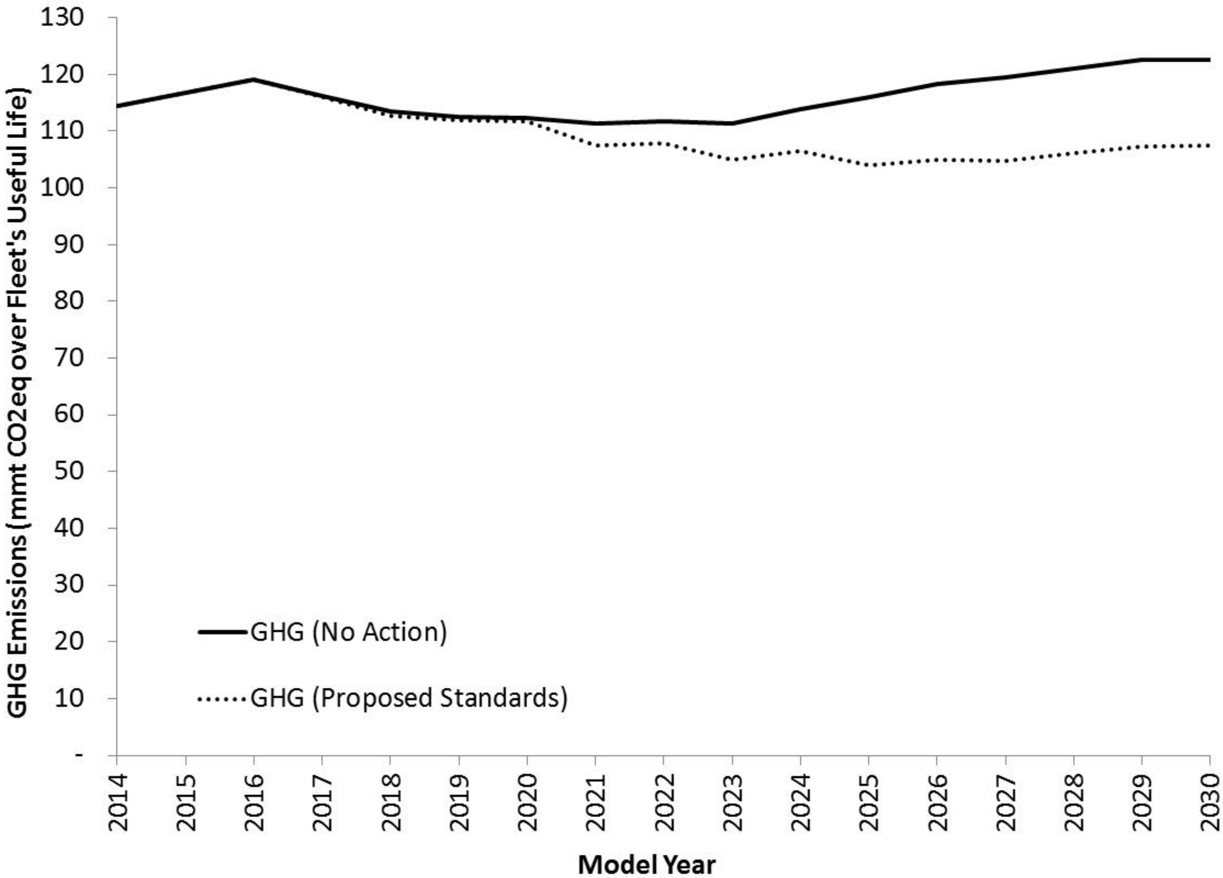

Figure 5-2 GHG Emissions (MMT CO_2eq) over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A

Table 5-35 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-2.4	0	0	-2.4
	Vocational	-2.4	0	0	-2.4
	Tractor-Trailers	-22.1	-0.4	0	-22.4
	Total	-26.9	-0.4	0	-27.2
2035	HD Pickups and Vans	-9.4	0	0	-9.4
	Vocational	-11.9	0	0	-11.9
	Tractor-Trailers	-64.7	-1	0	-65.6
	Total	-86.0	-1	0	-86.9
2050	HD Pickups and Vans	-11.8	0	0	-11.8
	Vocational	-17.2	0	0	-17.2
	Tractor-Trailers	-92.6	-1.4	0	-94.0
	Total	-121.6	-1.4	0	-123.0

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-36 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-2.9	0	0	-2.9
	Vocational	-2.4	0	0	-2.4
	Tractor-Trailers	-22.5	-0.4	0	-22.8
	Total	-27.7	-0.4	0	-28.1
2035	HD Pickups and Vans	-10.5	0	0	-10.5
	Vocational	-11.9	0	0	-11.9
	Tractor-Trailers	-71.1	-1	0	-72.1
	Total	-93.6	-1	0	-94.6
2050	HD Pickups and Vans	-13.1	0	0	-13.1
	Vocational	-17.2	0	0	-17.2
	Tractor-Trailers	-103.2	-1.4	0	-104.6
	Total	-133.5	-1.4	0	-134.9

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-37 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-3.3	0	0	-3.3
	Vocational	-4.0	0	0	-4.0
	Tractor-Trailers	-25.9	-0.4	0	-26.2
	Total	-33.2	-0.4	0	-33.5
2035	HD Pickups and Vans	-10.3	0	0	-10.3
	Vocational	-12.9	0	0	-12.9
	Tractor-Trailers	-66.7	-1	0	-67.7
	Total	-89.9	-1	0	-90.9
2050	HD Pickups and Vans	-12.6	0	0	-12.6
	Vocational	-17.3	0	0	-17.3
	Tractor-Trailers	-92.8	-1.4	0	-94.2
	Total	-122.6	-1.4	0	-124.0

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-38 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-4.0	0	0	-4.0
	Vocational	-4.0	0	0	-4.0
	Tractor-Trailers	-26.2	-0.4	0	-26.6
	Total	-34.3	-0.4	0	-34.6
2035	HD Pickups and Vans	-11.6	0	0	-11.6
	Vocational	-12.9	0	0	-12.9
	Tractor-Trailers	-73.2	-1	0	-74.2
	Total	-97.7	-1	0	-98.7
2050	HD Pickups and Vans	-14.0	0	0	-14.0
	Vocational	-17.3	0	0	-17.3
	Tractor-Trailers	-103.3	-1.4	0	-104.7
	Total	-134.6	-1.4	0	-136.0

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-39 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.1	0.1
	Vocational	0.2	0
	Tractor-Trailers	2.2	0
	Total	2.5	0.2
2035	HD Pickups and Vans	0.3	0.7
	Vocational	1.0	0.2
	Tractor-Trailers	6.3	0
	Total	7.6	0.9
2050	HD Pickups and Vans	0.3	0.9
	Vocational	1.4	0.3
	Tractor-Trailers	9.1	0
	Total	10.8	1.2

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-40 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.1	0.2
	Vocational	0.2	0
	Tractor-Trailers	2.2	0
	Total	2.5	0.2
2035	HD Pickups and Vans	0.3	0.8
	Vocational	1.0	0.2
	Tractor-Trailers	7.0	0
	Total	8.3	1.0
2050	HD Pickups and Vans	0.4	1.0
	Vocational	1.4	0.3
	Tractor-Trailers	10.1	0
	Total	11.9	1.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-41 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.1	0.2
	Vocational	0.3	0.1
	Tractor-Trailers	2.5	0
	Total	3.0	0.3
2035	HD Pickups and Vans	0.3	0.8
	Vocational	1.0	0.2
	Tractor-Trailers	6.5	0
	Total	7.9	1.0
2050	HD Pickups and Vans	0.4	1.0
	Vocational	1.4	0.3
	Tractor-Trailers	9.1	0
	Total	10.8	1.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-42 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.2	0.3
	Vocational	0.3	0.1
	Tractor-Trailers	2.6	0
	Total	3.1	0.3
2035	HD Pickups and Vans	0.4	0.8
	Vocational	1.0	0.2
	Tractor-Trailers	7.2	0
	Total	8.6	1.1
2050	HD Pickups and Vans	0.5	1.0
	Vocational	1.4	0.3
	Tractor-Trailers	10.1	0
	Total	12.0	1.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1.1 Upstream Impacts

Table 5-43 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-0.6	-0.1	0	-0.7
	Vocational	-0.7	-0.1	0	-0.8
	Tractor-Trailers	-7.0	-0.7	0	-7.8
	Total	-8.4	-0.9	-0.1	-9.3
2035	HD Pickups and Vans	-2.5	-0.4	-0.1	-2.9
	Vocational	-3.6	-0.4	0	-4.0
	Tractor-Trailers	-20.6	-2.1	-0.1	-22.8
	Total	-26.6	-2.8	-0.2	-29.7
2050	HD Pickups and Vans	-3.1	-0.4	-0.1	-3.7
	Vocational	-5.1	-0.6	0	-5.7
	Tractor-Trailers	-29.5	-3.0	-0.1	-32.6
	Total	-37.7	-4.0	-0.3	-42.0

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-44 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-0.7	-0.1	0	-0.9
	Vocational	-0.7	-0.1	0	-0.8
	Tractor-Trailers	-7.1	-0.7	0	-7.9
	Total	-8.6	-0.9	-0.1	-9.6
2035	HD Pickups and Vans	-2.8	-0.4	-0.1	-3.3
	Vocational	-3.6	-0.4	0	-4.0
	Tractor-Trailers	-22.6	-2.3	-0.1	-25.0
	Total	-29.0	-3.1	-0.2	-32.3
2050	HD Pickups and Vans	-3.5	-0.5	-0.1	-4.1
	Vocational	-5.1	-0.6	0	-5.7
	Tractor-Trailers	-32.8	-3.3	-0.2	-36.3
	Total	-41.4	-4.4	-0.3	-46.1

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-45 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-0.9	-0.1	0	-1.0
	Vocational	-1.2	-0.1	0	-1.3
	Tractor-Trailers	-8.2	-0.8	0	-9.1
	Total	-10.3	-1.1	-0.1	-11.5
2035	HD Pickups and Vans	-2.7	-0.4	-0.1	-3.2
	Vocational	-3.8	-0.4	0	-4.3
	Tractor-Trailers	-21.2	-2.2	-0.1	-23.5
	Total	-27.8	-3.0	-0.2	-31.0
2050	HD Pickups and Vans	-3.3	-0.5	-0.1	-4.0
	Vocational	-5.1	-0.6	0	-5.7
	Tractor-Trailers	-29.5	-3.0	-0.1	-32.7
	Total	-38.0	-4.0	-0.3	-42.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-46 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)[A]	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-1.0	-0.2	0	-1.2
	Vocational	-1.2	-0.1	0	-1.3
	Tractor-Trailers	-8.4	-0.8	0	-9.2
	Total	-10.6	-1.1	-0.1	-11.8
2035	HD Pickups and Vans	-3.1	-0.4	-0.1	-3.6
	Vocational	-3.8	-0.4	0	-4.3
	Tractor-Trailers	-23.3	-2.4	-0.1	-25.8
	Total	-30.2	-3.2	-0.2	-33.7
2050	HD Pickups and Vans	-3.7	-0.5	-0.1	-4.4
	Vocational	-5.1	-0.6	0	-5.7
	Tractor-Trailers	-32.9	-3.3	-0.2	-36.4
	Total	-41.7	-4.4	-0.3	-46.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1.1 HFC Impacts

The projected HFC emission reductions due to the proposed AC leakage standards are estimated to be 93,272 metric tons of CO_2eq in 2025, 253,118 metric tons of CO_2eq in 2035, and 299,590 metric tons CO_2eq in 2050.

5.4.1.1.2 Total (Downstream + Upstream + HFC) Impacts

Table 5-47 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-27.2	-86.9	-123.0
Upstream	-9.3	-29.7	-42.0
HFC	-0.09	-0.25	-0.3
Total	-36.6	-116.9	-165.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-48 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-28.1	-94.6	-134.9
Upstream	-9.6	-32.3	-46.1
HFC	-0.09	-0.25	-0.3
Total	-37.8	-127.2	-181.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-49 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-33.5	-90.9	-124.0
Upstream	-11.5	-31.0	-42.3
HFC	-0.09	-0.25	-0.3
Total	-45.1	-122.2	-166.6

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-50 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-34.6	-98.7	-136.0
Upstream	-11.8	-33.7	-46.5
HFC	-0.09	-0.25	-0.3
Total	-46.5	-132.7	-182.8

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1 Model Year Lifetime Analysis

Table 5-51 Lifetime GHG Reductions and Fuel Savings by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method A [a]

	ALTERNATIVE 3 (PROPOSED)		ALTERNATIVE 4	
NO-ACTION ALTERNATIVE (BASELINE)	1b (More Dynamic)	1a (Less Dynamic)	1b (More Dynamic)	1a (Less Dynamic)
Fuel Savings (Billion Gallons)	72.2	76.7	81.9	86.7
HD Pickups and Vans	7.8	8.9	9.4	10.8
Vocational	8.3	8.3	10.9	10.9
Tractor/Trailers	56.1	59.5	61.6	65.0
Total GHG Reductions (MMT CO_2eq)	986.5	1,047.4	1,114.8	1,181.1
HD Pickups and Vans	94.8	108.5	113.7	132.8
Vocational	109.7	109.7	143.0	143.0
Tractor/Trailers	782.0	829.2	858.1	905.3

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

5.4.2 Impacts of the Proposed Rules and Alternative 4 using Analysis Method B

5.4.2.1 Calendar Year Analysis

5.4.2.1.1 Downstream Impacts

After all the MOVES runs and post-processing was completed, the less dynamic reference (Alternative 1a) and control case (Alternative 3) inventories were totaled for all heavy-duty vehicle types and emission processes to estimate total downstream GHG and fuel consumption impacts of the program.

To estimate the fuel savings from the proposed rules, the total energy consumption for all HD segments was run as a surrogate in MOVES since fuel consumption is not directly modeled in MOVES. Then, the total energy consumption was converted to fuel consumption based on fuel heating values assumed in the Renewable Fuels Standard rulemaking[M] and used in the development of MOVES emission and energy rates.[N]

Table 5-52 and Table 5-53 summarize these downstream GHG impacts in calendar years 2025, 2035, and 2050, relative to Alternative 1a, for the preferred alternative and Alternative 4, respectively. Table 5-54 and Table 5-55 show the estimated fuel savings from the preferred alternative and Alternative 4 in 2025, 2035, and 2050, relative to Alternative 1a. The reductions in CO_2 emissions result from all heavy-duty vehicle categories (including the engines associated with tractor-trailer combinations and vocational vehicles) due to engine and vehicle improvements. N_2O emissions show a very slight increase because of a rebound in vehicle miles traveled (VMT). However, since N_2O is produced as a byproduct of fuel combustion, the increase in N_2O emissions is expected to be more than offset by the improvements in fuel efficiency from the proposed rules.[O] The methane emissions decrease primarily due to differences in hydrocarbon emission characteristics between on-road diesel engines and APUs. The amount of methane emitted as a fraction of total hydrocarbons is expected to be significantly less for APUs than for diesel engines. Overall, downstream GHG emissions would be reduced significantly. In addition, substantial fuel savings would be achieved from improved fuel efficiency. All emissions impacts reflect the heavy-duty sector only, and do not include emissions from light-duty vehicles or any other vehicle sector.

[M] Renewable Fuels Standards assumptions of 115,000 BTU/gallon gasoline (E0) and 76,330 BTU/gallon ethanol (E100) were weighted 90% and 10%, respectively, for E10 and 85% and 15%, respectively, for E15 and converted to kJ at 1.055 kJ/BTU. The conversion factors are 117,245 kJ/gallon for gasoline blended with ten percent ethanol (E10) and 115,205 kJ/gallon for gasoline blended with fifteen percent ethanol (E15).

[N] The conversion factor for diesel is 138,451 kJ/gallon. See MOVES2004 Energy and Emission Inputs. EPA420-P-05-003, March 2005. http://www.epa.gov/otaq/models/ngm/420p05003.pdf

[O] MOVES is not capable of modeling the changes in exhaust N_2O emissions from the improvements in fuel efficiency. Due to this limitation, a conservative approach was taken to only model the VMT rebounds in estimating the emissions impact on N_2O from the proposed rules, resulting in a slight increase in downstream N_2O inventory.

Table 5-52 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-2.1	0.0003	0.0005	-2.1
	Vocational	-2.4	0.0009	0.0007	-2.4
	Tractor-Trailers	-22.5	-0.4	0.0006	-22.9
	Total	-27.0	-0.4	0.002	-27.4
2035	HD Pickups and Vans	-10.6	0.0007	0.001	-10.6
	Vocational	-11.9	0.002	0.002	-11.9
	Tractor-Trailers	-71.2	-1.0	0.001	-72.2
	Total	-93.7	-1.0	0.004	-94.7
2050	HD Pickups and Vans	-14.8	0.0009	0.001	-14.8
	Vocational	-17.2	0.003	0.002	-17.2
	Tractor-Trailers	-103.1	-1.4	0.002	-104.5
	Total	-135.1	-1.4	0.005	-136.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-53 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category –Alternative 4 vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL DOWNSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-3.1	0.0003	0.0005	-3.1
	Vocational	-4.0	0.0009	0.0007	-4.0
	Tractor-Trailers	-26.2	-0.4	0.0006	-26.6
	Total	-33.3	-0.4	0.002	-33.7
2035	HD Pickups and Vans	-11.2	0.0007	0.001	-11.2
	Vocational	-12.9	0.0024	0.002	-12.9
	Tractor-Trailers	-73.2	-1.0	0.001	-74.2
	Total	-97.3	-1.0	0.004	-98.3
2050	HD Pickups and Vans	-14.9	0.0009	0.001	-14.9
	Vocational	-17.3	0.003	0.002	-17.3
	Tractor-Trailers	-103.3	-1.4	0.002	-104.7
	Total	-135.5	-1.4	0.005	-136.9

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-54 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.1	0.1
	Vocational	0.2	0.05
	Tractor-Trailers	2.2	0
	Total	2.5	0.2
2035	HD Pickups and Vans	0.5	0.6
	Vocational	1.0	0.2
	Tractor-Trailers	7.0	0
	Total	8.5	0.8
2050	HD Pickups and Vans	0.8	0.8
	Vocational	1.4	0.3
	Tractor-Trailers	10.1	0
	Total	12.3	1.1

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-55 Annual Fuel Savings in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	DIESEL SAVINGS (BILLION GALLONS)	GASOLINE SAVINGS (BILLION GALLONS)
2025	HD Pickups and Vans	0.2	0.2
	Vocational	0.3	0.1
	Tractor-Trailers	2.6	0
	Total	3.1	0.3
2035	HD Pickups and Vans	0.6	0.6
	Vocational	1.0	0.3
	Tractor-Trailers	7.2	0
	Total	8.8	0.9
2050	HD Pickups and Vans	0.8	0.8
	Vocational	1.4	0.3
	Tractor-Trailers	10.1	0
	Total	12.3	1.1

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.2.1.2 Upstream Impacts

The upstream GHG impacts of preferred alternative and Alternative 4 associated with the production and distribution of gasoline and diesel from crude oil, relative to Alternative 1a, are summarized in Table 5-56 and Table 5-57, for calendar years 2025, 2035, and 2050. These estimates show impacts for domestic emission reductions only. Additionally, since this rulemaking is not expected to impact biofuel volumes mandated by the Annual Renewable Fuel Standards (RFS) regulations, the impacts on upstream emissions from changes in biofuel feedstock (i.e., agricultural sources such as fertilizer, fugitive dust, and livestock) are not included. The reductions in upstream GHGs are proportional to the amount of fuel saved.

Table 5-56 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-0.6	-0.1	-0.003	-0.7
	Vocational	-0.7	-0.1	-0.004	-0.8
	Tractor-Trailers	-7.1	-0.7	-0.03	-7.8
	Total	-8.4	-0.9	-0.04	-9.3
2035	HD Pickups and Vans	-2.9	-0.3	-0.02	-3.2
	Vocational	-3.6	-0.4	-0.02	-4.0
	Tractor-Trailers	-22.6	-2.3	-0.1	-25.0
	Total	-29.1	-3.0	-0.1	-32.2
2050	HD Pickups and Vans	-4.0	-0.5	-0.02	-4.5
	Vocational	-5.1	-0.6	-0.03	-5.7
	Tractor-Trailers	-32.8	-3.3	-0.2	-36.3
	Total	-41.9	-4.4	-0.2	-46.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-57 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 by Heavy-Duty Vehicle Category – Alternative 4 vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL UPSTREAM (MMT CO_2EQ)
2025	HD Pickups and Vans	-0.8	-0.1	-0.005	-1.0
	Vocational	-1.2	-0.1	-0.01	-1.3
	Tractor-Trailers	-8.4	-0.8	-0.04	-9.2
	Total	-10.4	-1.0	-0.1	-11.5
2035	HD Pickups and Vans	-3.0	-0.4	-0.02	-3.4
	Vocational	-3.8	-0.4	-0.02	-4.2
	Tractor-Trailers	-23.3	-2.4	-0.1	-25.8
	Total	-30.1	-3.2	-0.1	-33.4
2050	HD Pickups and Vans	-4.0	-0.5	-0.02	-4.5
	Vocational	-5.1	-0.6	-0.03	-5.7
	Tractor-Trailers	-32.9	-3.3	-0.2	-36.4
	Total	-42.0	-4.4	-0.2	-46.6

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.2.1.3 HFC Impacts

Based on projected HFC emission reductions due to the proposed AC leakage standards, EPA estimates the HFC reductions to be 93,272 metric tons of CO_2eq in 2025, 253,118 metric tons of CO_2eq in 2035, and 299,590 metric tons CO_2eq in 2050.

5.4.2.1.4 Total (Downstream + Upstream + HFC) Impacts

The combined annual GHG emissions reductions of preferred alternative from downstream, upstream, and HFC, relative to Alternative 1a, are summarized in Table 5-58 for calendar years 2025, 2035 and 2050. The combined impact of Alternative 4 on total GHG emissions are shown in Table 5-59. Because of the differences in lead time, as expected, Alternative 4 shows greater annual GHG reductions in earlier years (i.e., calendar year 2025), but by 2050, the preferred alternative and Alternative 4 show the same magnitude of reductions in annual GHG emissions.

Table 5-58 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-27.4	-94.7	-136.5
Upstream	-9.3	-32.2	-46.5
HFC	-0.1	-0.25	-0.3
Total	-36.8	-127.2	-183.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-59 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

CY	2025 (MMT CO_2EQ)	2035 (MMT CO_2EQ)	2050 (MMT CO_2EQ)
Downstream	-33.7	-98.3	-136.9
Upstream	-11.5	-33.4	-46.6
HFC	-0.1	-0.25	-0.3
Total	-45.3	-132.0	-183.8

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Figure 5-3 graphically illustrates the total annual GHG trends for both Phase 1 and Phase 2 proposal, using Method B, for calendar years from 2014 to 2050. The less dynamic baseline from Phase 2 proposal is assumed to be equivalent to the Phase 1 program.

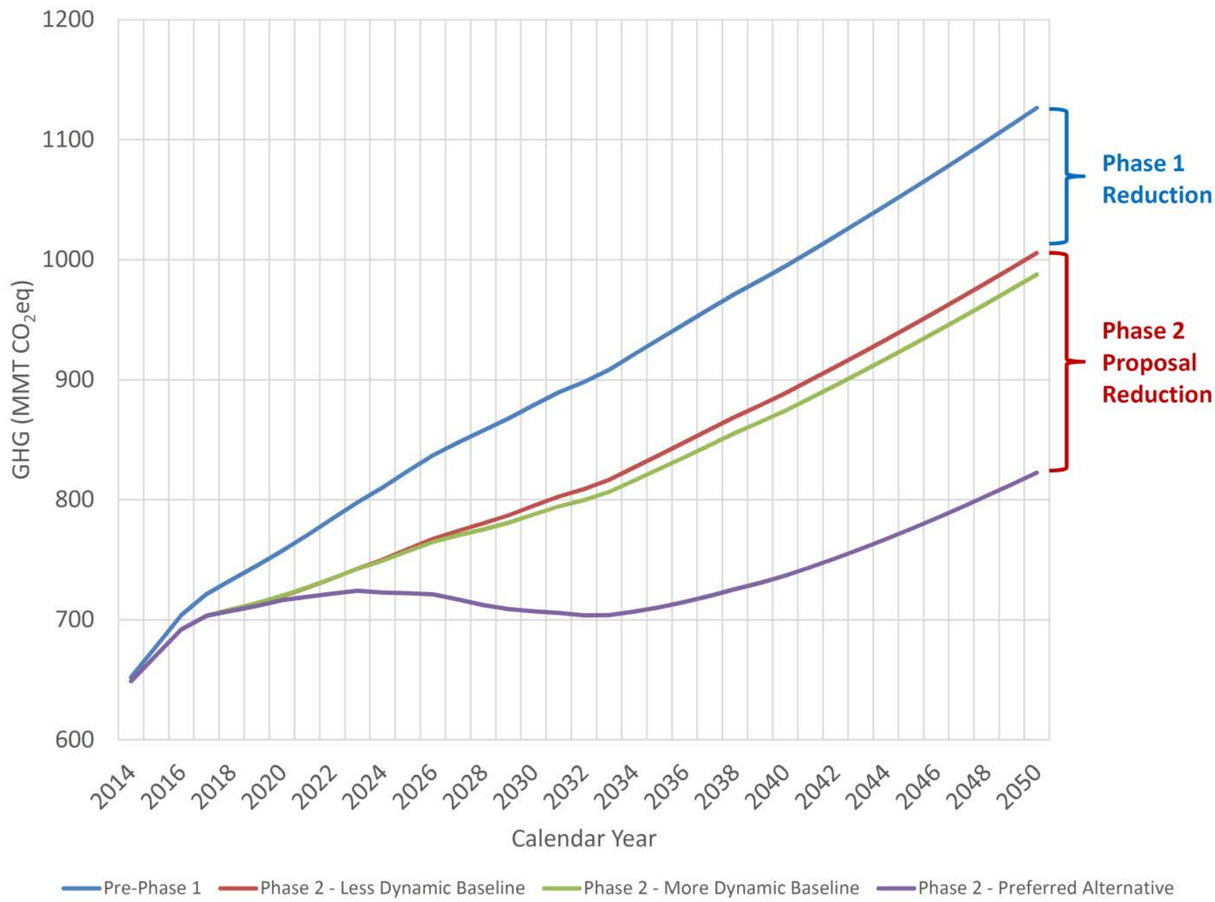

Figure 5-3 Total Annual GHG Trends for Phase 1 and Phase 2 Proposal, using Analysis Method B

5.4.2.2 Model Year Lifetime Analysis

In addition to the annual GHG emissions and fuel consumption reductions expected from the proposed rules and Alternative 4, the combined (downstream and upstream) GHG and fuel consumption impacts over the model year lifetimes of the impacted vehicles sold in the regulatory timeframe were estimated. In contrast to the calendar year analysis, the model year lifetime analyses show the impacts of the program on each of these model year fleets over the course of their lifetimes. Table 5-60 shows the fleet-wide GHG reductions and fuel savings from the proposed rules and Alternative 4 through the lifetime[P] of heavy-duty vehicles, relative to Alternative 1a. In addition, because the agencies are carefully considering Alternative 4 along with the preferred alternative, the lifetime GHG reductions and fuel savings of Alternative 4 are presented as well in Table 5-60. Compared to the preferred alternative, Alternative 4 shows greater lifetime GHG reductions and fuels savings by 12 percent and 13 percent, respectively.

[P] A lifetime of 30 years is assumed in MOVES.

Table 5-60 Lifetime GHG Reductions and Fuel Savings by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method B [a]

	ALTERNATIVE 3 (PROPOSED)	ALTERNATIVE 4
NO-ACTION ALTERNATIVE (BASELINE)	1a (Less Dynamic)	1a (Less Dynamic)
Fuel Savings (Billion Gallons)	75.8	85.4
HD Pickups and Vans	8.0	9.5
Vocational	8.3	10.9
Tractor/Trailers	59.5	65.0
Total GHG Reductions (MMT CO_2eq)	1,036.4	1,163.1
HD Pickups and Vans	97.5	114.8
Vocational	109.7	143.0
Tractor/Trailers	829.2	905.3

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

Furthermore, the combined lifetime GHG reductions and fuel savings of Phase 1 and proposed Phase 2 programs are presented in Table 5-62. To be consistent with the emissions modeling done for this proposed program, the lifetime GHG reductions and fuel savings from Phase 1 were estimated using the same modeling tools used in the proposed program.

Table 5-61 Combined Lifetime GHG Reductions and Fuel Savings of Phase 1 and Proposed Phase 2 Program using Analysis Method B [a]

	TOTAL GHG REDUCTIONS (MMT CO_2EQ)	FUEL SAVINGS (BILLION GALLONS)
Phase 1		
MY 2014-2018	313	23
MY 2019-2029	1,020	75
Phase 2 - Proposed		
MY 2018-2029	1,036	76
Combined Total	2,369	174

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

5.5 Non-Greenhouse Gas Emission Impacts

The proposed heavy-duty vehicle standards and Alternative 4 are expected to influence the emissions of criteria air pollutants and several air toxics. Similar to Section 5.4, the following subsections summarize two slightly different analyses of the annual non-GHG emissions reductions expected from the proposed standards. Section 5.5.1 shows the impacts of the proposed rules and Alternative 4 on non-GHG emissions using the analytical Method A, relative to two different reference cases – less dynamic and more dynamic. Section 5.5.2 shows the impacts of the proposed standards and Alternative 4, relative to the less dynamic reference case only, using the MOVES model for all heavy-duty vehicle categories.

5.5.1 Impacts of the Proposed Rules and Alternative 4 using Analysis Method A

5.5.1.1 Calendar Year Analysis

5.5.1.1.1 Downstream Impacts

Table 5-62 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-3%	-21	-12%	-30	-16%
Acetaldehyde	-669	-10%	-1,882	-31%	-2,667	-36%
Acrolein	-97	-10%	-272	-31%	-385	-37%
Benzene	-123	-6%	-347	-19%	-490	-24%
CO	-26,485	-3%	-75,199	-8%	-106,756	-9%
Formaldehyde	-2,100	-12%	-5,910	-32%	-8,376	-37%
NO_X	-92,444	-7%	-260,949	-28%	-370,663	-34%
$PM_{2.5}$	643	2%	1,722	8%	2,410	10%
SO_X	-229	-4%	-715	-13%	-1,026	-15%
VOC	-13,161	-6%	-38,051	-21%	-54,139	-26%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-63 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-3%	-21	-12%	-30	-16%
Acetaldehyde	-669	-10%	-1,880	-31%	-2,664	-36%
Acrolein	-97	-10%	-271	-31%	-384	-37%
Benzene	-123	-6%	-346	-19%	-490	-24%
CO	-26,576	-3%	-75,571	-8%	-107,287	-9%
Formaldehyde	-2,100	-12%	-5,904	-32%	-8,369	-37%
NO_X	-93,197	-8%	-266,890	-29%	-380,303	-35%
$PM_{2.5}$	632	2%	1,635	8%	2,267	9%
SO_X	-232	-4%	-776	-14%	-1,125	-16%
VOC	-13,210	-6%	-38,964	-22%	-55,628	-26%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-64 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-2%	-21	-12%	-30	-16%
Acetaldehyde	-669	-10%	-1,882	-31%	-2,667	-36%
Acrolein	-97	-10%	-271	-31%	-385	-37%
Benzene	-124	-6%	-347	-19%	-490	-24%
CO	-26,705	-3%	-75,407	-8%	-106,874	-9%
Formaldehyde	-2,100	-12%	-5,908	-32%	-8,375	-37%
NO_X	-93,984	-8%	-262,150	-28%	-370,704	-34%
$PM_{2.5}$	619	2%	1,705	8%	2,412	10%
SO_X	-280	-5%	-742	-13%	-1,029	-15%
VOC	-13,925	-7%	-38,472	-22%	-54,150	-26%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-65 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-2%	-21	-12%	-29	-16%
Acetaldehyde	-668	-10%	-1,880	-31%	-2,664	-36%
Acrolein	-97	-10%	-271	-31%	-384	-37%
Benzene	-124	-6%	-346	-19%	-489	-24%
CO	-26,821	-3%	-75,795	-8%	-107,414	-9%
Formaldehyde	-2,099	-12%	-5,902	-32%	-8,367	-37%
NO_X	-94,724	-8%	-268,075	-29%	-380,328	-35%
$PM_{2.5}$	609	2%	1,618	8%	2,269	9%
SO_X	-282	-5%	-803	-14%	-1,127	-16%
VOC	-13,971	-7%	-39,383	-22%	-55,638	-26%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.1.2 Upstream Impacts

Table 5-66 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-5%	-3	-14%	-5	-17%
Acetaldehyde	-3	-3%	-10	-11%	-15	-13%
Acrolein	0	-4%	-1	-12%	-2	-15%
Benzene	-21	-4%	-74	-13%	-104	-15%
CO	-3,798	-5%	-12,087	-14%	-17,120	-17%
Formaldehyde	-19	-5%	-59	-14%	-84	-17%
NO_X	-9,472	-5%	-30,333	-14%	-42,839	-17%
$PM_{2.5}$	-1,019	-5%	-3,257	-14%	-4,609	-17%
SO_X	-5,983	-5%	-19,190	-14%	-27,074	-17%
VOC	-3,066	-4%	-11,029	-13%	-15,386	-15%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-67 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-5%	-4	-15%	-5	-18%
Acetaldehyde	-3	-3%	-11	-12%	-16	-14%
Acrolein	0	-4%	-1	-13%	-2	-15%
Benzene	-22	-4%	-80	-14%	-113	-16%
CO	-3,911	-5%	-13,153	-15%	-18,794	-18%
Formaldehyde	-19	-5%	-65	-15%	-92	-18%
NO_X	-9,787	-5%	-33,021	-15%	-47,028	-18%
$PM_{2.5}$	-1,051	-5%	-3,545	-15%	-5,058	-18%
SO_X	-6,189	-5%	-20,896	-15%	-29,726	-18%
VOC	-3,193	-4%	-11,848	-13%	-16,625	-16%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-68 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-6%	-3	-15%	-5	-17%
Acetaldehyde	-4	-5%	-11	-12%	-15	-14%
Acrolein	-1	-5%	-1	-13%	-2	-15%
Benzene	-28	-5%	-78	-13%	-105	-16%
CO	-4,679	-6%	-12,640	-15%	-17,263	-17%
Formaldehyde	-23	-6%	-62	-15%	-85	-17%
NO_X	-11,708	-6%	-31,769	-15%	-43,263	-17%
$PM_{2.5}$	-1,259	-6%	-3,408	-15%	-4,649	-17%
SO_X	-7,402	-6%	-20,107	-15%	-27,356	-17%
VOC	-4,081	-5%	-11,717	-13%	-15,645	-15%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-69 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-6%	-4	-16%	-5	-18%
Acetaldehyde	-4	-5%	-12	-12%	-16	-14%
Acrolein	-1	-5%	-1	-13%	-2	-16%
Benzene	-29	-5%	-84	-14%	-114	-17%
CO	-4,816	-6%	-13,720	-16%	-18,945	-18%
Formaldehyde	-24	-6%	-67	-16%	-93	-18%
NO_X	-12,098	-6%	-34,501	-16%	-47,477	-18%
$PM_{2.5}$	-1,298	-6%	-3,700	-16%	-5,101	-18%
SO_X	-7,658	-6%	-21,843	-16%	-30,024	-18%
VOC	-4,251	-5%	-12,541	-14%	-16,870	-16%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.1.3 Total Impacts

Table 5-70 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-3%	-25	-13%	-34	-16%
Acetaldehyde	-672	-10%	-1,893	-30%	-2,682	-36%
Acrolein	-97	-10%	-273	-31%	-387	-37%
Benzene	-145	-5%	-421	-18%	-595	-22%
CO	-30,282	-3%	-87,286	-8%	-123,876	-10%
Formaldehyde	-2,119	-11%	-5,969	-32%	-8,460	-37%
NO_X	-101,916	-7%	-291,282	-26%	-413,501	-31%
$PM_{2.5}$	-376	-1%	-1,535	-3%	-2,199	-4%
SO_X	-6,213	-5%	-19,905	-14%	-28,101	-17%
VOC	-16,227	-6%	-49,080	-18%	-69,525	-22%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-71 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-3%	-25	-13%	-35	-16%
Acetaldehyde	-672	-10%	-1,891	-30%	-2,680	-36%
Acrolein	-97	-10%	-273	-31%	-386	-37%
Benzene	-145	-5%	-425	-18%	-603	-22%
CO	-30,487	-3%	-88,724	-8%	-126,081	-10%
Formaldehyde	-2,119	-11%	-5,969	-32%	-8,461	-37%
NO_X	-102,983	-7%	-299,911	-26%	-427,332	-32%
$PM_{2.5}$	-419	-1%	-1,910	-4%	-2,791	-5%
SO_X	-6,421	-5%	-21,672	-15%	-30,850	-18%
VOC	-16,403	-6%	-50,812	-19%	-72,253	-23%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-72 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-3%	-25	-13%	-34	-16%
Acetaldehyde	-673	-10%	-1,893	-30%	-2,682	-36%
Acrolein	-97	-10%	-273	-31%	-387	-37%
Benzene	-152	-6%	-426	-18%	-595	-22%
CO	-31,383	-3%	-88,047	-8%	-124,137	-10%
Formaldehyde	-2,123	-11%	-5,970	-32%	-8,460	-37%
NO_X	-105,693	-7%	-293,918	-26%	-413,967	-31%
$PM_{2.5}$	-639	-1%	-1,703	-4%	-2,237	-4%
SO_X	-7,682	-6%	-20,849	-15%	-28,385	-17%
VOC	-18,006	-6%	-50,189	-19%	-69,796	-22%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-73 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-3%	-25	-13%	-35	-16%
Acetaldehyde	-672	-10%	-1,891	-30%	-2,679	-36%
Acrolein	-97	-10%	-273	-31%	-386	-37%
Benzene	-153	-6%	-430	-18%	-603	-22%
CO	-31,637	-3%	-89,514	-8%	-126,360	-10%
Formaldehyde	-2,123	-11%	-5,969	-32%	-8,460	-37%
NO_X	-106,822	-7%	-302,575	-26%	-427,805	-32%
$PM_{2.5}$	-689	-1%	-2,082	-5%	-2,833	-5%
SO_X	-7,941	-6%	-22,646	-16%	-31,151	-18%
VOC	-18,222	-6%	-51,924	-19%	-72,509	-23%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.2 Model Year Lifetime Analysis

Table 5-74 Lifetime Non-GHG Reductions by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method A (US Short Tons) [a]

	ALTERNATIVE 3 (PROPOSED)		ALTERNATIVE 4	
NO-ACTION ALTERNATIVE (BASELINE)	1b (More Dynamic)	1a (Less Dynamic)	1b (More Dynamic)	1a (Less Dynamic)
NO_X	2,359,548	2,409,738	2,420,931	2,472,021
HD Pickups and Vans	24,663	27,772	30,213	34,222
Vocational	15,810	15,810	24,265	24,265
Tractor/Trailers	2,319,075	2,366,156	2,366,453	2,413,534
$PM_{2.5}$	13,496	15,706	17,524	19,839
HD Pickups and Vans	2,502	2,842	3,038	3,484
Vocational	2,509	2,509	3,421	3,421
Tractor/Trailers	8,485	10,355	11,065	12,934
SO_X	167,415	177,948	189,670	200,992
HD Pickups and Vans	19,221	21,813	23,395	26,776
Vocational	17,295	17,295	22,416	22,416
Tractor/Trailers	130,899	138,840	143,859	151,800

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

5.5.2 Impacts of the Proposed Rules and Alternative 4 using Analysis Method B

5.5.2.1 Calendar Year Analysis

5.5.2.1.1 Downstream Impacts

After all the MOVES runs[Q] and post-processing were completed, the less dynamic reference (Alternative 1a) and control case (Alternative 3) inventories were aggregated for all vehicle types and emission processes to estimate the total downstream non-GHG impacts of the proposed program. Table 5-75 and Table 5-76 summarize these downstream non-GHG impacts of preferred alternative and Alternative 4 for calendar years 2025, 2035 and 2050, relative to Alternative 1a. The results are shown both in changes in absolute tons and in percent reductions from the less dynamic reference to alternatives for the heavy-duty sector.

The agencies expect the proposed program to impact the downstream emissions of non-GHG pollutants. These pollutants include oxides of nitrogen (NO_X), oxides of sulfur (SO_X),

[Q] For non-GHGs, MOVES was run only for January and July and the annual emissions were extrapolated by scaling up each month by a factor of 5.88 for all pollutants except particulate matter (PM). For PM, to offset the disproportionate effect of the cold temperature on January results, a scaling factor of 4.3 was applied to January and 7.5 to July; these factors were determined based on analysis of annual PM emissions during modeling for the RFS2 rule. Note that for GHGs, MOVES was run for all months.

volatile organic compounds (VOC), carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), and air toxics. The agencies are expecting reductions in downstream emissions of NO_X, VOC, SO_X, CO, and air toxics. Much of these estimated net reductions are a result of the agencies' anticipation of increased use of auxiliary power units (APUs) in combination tractors during extended idling; APUs emit these pollutants at a lower rate than on-road engines during extended idle operation, with the exception of $PM_{2.5}$.

Additional reductions in tailpipe emissions of NO_X and CO and refueling emissions of VOC would be achieved through improvements in engine efficiency and reduced road load (improved aerodynamics and tire rolling resistance), which reduces the amount of work required to travel a given distance and increases fuel economy.

For vehicle types not affected by road load improvements, such as HD pickups and vans[R], non-GHG emissions would increase very slightly due to VMT rebound. In addition, brake wear and tire wear emissions of $PM_{2.5}$ would also increase very slightly due to VMT rebound. The agencies estimate that downstream emissions of SO_X would be reduced, because they are roughly proportional to fuel consumption. Alternative 4 would have directionally similar effects as the preferred alternative.

Table 5-75 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-2.6%	-22	-15.1%	-31	-19.6%
Acetaldehyde	-670	-10.3%	-1,884	-31.0%	-2,671	-36.5%
Acrolein	-97	-9.9%	-272	-31.6%	-385	-37.3%
Benzene	-125	-5.9%	-353	-21.0%	-501	-25.7%
CO	-25,824	-1.7%	-72,960	-6.0%	-103,887	-7.6%
Formaldehyde	-2,102	-11.5%	-5,911	-32.1%	-8,379	-37.5%
NO_X	-93,220	-7.5%	-267,125	-29.1%	-380,721	-35.2%
$PM_{2.5}$	634	1.6%	1,631	7.6%	2,257	9.1%
SO_X	-254	-4.8%	-876	-15.0%	-1,264	-18.1%
VOC	-13,440	-6.4%	-40,148	-21.7%	-57,308	-26.1%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[R] HD pickups and vans are subject to gram per mile (distance) emissions standards, as opposed to larger heavy-duty vehicles which are certified to a gram per brake horsepower (work) standard.

Table 5-76 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-8	-2.6%	-22	-15.1%	-31	-19.6%
Acetaldehyde	-670	-10.3%	-1,884	-31.0%	-2,671	-36.5%
Acrolein	-97	-9.9%	-272	-31.6%	-385	-37.3%
Benzene	-126	-5.9%	-354	-21.0%	-501	-25.7%
CO	-25,919	-1.7%	-73,041	-6.0%	-103,891	-7.6%
Formaldehyde	-2,101	-11.5%	-5,910	-32.1%	-8,378	-37.5%
NO_X	-94,787	-7.6%	-268,373	-29.2%	-380,810	-35.2%
$PM_{2.5}$	610	1.5%	1,611	7.5%	2,256	9.1%
SO_X	-313	-5.9%	-909	-15.6%	-1,267	-18.1%
VOC	-14,310	-6.8%	-40,640	-22.0%	-57,348	-26.1%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

As shown in Table 5-77, a net increase in downstream $PM_{2.5}$ emissions is expected in both 2035 and 2050. Although the improvements in engine efficiency and road load are expected to reduce tailpipe emissions of $PM_{2.5}$, the projected increased use (Table 5-23) of APUs would lead to higher $PM_{2.5}$ emissions that more than offset the reductions from the tailpipe, since engines powering APUs are currently required to meet less stringent PM standards than on-road engines. Therefore, EPA conducted an evaluation of a program that would reduce the unintended consequence of increase in $PM_{2.5}$ emissions from increased APU use by fitting the APU with a diesel particulate filter or having the APU exhaust plumbed into the vehicle's exhaust system upstream of the particulate matter aftertreatment device. Such program requiring additional $PM_{2.5}$ controls on APU could significantly reduce $PM_{2.5}$ emissions, as shown in Table 5-77 below. For additional details, see Section III.C.3 of the preamble.

Table 5-77 Projected Impact on $PM_{2.5}$ Emissions of Further $PM_{2.5}$ Control on APUs using Analysis Method B[a]

CY	PROPOSED PROGRAM INVENTORY WITHOUT FURTHER $PM_{2.5}$ CONTROL ON APUS	PROPOSED PROGRAM INVENTORY WITH FURTHER $PM_{2.5}$ CONTROL ON APUS	NET IMPACT OF FURTHER $PM_{2.5}$ CONTROL ON APUS
2035	23,083	19,999	-3,084
2050	26,932	22,588	-4,344

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

It is worth noting that the emission reductions shown in Table 5-75 are not incremental to the emissions reductions projected in the Phase 1 rulemaking. This is because the agencies have revised their assumptions about the adoption rate of APUs. This proposal assumes that without the proposed Phase 2 program (i.e., in the Phase 2 reference case), the APU adoption rate will be 30 percent for model years 2010 and later, which is the value used in the Phase 1 reference case. This decision was based on the agencies' assessment of how the current level of automatic engine shutdown and idle reduction technologies are used by the tractor manufacturers to comply with the 2014 model year CO_2 and fuel consumption standards. To date, the manufacturers are meeting the 2014 model year standards without the use of this technology. Compared to Phase 1, the proposed program projects much delayed penetration of APUs starting in model year 2021 (Figure 5-4).

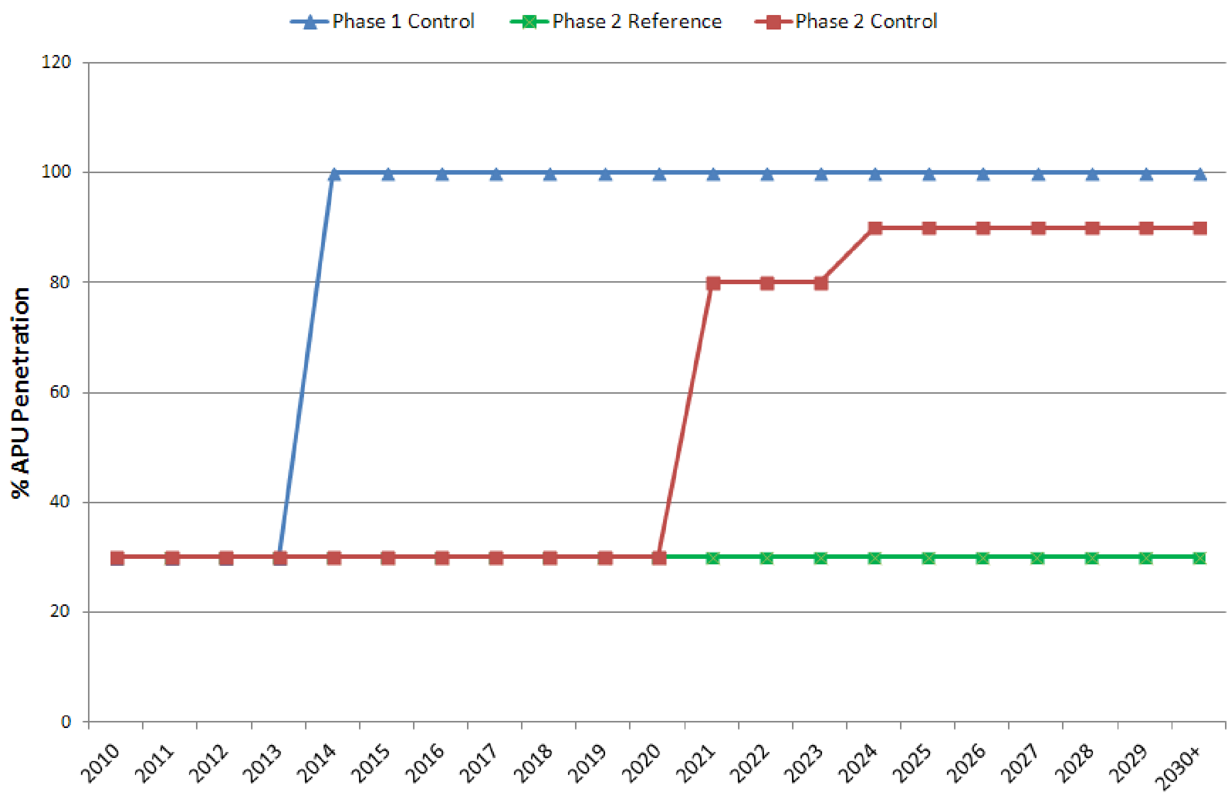

Figure 5-4 Comparison of Assumed APU Use during Extended Idle in Phase 1 and Phase 2

Considering the change in assumptions about APU use and the magnitude of impact of APUs on criteria emissions, EPA conducted an analysis estimating the combined emissions impacts of the Phase 1 and proposed Phase 2 programs for NO_X, VOC, SO_X and $PM_{2.5}$ in calendar year 2050. The analysis estimated the combined Phase 1 and Phase 2 emissions impacts by comparing the Phase 2 control case inventories to the Phase 1 reference case inventories. To be consistent with the emissions modeling done for this proposed program, the emissions inventories for Phase 1 reference case were estimated using MOVES2014.[S] The results are shown in Table 5-78. The differences in downstream reduction estimates between

[S] The emissions modeling for Phase 1 was performed using MOVES2010a.

Phase 2 alone (Table 5-75) and combined Phase 1 and Phase 2 (Table 5-78) reflect the improvements in road loads from Phase 1. For NO_X and $PM_{2.5}$ only, we also estimated the combined Phase 1 and Phase 2 downstream and upstream emissions impacts for calendar year 2025, and project that the two rules combined would reduce NO_X by up to 120,000 tons and $PM_{2.5}$ by up to 2,000 tons in that year.

Table 5-78 Combined Phase 1 and Phase 2 Annual Downstream Reductions of Heavy-Duty Criteria Emissions in Calendar Year 2050 using Analysis Method B [a]

CY	NO_X	VOC	SO_X	$PM_{2.5}$ [b]
2050	403,915	69,415	2,111	-1,890

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Negative reduction reflects an increase in emissions.

5.5.2.1.2 Upstream Impacts

The proposed program is projected to provide emissions reductions in all pollutants associated with upstream from production and distribution as the projected fuel savings reduce the demands for gasoline and diesel. Table 5-79 and Table 5-80 summarize the annual upstream reductions of preferred alternative and Alternative 4 for criteria pollutants and individual air toxic pollutants in calendar years 2025, 2035 and 2050, relative to Alternative 1a. The results are shown both in changes in absolute tons and in percent reductions from the less dynamic reference to alternatives for the heavy-duty sector.

Table 5-79 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-5.0%	-4	-15.3%	-5	-18.4%
Acetaldehyde	-4	-3.0%	-18	-11.9%	-26	-14.6%
Acrolein	-0.5	-3.4%	-2	-12.7%	-3	-15.5%
Benzene	-24	-3.8%	-92	-13.4%	-132	-16.3%
CO	-3,798	-4.9%	-13,001	-15.3%	-18,772	-18.4%
Formaldehyde	-19	-4.7%	-67	-14.9%	-98	-18.0%
NO_X	-9,282	-4.9%	-31,782	-15.3%	-45,888	-18.4%
$PM_{2.5}$	-1,020	-4.9%	-3,514	-15.2%	-5,072	-18.2%
SO_X	-5,817	-4.9%	-19,902	-15.3%	-28,736	-18.4%
VOC	-3,283	-3.7%	-12,724	-13.2%	-18,214	-16.1%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-80 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-1	-6.1%	-4	-15.9%	-5	-18.4%
Acetaldehyde	-6	-4.3%	-20	-12.6%	-26	-14.7%
Acrolein	-1	-4.7%	-2	-13.3%	-3	-15.5%
Benzene	-32	-5.0%	-97	-14.0%	-133	-16.3%
CO	-4,661	-6.1%	-13,485	-15.9%	-18,812	-18.4%
Formaldehyde	-24	-5.9%	-70	-15.5%	-97	-18.0%
NO_X	-11,393	-6.1%	-32,965	-15.9%	-45,986	-18.4%
$PM_{2.5}$	-1,256	-6.0%	-3,647	-15.7%	-5,083	-18.3%
SO_X	-7,137	-6.1%	-20,641	-15.9%	-28,797	-18.4%
VOC	-4,342	-4.9%	-13,326	-13.8%	-18,273	-16.1%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.2.1.3 Total Impacts

As shown in Table 5-81 and Table 5-82, the agencies estimate that this proposed program and Alternative 4 would result in overall net reductions of NO_X, VOC, SO_X, CO, $PM_{2.5}$, and air toxics emissions. The downstream increase in $PM_{2.5}$ due to APU use is expected to be more than offset by reductions in $PM_{2.5}$ from upstream.[T] The results are shown both in changes in absolute tons and in percent reductions from the less dynamic reference to the alternatives for the heavy-duty sector. By 2050, the total impacts of the proposed program and Alternative 4 on criteria pollutants and air toxics are indistinguishable.

[T] Although a net reduction in $PM_{2.5}$ is expected at the national level, it is unlikely that the geographic location of increases in downstream $PM_{2.5}$ emissions will coincide with the location of decreases in upstream $PM_{2.5}$ emissions. For the final rulemaking, a national-scale air quality modeling analysis will be performed to estimate the future year ambient $PM_{2.5}$ concentrations for 2040. For further details, see Section VIII.D of this preamble and Chapter 8 of the draft RIA.

Table 5-81 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Preferred Alternative vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-2.7%	-25	-15.1%	-36	-19.4%
Acetaldehyde	-674	-10.1%	-1,902	-30.5%	-2,697	-36.0%
Acrolein	-97	-9.8%	-274	-31.3%	-388	-36.9%
Benzene	-149	-5.4%	-445	-18.8%	-633	-22.9%
CO	-29,622	-1.9%	-85,961	-6.6%	-122,659	-8.4%
Formaldehyde	-2,121	-11.4%	-5,978	-31.7%	-8,475	-37.0%
NO_X	-102,502	-7.2%	-298,907	-26.6%	-426,610	-32.1%
$PM_{2.5}$	-386	-0.6%	-1,883	-4.2%	-2,815	-5.4%
SO_X	-6,070	-4.9%	-20,777	-15.3%	-30,000	-18.4%
VOC	-16,724	-5.6%	-52,872	-18.8%	-75,521	-22.7%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-82 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2035 and 2050 – Alternative 4 vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2035		CY2050	
	US Short Tons	% Reduction	US Short Tons	% Reduction	US Short Tons	% Reduction
1,3-Butadiene	-9	-2.8%	-26	-15.2%	-36	-19.4%
Acetaldehyde	-676	-10.1%	-1,903	-30.6%	-2,697	-36.0%
Acrolein	-97	-9.8%	-274	-31.3%	-388	-36.9%
Benzene	-157	-5.7%	-450	-18.9%	-634	-22.9%
CO	-30,580	-1.9%	-86,526	-6.6%	-122,703	-8.4%
Formaldehyde	-2,125	-11.4%	-5,980	-31.7%	-8,476	-37.0%
NO_X	-106,180	-7.4%	-301,339	-26.8%	-426,796	-32.1%
$PM_{2.5}$	-646	-1.1%	-2,036	-4.6%	-2,827	-5.4%
SO_X	-7,450	-6.1%	-21,550	-15.9%	-30,064	-18.4%
VOC	-18,652	-6.2%	-53,966	-19.2%	-75,621	-22.7%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.2.2 Model Year Lifetime Analysis

In addition to the annual non-GHG emissions reductions expected from the proposed rules and Alternative 4, the combined (downstream and upstream) non-GHG impacts for the lifetime of the impacted vehicles were estimated by heavy-duty vehicle category. Table 5-83 shows the fleet-wide reductions of NO_X, $PM_{2.5}$ and SO_X from the preferred alternative and Alternative 4, relative to Alternative 1a, through the lifetime[U] of heavy-duty vehicles.

Table 5-83 Lifetime Non-GHG Reductions by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method B (US Short Tons) [a]

	ALTERNATIVE 3 (PROPOSED)	ALTERNATIVE 4
NO-ACTION ALTERNATIVE (BASELINE)	1a (Less Dynamic)	1a (Less Dynamic)
NO_X	2,399,990	2,459,497
HD Pickups and Vans	18,024	21,698
Vocational	15,810	24,265
Tractor/Trailers	2,366,156	2,413,534
$PM_{2.5}$	15,206	19,151
HD Pickups and Vans	2,342	2,796
Vocational	2,509	3,421
Tractor/Trailers	10,355	12,934
SO_X	169,436	189,904
HD Pickups and Vans	13,301	15,688
Vocational	17,295	22,416
Tractor/Trailers	138,840	151,800

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

[U] A lifetime of 30 years is assumed in MOVES.

References

[1] Intergovernmental Panel on Climate Change Working Group I. 2007. Climate Change 2007 – The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

[2] U.S. EPA. 2014. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012. EPA 430-R-14-003. Available at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

[3] U.S. EPA. 2009. Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC. pp. 180-194. Available at http://epa.gov/climatechange/endangerment/downloads/Endangerment%20TSD.pdf

[4] U.S. EPA. 2014. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012. EPA 430-R-14-003. Available at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

[5] MOVES2014 homepage: http://www.epa.gov/otaq/models/moves/index.htm

[6] Argonne National Laboratory. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model versions 1.8.c. http://www.transportation.anl.gov/modeling_simulation/GREET/.

[7] 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)

[8] MOVES2014 homepage: http://www.epa.gov/otaq/models/moves/index.htm

[9] Memorandum to the Docket "Runspecs, Model Inputs, MOVES Code and Database for HD GHG Phase 2 NPRM Emissions Modeling" Docket No. EPA-HQ-OAR-2014-0827

[10] U.S. EPA. Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program. Chapters 2 and 3. May 26, 2009. Docket No. EPA-HQ-OAR-2009-0472-0119

[11] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards (77 FR 62623, October 15, 2012)

[12] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles (76 FR 57106, September 15, 2011)

[13] Memorandum to the Docket "Upstream Emissions Modeling Files for HDGHG Phase 2 NPRM" Docket No. EPA-HQ-OAR-2014-0827

[14] U.S. EPA. 2015. Population and Activity of On-road Vehicles in MOVES2014 – Draft Report" Docket No. EPA-HQ-OAR-2014-0827.

[15] Annual Energy Outlook 2014. http://www.eia.doe.gov/oiaf/aeo/

[16] U.S. EPA. 2015. "Exhaust Emission Rates for Heavy-Duty On-road Vehicles in MOVES2014 – Draft Report" Docket No. EPA-HQ-OAR-2014-0827.

[17] Memorandum to the Docket "NPRM - Tractor-Trailer Inputs to MOVES" Docket No. EPA-HQ-OAR-2014-0827

[18] ACT Research Co., LLC. U.S. Trailers Monthly Market Indicators. Available at www.actresearch.net/reports Accessed 7/28/2014

[19] U.S. Census Bureau. 2002 Vehicle Inventory and Use Survey. Available at https://www.census.gov/svsd/www/vius/2002.html Accessed 6/30/2014

[20] Memorandum to the Docket "NPRM - Vocational Inputs to MOVES" Docket No. EPA-HQ-OAR-2014-0827

[21] Craig Harvey, EPA, "Calculation of Upstream Emissions for the GHG Vehicle Rule." 2009. Docket No. EPA-HQ-OAR-2009-0472-0216

[22] The Minnesota refrigerant leakage data: http://www.pca.state.mn.us/climatechange/mobileair.html#leakdata

[23] Eastern Research Group. "A Study of R134a Leaks in Heavy Duty Vehicles." CARB Contract 06-342. Presented during CARB Seminar on January 6, 2011.

Chapter 6: Health and Environmental Impacts

6.1 Health and Environmental Effects of Non-GHG Pollutants

6.1.1 Health Effects Associated with Exposure to Non-GHG Pollutants

In this section we will discuss the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the standards, but the standards will affect emissions of these pollutants and precursors.

6.1.1.1 Particulate Matter

6.1.1.1.1 *Background on Particulate Matter*

Particulate matter (PM) is a highly complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles range in size from those smaller than 1 nanometer (10^{-9} meter) to over 100 micrometer (µm, or 10^{-6} meter) in diameter (for reference, a typical strand of human hair is 70 µm in diameter and a grain of salt is about 100 µm). Atmospheric particles can be grouped into several classes according to their aerodynamic and physical sizes. Generally, the three broad classes of particles considered by EPA include ultrafine particles (UFP, aerodynamic diameter <0.1 µm), "fine" particles ($PM_{2.5}$; particles with a nominal mean aerodynamic diameter less than or equal to 2.5 µm), and "thoracic" particles (PM_{10}; particles with a nominal mean aerodynamic diameter less than or equal to 10 µm). Particles that fall within the size range between $PM_{2.5}$ and PM_{10}, are referred to as "thoracic coarse particles" ($PM_{10-2.5,}$ particles with a nominal mean aerodynamic diameter less than or equal to 10 µm and greater than 2.5 µm). EPA currently has standards that regulate $PM_{2.5}$ and PM_{10}.[A]

Particles span many sizes and shapes and may consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. Particle concentration and composition varies by time of year and location, and in addition to differences in source emissions, is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from particles' ability to shift between solid/liquid and gaseous phases, which is influenced by concentration and meteorology, especially temperature.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., sulfur oxides (SO_X), nitrogen oxides (NO_X) and volatile organic compounds (VOCs)) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may

[A] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR Parts 50, 53, and 58. With regard to national ambient air quality standards (NAAQS) which provide protection against health and welfare effects, the 24-hour PM_{10} standard provides protection against effects associated with short-term exposure to thoracic coarse particles (i.e., $PM_{10-2.5}$).

vary greatly with time, region, meteorology, and source category. Thus, $PM_{2.5}$ may include a complex mixture of different components including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.[1]

6.1.1.1.2 *Health Effects of Particulate Matter*

Scientific studies show ambient PM is associated with a broad range of health effects. These health effects are discussed in detail in the December 2009 Integrated Science Assessment for Particulate Matter (PM ISA).[2] The PM ISA summarizes health effects evidence associated with both short- and long-term exposures to $PM_{2.5}$, $PM_{10-2.5}$, and ultrafine particles. The PM ISA concludes that human exposures to ambient $PM_{2.5}$ concentrations are associated with a number of adverse health effects and characterizes the weight of evidence for these health outcomes.[B] The discussion below highlights the PM ISA's conclusions pertaining to health effects associated with both short- and long-term PM exposures. Further discussion of health effects associated with $PM_{2.5}$ can also be found in the rulemaking documents for the most recent review of the PM NAAQS completed in 2012.[3,4]

EPA has concluded that a causal relationship exists between both long- and short-term exposures to $PM_{2.5}$ and premature mortality and cardiovascular effects and a likely causal relationship exists between long- and short-term $PM_{2.5}$ exposures and respiratory effects. Further, there is evidence suggestive of a causal relationship between long-term $PM_{2.5}$ exposures and other health effects, including developmental and reproductive effects (e.g., low birth weight, infant mortality) and carcinogenic, mutagenic, and genotoxic effects (e.g., lung cancer mortality).[C]

As summarized in the Final PM NAAQS rule, and discussed extensively in the 2009 PM ISA, the available scientific evidence significantly strengthens the link between long- and short-term exposure to $PM_{2.5}$ and premature mortality, while providing indications that the magnitude of the $PM_{2.5}$- mortality association with long-term exposures may be larger than previously estimated.[5,6] The strongest evidence comes from recent studies investigating long-term exposure to $PM_{2.5}$ and cardiovascular-related mortality. The evidence supporting a causal relationship between long-term $PM_{2.5}$ exposure and mortality also includes consideration of new studies that demonstrated an improvement in community health following reductions in ambient fine particles.[7]

[B] The causal framework draws upon the assessment and integration of evidence from across epidemiological, controlled human exposure, and toxicological studies, and the related uncertainties that ultimately influence our understanding of the evidence. This framework employs a five-level hierarchy that classifies the overall weight of evidence and causality using the following categorizations: causal relationship, likely to be causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship (U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Table 1–3).

[C] These causal inferences are based not only on the more expansive epidemiological evidence available in this review of the PM NAAQS but also reflect consideration of important progress that has been made to advance understanding of a number of potential biologic modes of action or pathways for PM-related cardiovascular and respiratory effects (U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Chapter 5).

Several studies evaluated in the 2009 PM ISA have examined the association between cardiovascular effects and long-term $PM_{2.5}$ exposures in multi-city studies conducted in the U.S. and Europe. These studies have provided new evidence linking long-term exposure to $PM_{2.5}$ with an array of cardiovascular effects such as heart attacks, congestive heart failure, stroke, and mortality. This evidence is coherent with studies of short-term exposure to $PM_{2.5}$ that have observed associations with a continuum of effects ranging from subtle changes in indicators of cardiovascular health to serious clinical events, such as increased hospitalizations and emergency department visits due to cardiovascular disease and cardiovascular mortality.[8]

As detailed in the 2009 PM ISA, extended analyses of seminal epidemiological studies, as well as more recent epidemiological studies conducted in the U.S. and abroad, provide strong evidence of respiratory-related morbidity effects associated with long-term $PM_{2.5}$ exposure. The strongest evidence for respiratory-related effects is from studies that evaluated decrements in lung function growth (in children), increased respiratory symptoms, and asthma development. The strongest evidence from short-term $PM_{2.5}$ exposure studies has been observed for increased respiratory-related emergency department visits and hospital admissions for chronic obstructive pulmonary disease (COPD) and respiratory infections.[9]

The body of scientific evidence detailed in the 2009 PM ISA is still limited with respect to associations between long-term $PM_{2.5}$ exposures and developmental and reproductive effects as well as cancer, mutagenic, and genotoxic effects. The strongest evidence for an association between $PM_{2.5}$ and developmental and reproductive effects comes from epidemiological studies of low birth weight and infant mortality, especially due to respiratory causes during the post-neonatal period (i.e., 1 month to 12 months of age). With regard to cancer effects, ‘‘[m]ultiple epidemiologic studies have shown a consistent positive association between $PM_{2.5}$ and lung cancer mortality, but studies have generally not reported associations between $PM_{2.5}$ and lung cancer incidence.’’[10,11]

Specific groups within the general population are at increased risk for experiencing adverse health effects related to PM exposures.[12,13,14,15] The evidence detailed in the 2009 PM ISA expands our understanding of previously identified at-risk populations and lifestages (i.e., children, older adults, and individuals with pre-existing heart and lung disease) and supports the identification of additional at-risk populations (e.g., persons with lower socioeconomic status, genetic differences). Additionally, there is emerging, though still limited, evidence for additional potentially at-risk populations and lifestages, such as those with diabetes, people who are obese, pregnant women, and the developing fetus.[16]

For $PM_{10-2.5}$, the 2009 PM ISA concluded that available evidence was suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and cardiovascular effects (e.g., hospital admissions and ED visits, changes in cardiovascular function), respiratory effects (e.g., ED visits and hospital admissions, increase in markers of pulmonary inflammation), and premature mortality. Data were inadequate to draw conclusions regarding the relationships between long-term exposure to $PM_{10-2.5}$ and various health effects.[17,18,19]

For ultrafine particles, the 2009 PM ISA concluded that the evidence was suggestive of a causal relationship between short-term exposures and cardiovascular effects, including changes in heart rhythm and vasomotor function (the ability of blood vessels to expand and contract). It also concluded that there was evidence suggestive of a causal relationship between short-term exposure to ultrafine particles and respiratory effects, including lung function and pulmonary inflammation, with limited and inconsistent evidence for increases in ED visits and hospital admissions. Data were inadequate to draw conclusions regarding the relationship between short-term exposure to ultrafine particle and additional health effects including premature mortality as well as long-term exposure to ultrafine particles and all health outcomes evaluated.[20,21]

6.1.1.2 Ozone

6.1.1.2.1 *Background on Ozone*

Ground-level ozone pollution is typically formed through reactions involving VOCs and NO_X in the lower atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone and its precursors can be transported hundreds of miles downwind of precursor emissions, resulting in elevated ozone levels even in areas with low VOC or NO_X emissions.

The highest levels of ozone are produced when both VOC and NO_X emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_X enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_X. Under these conditions NO_X reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_X-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X-limited.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2). As the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO_X, VOC, and ozone, all of which change with time and location. When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large. Rural areas are usually NO_X-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NO_X-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

6.1.1.2.2 *Health Effects of Ozone*

This section provides a summary of the health effects associated with exposure to ambient concentrations of ozone.[D] The information in this section is based on the information and conclusions in the February 2013 Integrated Science Assessment for Ozone (Ozone ISA).[22] The Ozone ISA concludes that human exposures to ambient concentrations of ozone are associated with a number of adverse health effects and characterizes the weight of evidence for these health effects.[E] The discussion below highlights the Ozone ISA's conclusions pertaining to health effects associated with both short-term and long-term periods of exposure to ozone.

For short-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including lung function decrements, pulmonary inflammation, exacerbation of asthma, respiratory-related hospital admissions, and mortality, are causally associated with ozone exposure. It also concludes that cardiovascular effects, including decreased cardiac function and increased vascular disease, and total mortality are likely to be causally associated with short-term exposure to ozone and that evidence is suggestive of a causal relationship between central nervous system effects and short-term exposure to ozone.

For long-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including new onset asthma, pulmonary inflammation and injury, are likely to be causally related with ozone exposure. The Ozone ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term ozone exposure and cardiovascular effects, reproductive and developmental effects, central nervous system effects and total mortality. The evidence is inadequate to infer a causal relationship between chronic ozone exposure and increased risk of lung cancer.

Finally, interindividual variation in human responses to ozone exposure can result in some groups being at increased risk for detrimental effects in response to exposure. The Ozone ISA identified several groups that are at increased risk for ozone-related health effects. These groups are people with asthma, children and older adults, individuals with reduced intake of certain nutrients (i.e., Vitamins C and E), outdoor workers, and individuals having certain genetic variants related to oxidative metabolism or inflammation. Ozone exposure during childhood can have lasting effects through adulthood. Such effects include altered function of the respiratory and immune systems. Children absorb higher doses (normalized to lung surface area) of ambient ozone, compared to adults, due to their increased time spent outdoors, higher ventilation rates relative to body size, and a tendency to breathe a greater fraction of air through the mouth. Children also have a higher asthma prevalence compared to adults. Additional children's vulnerability and susceptibility factors are listed in Section XIV of the preamble.

[D] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentrations but also by the breathing route and rate.

[E] The ISA evaluates evidence and draws conclusions on the causal relationship between relevant pollutant exposures and health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II in the Preamble of the ISA.

6.1.1.3 Nitrogen Oxides

6.1.1.3.1 *Background on Nitrogen Oxides*

Nitrogen dioxide (NO_2) is a member of the nitrogen oxide (NO_X) family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. NO_2 and its gas phase oxidation products can dissolve in water droplets and further oxidize to form nitric acid which reacts with ammonia to form nitrates, which are important components of ambient PM. The health effects of ambient PM are discussed in Chapter 6.1.1.1.2. NO_X along with VOCs are the two major precursors of ozone. The health effects of ozone are covered in Chapter 6.1.1.2.2.

6.1.1.3.2 *Health Effects of Nitrogen Oxides*

The most recent review of the health effects of oxides of nitrogen completed by EPA can be found in the 2008 Integrated Science Assessment for Oxides of Nitrogen – Health Criteria (Oxides of Nitrogen ISA).[23] EPA concluded that the findings of epidemiological, controlled human exposure, and animal toxicological studies provided evidence that was sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The 2008 ISA for Oxides of Nitrogen concluded that the strongest evidence for such a relationship comes from epidemiological studies of respiratory effects including increased respiratory symptoms, emergency department visits, and hospital admissions. Based on both short- and long-term exposure studies, the 2008 ISA for Oxides of Nitrogen concluded that individuals with preexisting pulmonary conditions (e.g., asthma or COPD), children, and older adults are potentially at greater risk of NO_2-related respiratory effects. Based on findings from controlled human exposure studies, the 2008 ISA for Oxides of Nitrogen also drew two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the NO_X ISA concluded that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatic adults to NO_2 concentrations as low as 260 ppb.[24] Second, exposure to NO_2 was found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of healthy and asthmatic adults. Statistically significant increases in nonspecific airway responsiveness were reported for asthmatic adults following 30-minute exposures to 200-300 ppb NO_2 and following 1-hour exposures to 100 ppb NO_2.[25] Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiological and experimental data sets formed a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admissions and emergency department visits for respiratory causes, especially asthma.[26]

In evaluating a broader range of health effects, the 2008 ISA for Oxides of Nitrogen concluded evidence was "suggestive but not sufficient to infer a causal relationship" between short-term NO_2 exposure and premature mortality and between long-term NO_2 exposure and respiratory effects. The latter was based largely on associations observed between long-term NO_2 exposure and decreases in lung function growth in children. Furthermore, the 2008 ISA for

Oxides of Nitrogen concluded that evidence was "inadequate to infer the presence or absence of a causal relationship" between short-term NO_2 exposure and cardiovascular effects as well as between long-term NO_2 exposure and cardiovascular effects, reproductive and developmental effects, premature mortality, and cancer.[27] The conclusions for these health effect categories were informed by uncertainties in the evidence base such as the independent effects of NO_2 exposure within the broader mixture of traffic-related pollutants, limited evidence from experimental studies, and/or an overall limited literature base.

6.1.1.4 Sulfur Oxides

6.1.1.4.1 *Background*

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. SO_2 and its gas phase oxidation products can dissolve in water droplets and further oxidize to form sulfuric acid which reacts with ammonia to form sulfates, which are important components of ambient PM. The health effects of ambient PM are discussed in Chapter 6.1.1.1.2.

6.1.1.4.2 *Health Effects of Sulfur Oxides*

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the 2008 Integrated Science Assessment for Sulfur Oxides – Health Criteria (SO_X ISA).[28] Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. In addition to those with asthma (both children and adults), potentially sensitive groups include all children and the elderly. In free-breathing laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations $\geq$ 400 ppb in asthmatics engaged in moderate to heavy levels of exercise, with respiratory effects occurring at concentrations as low as 200 ppb in some asthmatics. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 200 and 1000 ppb, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults ($\geq$ 65 years), and for asthma. A limited subset of epidemiologic studies has examined potential confounding by copollutants using multipollutant regression models. These analyses indicate that although copollutant adjustment has varying degrees of influence on the SO_2 effect estimates, the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous and particulate copollutants, suggesting that the observed effects of SO_2 on respiratory endpoints occur independent of the effects of other ambient air pollutants.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these observed mortality associations due to potential confounding by various copollutants. Therefore, EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality. Significant associations between short-term exposure to SO_2 and emergency department visits and hospital admissions for cardiovascular diseases have also been reported. However, these findings have been inconsistent across studies and do not provide adequate evidence to infer a causal relationship between SO_2 exposure and cardiovascular morbidity.

6.1.1.5 Carbon Monoxide

6.1.1.5.1 *Background*

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources.

6.1.1.5.2 *Health Effects of Carbon Monoxide*

Information on the health effects of carbon monoxide (CO) can be found in the January 2010 Integrated Science Assessment for Carbon Monoxide (CO ISA).[29] The CO ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[F] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[G]

Controlled human exposure studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease,

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[F] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[G] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and non-ambient components; and both components may contribute to adverse health effects.

myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The CO ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report central nervous system and behavioral effects following low-level CO exposures, although the findings have not been consistent across all studies. The CO ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of studies cited in the CO ISA have evaluated the role of CO exposure in birth outcomes such as preterm birth or cardiac birth defects. The epidemiologic studies provide limited evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found perinatal CO exposure to affect birth weight, as well as other developmental outcomes. The CO ISA concludes the evidence is suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of associations between ambient CO concentrations and respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50-100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The CO ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the CO ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term concentrations of CO and mortality. Epidemiologic studies provide evidence of an association between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in copollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The CO ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

6.1.1.6 Diesel Exhaust

6.1.1.6.1 *Background on Diesel Exhaust*

Diesel exhaust consists of a complex mixture composed of carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, 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 diesel particulate matter present in diesel exhaust consists mostly of fine particles (< 2.5 µm), of which a significant fraction is ultrafine particles (< 0.1 µm). 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.

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

6.1.1.6.2 *Health Effects of Diesel Exhaust*

In EPA's 2002 Diesel Health Assessment Document (Diesel HAD), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[30,31] A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) had made similar hazard classifications prior to 2002. EPA also concluded in the 2002 Diesel HAD that it was not possible to calculate a cancer unit risk for diesel exhaust due to limitations in the exposure data for the occupational groups or the absence of a dose-response relationship.

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

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

It is important to note that the Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses EPA's then-annual $PM_{2.5}$ NAAQS of 15 $\mu g/m^3$. In 2012, EPA revised the annual $PM_{2.5}$ NAAQS to 12 $\mu g/m^3$. There is a large and extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The $PM_{2.5}$ NAAQS is designed to provide protection from the noncancer health effects and premature mortality attributed to exposure to $PM_{2.5}$. The contribution of diesel PM to total ambient PM varies in different regions of the country and also, within a region, from one area to another. The contribution can be high in near-roadway environments, for example, or in other locations where diesel engine use is concentrated.

Since 2002, several new studies have been published which continue to report increased lung cancer risk with occupational exposure to diesel exhaust from older engines. Of particular note since 2011 are three new epidemiology studies which have examined lung cancer in occupational populations, for example, truck drivers, underground nonmetal miners and other diesel motor related occupations. These studies reported increased risk of lung cancer with exposure to diesel exhaust with evidence of positive exposure-response relationships to varying degrees.[32,33,34] These newer studies (along with others that have appeared in the scientific literature) add to the evidence EPA evaluated in the 2002 Diesel HAD and further reinforces the concern that diesel exhaust exposure likely poses a lung cancer hazard. The findings from these newer studies do not necessarily apply to newer technology diesel engines since the newer engines have large reductions in the emission constituents compared to older technology diesel engines.

In light of the growing body of scientific literature evaluating the health effects of exposure to diesel exhaust, in June 2012 the World Health Organization's International Agency for Research on Cancer (IARC), a recognized international authority on the carcinogenic potential of chemicals and other agents, evaluated the full range of cancer related health effects data for diesel engine exhaust. IARC concluded that diesel exhaust should be regarded as "carcinogenic to humans."[35] This designation was an update from its 1988 evaluation that considered the evidence to be indicative of a "probable human carcinogen."

6.1.1.7 Air Toxics

Heavy-duty vehicle emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to the class of pollutants known collectively as "air toxics."[36] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter, and naphthalene. These compounds were identified as national or regional risk drivers or contributors in the 2005 National-scale Air Toxics Assessment and have significant inventory contributions from mobile sources.[37]

6.1.1.7.1 *Health Effects of Benzene*

EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[38,39,40] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. EPA's IRIS documentation for benzene also lists a range of 2.2×10^{-6} to 7.8×10^{-6} as the unit risk estimate (URE) for benzene.[H,41] The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[42,43]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[44,45] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[46,47] EPA's inhalation reference concentration (RfC) for benzene is 30 $\mu g/m^3$. The RfC is based on suppressed absolute lymphocyte counts seen in humans under occupational exposure conditions. In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[48,49,50,51] EPA's IRIS program has not yet evaluated these new data. EPA does not currently have an acute reference concentration for benzene. The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Level (MRL) for acute exposure to benzene is 29 $\mu g/m^3$ for 1-14 days exposure.[52,I]

6.1.1.7.2 *Health Effects of 1,3-Butadiene*

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[53,54] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has

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[H] A unit risk estimate is defined as the increase in the lifetime risk of an individual who is exposed for a lifetime to 1 µg/m3 benzene in air.

[I] A minimal risk level (MRL) is defined as an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.

characterized 1,3-butadiene as a known human carcinogen.[55,56,57] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. The URE for 1,3-butadiene is 3×10^{-5} per $\mu g/m^3$.[58] 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[59] Based on this critical effect and the benchmark concentration methodology, an RfC for chronic health effects was calculated at 0.9 ppb (approximately 2 $\mu g/m^3$).

6.1.1.7.3 *Health Effects of Formaldehyde*

In 1991, EPA concluded that formaldehyde is a carcinogen based on nasal tumors in animal bioassays.[60] An Inhalation URE for cancer and a Reference Dose for oral noncancer effects were developed by the agency and posted on the Integrated Risk Information System (IRIS) database. Since that time, the National Toxicology Program (NTP) and International Agency for Research on Cancer (IARC) have concluded that formaldehyde is a known human carcinogen.[61,62,63]

The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991 in combination with previous animal, human and mechanistic evidence. Research conducted by the National Cancer Institute reported an increased risk of nasopharyngeal cancer and specific lymphohematopoietic malignancies among workers exposed to formaldehyde.[64,65,66] A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde.[67] Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[68] Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid leukemia but not brain cancer.[69]

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999[70] and supplemented in 2010,[71] and by the World Health Organization.[72] These organizations reviewed the scientific literature concerning health effects linked to formaldehyde exposure to evaluate hazards and dose response relationships and defined exposure concentrations for minimal risk levels (MRLs). The health endpoints reviewed included 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 that formaldehyde may increase the risk of asthma – particularly in the young.

EPA released a draft Toxicological Review of Formaldehyde – Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment in June 2010.[73] The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011[74] (http://www.nap.edu/catalog.php?record_id=13142). EPA is currently developing a new draft assessment in response to this review.

6.1.1.7.4 *Health Effects of Acetaldehyde*

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[75] The URE in IRIS for acetaldehyde is 2.2×10^{-6} per $\mu g/m^3$.[76] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 13th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[77,78] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[79] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[80,81] Data from these studies were used by EPA to develop an inhalation reference concentration of 9 $\mu g/m^3$. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[82] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

6.1.1.7.5 *Health Effects of Acrolein*

EPA most recently evaluated the toxicological and health effects literature related to acrolein in 2003 and concluded that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[83] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[84]

Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[85] The agency has developed an RfC for acrolein of 0.02 $\mu g/m^3$ and an RfD of 0.5 μg/kg-day.[86] EPA is considering updating the acrolein assessment with data that have become available since the 2003 assessment was completed.

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[87] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[88] Studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms. Acute exposures in animal studies report bronchial hyper-responsiveness. Based on animal data (more pronounced respiratory irritancy in mice with allergic airway disease in comparison to non-diseased mice[89]) and demonstration of similar effects in humans (e.g., reduction in respiratory rate), 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. EPA does not currently have an acute reference concentration for acrolein. The available health effect reference values for acrolein have been summarized by EPA and include an ATSDR MRL for acute exposure to acrolein of 7 $\mu g/m^3$ for 1-14 days exposure; and Reference Exposure Level (REL) values from the California Office of Environmental Health Hazard Assessment (OEHHA) for one-hour and 8-hour exposures of 2.5 $\mu g/m^3$ and 0.7 $\mu g/m^3$, respectively.[90]

6.1.1.7.6 *Health Effects of Polycyclic Organic Matter (POM)*

The term polycyclic organic matter (POM) defines a broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). One of these compounds, naphthalene, is discussed separately below. POM compounds are formed primarily from combustion and are present in the atmosphere in gas and particulate form. Cancer is the major concern from exposure to POM. Epidemiologic studies have reported an increase in lung cancer in humans exposed to diesel exhaust, coke oven emissions, roofing tar emissions, and cigarette smoke; all of these mixtures contain POM compounds.[91][92] Animal studies have reported respiratory tract tumors from inhalation exposure to benzo[a]pyrene and alimentary tract and liver tumors from oral exposure to benzo[a]pyrene.[93] In 1997 EPA classified seven PAHs (benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene) as Group B2, probable human carcinogens.[94] Since that time, studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development in preschool children (3 years of age).[95,96] These and similar studies are being evaluated as a part of the ongoing IRIS assessment of health effects associated with exposure to benzo[a]pyrene.

6.1.1.7.7 *Health Effects of Naphthalene*

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, or dermal contact is associated with hemolytic anemia and damage to the liver and the nervous system.[97] Chronic (long term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and retinal damage.[98] EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[99] The draft reassessment completed external peer review.[100] Based on external peer review comments received, a revised draft assessment that considers all routes of exposure, as well as cancer and noncancer effects, is under development. The external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[101]

California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[102]

Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[103] The current EPA IRIS assessment includes noncancer data on hyperplasia and metaplasia in nasal tissue that form the basis of the inhalation RfC of 3 µg/m^3.[104] The ATSDR MRL for acute exposure to naphthalene is 0.6 mg/kg/day.

6.1.1.7.8 *Health Effects of Other Air Toxics*

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles will be affected by this proposal. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[105]

6.1.1.8 Exposure and Health Effects Associated with Traffic

In addition to health concerns resulting from specific air pollutants, a large number of studies have examined the health status of populations near major roadways. These studies frequently have employed exposure metrics that are not specific to individual pollutants, but rather reflect the large number of different pollutants found in elevation near major roads.

In this section of the RIA, information on health effects associated with air quality near major roads or traffic in general is summarized. Generally, the section makes use of publications that systematically review literature on a given health topic. In particular, this section makes frequent reference of a report of by the Health Effects Institute (HEI) Panel on the Health Effects of Traffic-Related Air Pollution, published in 2010 as a review of relevant studies.[J,106] Other systematic reviews of relevant literature are cited were appropriate.

6.1.1.8.1 *Populations near Major Roads*

Numerous studies have estimated the size and demographics of populations that live near major roads. Other studies have estimated the number of schools near major roads, and the populations of students in such schools.

Every two years, the U.S. Census Bureau's American Housing Survey (AHS) has reported whether housing units are within 300 feet of an "airport, railroad, or highway with four or more lanes." The 2009 survey reports that over 22 million homes, or 17 percent of all housing

[J] It should be noted that there are no peer reviewed EPA-authored reviews of traffic-related health studies. The HEI panel primarily used epidemiology studies for inferring whether there was sufficient evidence of a causal association exists between a particular health effect and traffic-related air pollution. In its weight-of-evidence determinations, the panel also placed "considerable weight" on controlled human exposure studies. However, it restricted consideration of other toxicological studies to whether or not the studies provided "general mechanistic support" for the inferences of causality made on the basis of epidemiology.

units in the U.S., were located in such areas. Assuming that populations and housing units are in the same locations, this corresponds to a population of more than 50 million U.S. residents in close proximity to high-traffic roadways or other transportation sources. According to the Central Intelligence Agency's World Factbook, in 2010, the United States had 6,506,204 km or roadways, 224,792 km of railways, and 15,079 airports. As such, highways represent the overwhelming majority of transportation facilities described by this factor in the AHS.

The AHS reports are published every two years, and until 2011 recorded whether homes were located near highways with four or more lanes, railroads, or airports. As such, trends in the AHS can be reported to describe whether a greater or lesser proportion of homes are located near major roads over time. Figure 6-1 depicts trends in the number and proportion of homes located near major transportation sources, which generally indicate large roadways. As the figure indicates, since 2005, there has been a substantial increase in the number and percentage of homes located near major transportation sources. As such, the population in close proximity to these sources, which may be affected by near-road air quality and health concerns, appears to have increased over time.

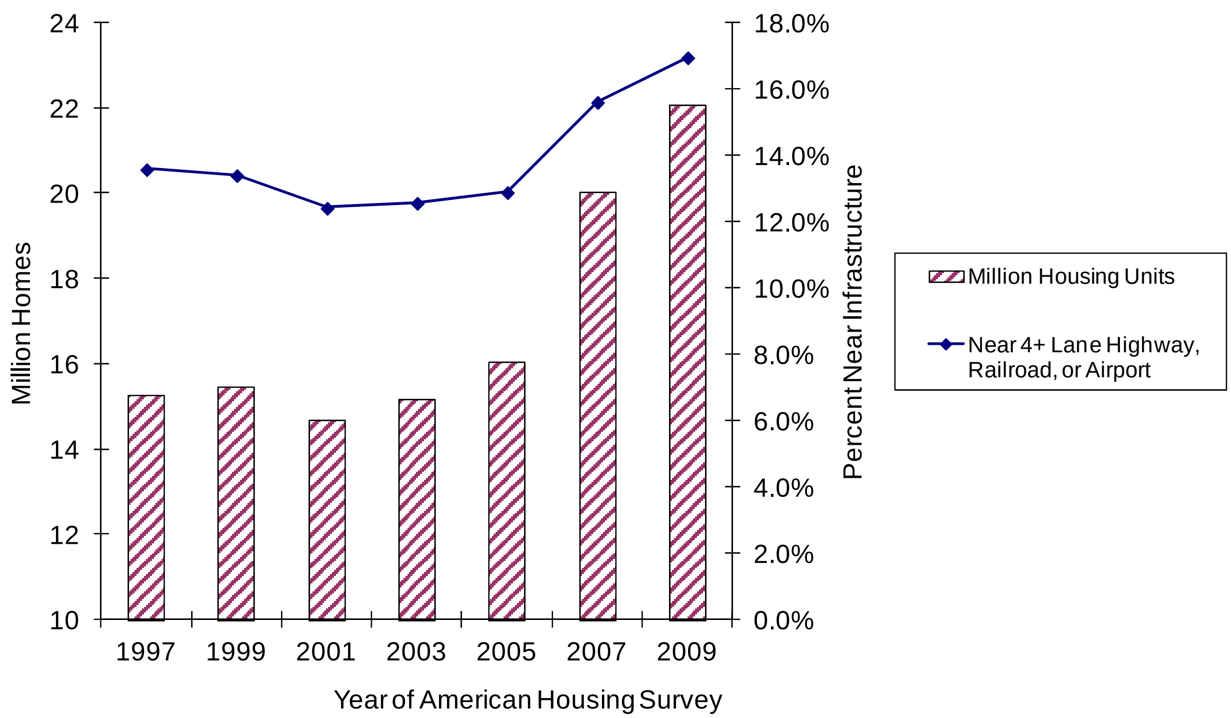

Figure 6-1 Trends in Populations Near Large Highways, Railroads, and Airports

Furthermore, according to data from the 2008 American Time Use Survey (ATUS), conducted by the Bureau of Labor Statistics (BTS), Americans spend more than an hour traveling each day, on average.[107] Although the ATUS does not indicate their mode of travel, the majority of trips undertaken nationally is by motor vehicle.[108] As such, daily travel activity brings nearly all residents into a high-exposure microenvironment for part of the day.

6.1.1.8.2 *Premature Mortality*

The HEI panel report concluded that evidence linking traffic-associated air pollution with premature mortality from all causes was "suggestive but not sufficient" to infer a causal relationship. This conclusion was based largely on several long-term studies that "qualitatively" examined whether or not someone was exposed to traffic-associated air pollution. In addition, based on several short-term studies of exposure, the panel concluded that there was "suggestive but not sufficient" evidence to infer a causal relation between traffic-related exposure and cardiovascular mortality.

6.1.1.8.3 *Cardiovascular Effects*

6.1.1.8.3.1 Cardiac Physiology

Exposure to traffic-associated pollutants has been associated with changes in cardiac physiology, including cardiac function. One common measure of cardiac function is heart rate variability (HRV), an indicator of the heart's ability to respond to variations in stress, reflecting the nervous system's ability to regulate the heart.[K] Reduced HRV is associated with adverse cardiovascular events, such as myocardial infarction, in heart disease patients. The HEI panel concluded that available evidence provides evidence for a causal association between exposure to traffic-related pollutants and reduced control of HRV by the nervous system. Overall, the panel concluded that the evidence was "suggestive but not sufficient" to infer a causal relation between traffic-related pollutants and cardiac function. Studies suggest that the HRV changes from traffic-related air pollution result in changes to heart rhythms, which can lead to arrhythmia.[109,110]

6.1.1.8.3.2 Heart Attack and Atherosclerosis

The HEI panel concluded that epidemiologic evidence of the association between traffic-related pollutants and heart attacks and atherosclerosis was "suggestive but not sufficient" to infer a causal association. In addition, the panel concluded that the toxicology studies they reviewed provided "suggestive evidence that exposure to traffic emissions, including ambient and laboratory-generated [PM] and diesel- and gasoline-engine exhaust, alters cardiovascular function." The panel noted there are few studies of human volunteers exposed to real-world traffic mixture, which were not entirely consistent. The panel notes that the studies provide consistent evidence for exposure to PM and impaired cardiovascular responses. In addition to the HEI study, several other reviews of available evidence conclude that there is evidence supporting a causal association between traffic-related air pollution and cardiovascular disease.[111]

A number of mechanisms for cardiovascular disease are highlighted in the HEI and AHA report, including modified blood vessel endothelial function (e.g., the ability to dilate), atherosclerosis, and oxidative stress. The HEI review cites "two well executed studies" in which

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[K] The autonomic nervous system (ANS) consists of sympathetic and parasympathetic components. The sympathetic ANS signals body systems to "fight or flight." The parasympathetic ANS signals the body to "rest and digest." In general, HRV is indicative of parasympathetic control of the heart.

hospitalization for acute myocardial infarction (i.e., heart attack) were associated with traffic exposures and a prospective study finding higher rates of arterial hardening and coronary heart disease near traffic.

6.1.1.8.4 *Respiratory Effects*

6.1.1.8.4.1 Asthma

Pediatric asthma and asthma symptoms are the effects that have been evaluated by the largest number of studies in the epidemiologic literature on the topic. In general, studies consistently show effects of residential or school exposure to traffic and asthma symptoms, and the effects are frequently statistically significant. Studies have employed both short-term and long-term exposure metrics, and a range of different respiratory measures. HEI Special Report 17 (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010) concluded that there is sufficient evidence for a causal association between exposure to traffic-related air pollution and exacerbation of asthma symptoms in children.

While there is general consistency in studies examining asthma incidence in children, the available studies employ different definitions of asthma (e.g., self-reported vs. hospital records), methods of exposure assessment, and population age ranges. As such, the overall evidence, while supportive of an association between traffic exposure and new onset asthma, are less consistent than for asthma symptoms. The HEI report determined that evidence is between "sufficient" and "suggestive" of a causal relationship between exposure to traffic-related air pollution and incident (new onset) asthma in children (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). A recent meta-analysis of studies on incident asthma and air pollution in general, based on studies dominated by traffic-linked exposure metrics, also concluded that available evidence is consistent with HEI's conclusion (Anderson et al., 2011). The study reported excess main risk estimates for different pollutants ranging from 7-16 percent per 10 $\mu g/m^3$ of long-term exposure (random effects models). Other qualitative reviews (Salam et al., 2008; Braback and Forsberg, 2009) conclude that available evidence is consistent with the hypothesis that traffic-associated air pollutants are associated with incident asthma.

6.1.1.8.4.2 Chronic Obstructive Pulmonary Disease (COPD)

The HEI panel reviewed available studies examining COPD in the context of traffic-associated air pollution. Because of how the panel selected studies for inclusion in review, there were only two studies that they used to review the available evidence. Both studies reported some positive associations, but not for all traffic metrics. The small number of studies and lack of consistency across traffic metrics led the panel to conclude that there is insufficient evidence for traffic-associated air pollution causing COPD.

6.1.1.8.4.3 Allergy

There are numerous human and animal experimental studies that provides strongly suggestive evidence that traffic-related air pollutants can enhance allergic responses to common allergens.[112,113,114] However, in its review of 16 epidemiologic studies that address traffic-related air pollution's effect on allergies, the HEI expert panel (HEI, 2010) reported that only two such studies showed consistently positive associations. As a result, despite the strongly suggestive experimental evidence, the panel concluded that there is "inadequate/insufficient" evidence of an association between allergy and traffic-associated air pollution. As noted above, the HEI panel considered toxicological studies only based on whether or not they provide mechanistic support for observations and inferences derived from epidemiology.

6.1.1.8.4.4 Lung Function

There are numerous measurements of breathing (spirometry) that indicate the presence or degree of airway disease, such as asthma and chronic obstructive pulmonary disease (COPD). Forced vital capacity (FVC) is measured when a patient maximally fills their lungs and then blows their hardest in completely exhaling. The peak expiratory flow (PEF) is the maximum air flow achievable during exhalation. The forced expiratory volume in the first second of exhalation is referred to as FEV_1. FEV_1 and PEF reflect the function of the large airways. FVC and FEV_1, along with their ratio (FVC/FEV_1) are used to classify airway obstruction in asthma and COPD. Measurements of air flow at various times during forced exhalation, such as 25 percent, 50 percent, and 75 percent, are also used. The flow at 75 percent of forced exhalation (FEF_{75}) reflects the status of small airways, which asthma and COPD affect.

The HEI panel concluded that the available literature suggests that long-term exposure to traffic-related air pollution is associated with reduced lung function in adolescents and young adults and that lung function is lower in populations in areas with high traffic-related air pollutant levels. However, the panel noted the difficulty of disentangling traffic-specific exposures from urban air pollution in general. The studies reviewed that were more specifically oriented toward traffic were not consistent in their findings. As a result, the panel found that the evidence linking lung function and traffic exposure is "inadequate and insufficient" to infer a causal relationship.

6.1.1.8.5 *Reproductive and Developmental Effects*

Several studies have reported associations between traffic-related air pollution and adverse birth outcomes, such as preterm birth and low birth weight. At the time of the HEI review, the panel concluded that evidence for adverse birth outcomes being causally associated with traffic-related exposures was "inadequate and insufficient." Only four studies met the panel's inclusion criteria, and had limited geographic coverage. One study provided evidence of small but consistently increased risks using multiple exposure metrics. No studies were at the time available that examined traffic-specific exposures and congenital abnormalities. Since then, several studies investigating birth outcomes have been published, but no new systematic reviews. One new meta-analysis of air pollution and congenital abnormalities has been published, though none of the reviewed studies includes traffic-specific exposure information.

The HEI panel also reviewed toxicological studies of traffic-related air pollutants and fertility. While numerous studies examining animal or human exposure and sperm count have been published, the panel concluded that the generally high exposure concentrations employed in the studies limited the applicability to typical ambient concentrations. Because there was no overlap in the effects studied by epidemiology and toxicology studies, no synthesis review of the combined literature was undertaken.

Since the HEI panel's publication, a systematic review and meta-analysis of air pollution and congenital abnormalities was published.[115] In that review, only one study directly included nearby traffic in its exposure analysis. As such, there are no systematic reviews that specifically address traffic's impact on congenital abnormalities.

6.1.1.8.6 *Cancer*

6.1.1.8.6.1 Childhood Cancer

Earlier this year, Boothe et al. (2014) published a systematic review and meta-analysis of studies of childhood leukemia risks associated for populations near major roads.[116] The study concluded that childhood leukemia was positively associated with residential exposure during childhood, but not during the prenatal period. Other literature reviews have not concluded that available evidence supports an association between childhood leukemia and traffic exposure.[117,118] For example, the HEI panel concluded that the available epidemiologic evidence was "inadequate and insufficient" to infer a causal relationship between traffic-related air pollution and childhood cancer.

6.1.1.8.6.2 Adult Cancer

Several studies have examined the risk of adult lung cancers in relation to exposure to traffic-related air pollutants. The HEI panel evaluated four such studies, and rated the available evidence as "inadequate and insufficient" to infer a causal relation for non-occupational lung cancer.

6.1.1.8.7 *Neurological Effects*

The HEI panel found that current toxicologic and epidemiologic literature on the neurotoxicity of traffic-related air pollution was inadequate for their evaluation. The panel noted that there were a number of toxicologic studies of traffic-associated pollutants, but found them to have diverse exposure protocols, animal models, and endpoints, making them unsuitable for systematic evaluation.

6.1.2 Environmental Effects Associated with Exposure to Non-GHG Pollutants

In this section we will discuss the environmental effects associated with non-GHG pollutants, specifically: particulate matter, ozone, NO_X, SO_X and air toxics.

6.1.2.1 Visibility Degradation

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[119] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil.[120] Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2009 PM ISA.[121]

The extent to which any amount of light extinction affects a person's ability to view a scene depends on both scene and light characteristics. For example, the appearance of a nearby object (e.g., a building) is generally less sensitive to a change in light extinction than the appearance of a similar object at a greater distance. See Figure 6-2 for an illustration of the important factors affecting visibility.

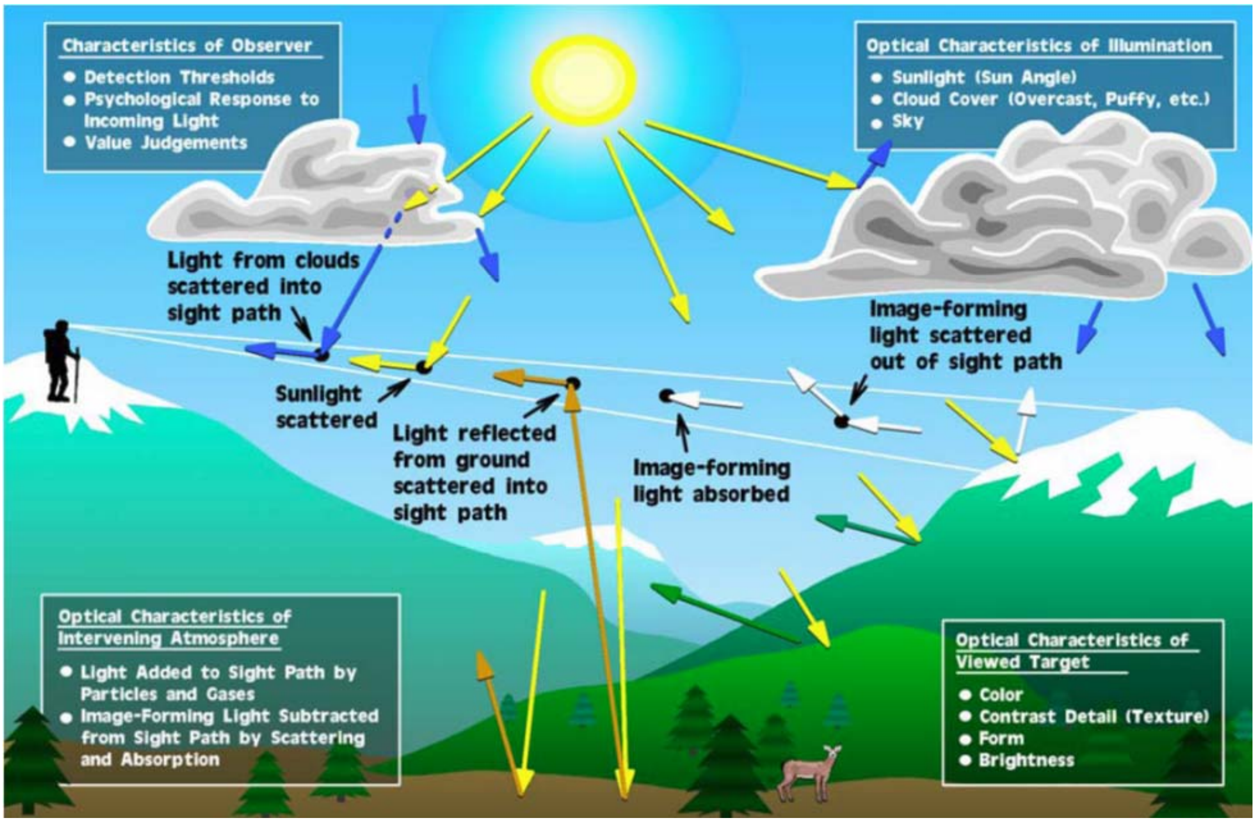

Figure 6-2 Important Factors Involved in Seeing a Scenic Vista (Malm, 1999)

EPA is working to address visibility impairment. Reductions in air pollution from implementation of various programs associated with the Clean Air Act Amendments of 1990 (CAAA) provisions have resulted in substantial improvements in visibility, and will continue to do so in the future. Because trends in haze are closely associated with trends in particulate sulfate and nitrate due to the simple relationship between their concentration and light extinction, visibility trends have improved as emissions of SO_2 and NO_X have decreased over time due to air pollution regulations such as the Acid Rain Program.[122]

In the Clean Air Act Amendments of 1977, Congress recognized visibility's value to society by establishing a national goal to protect national parks and wilderness areas from visibility impairment caused by manmade pollution.[L] In 1999, EPA finalized the regional haze

[L] See Section 169(a) of the Clean Air Act.

program (64 FR 35714) to protect the visibility in Mandatory Class I Federal areas. There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas (62 FR 38680-38681, July 18, 1997). These areas are defined in CAA Section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977. Figure 6-3 shows the location of the 156 Mandatory Class I Federal areas.

Figure 6-3 Mandatory Class I Federal Areas in the U.S.

EPA has also concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not protected by the Regional Haze Rule, depending on $PM_{2.5}$ concentrations and other factors such as dry chemical composition and relative humidity (i.e., an indicator of the water composition of the particles). EPA revised the $PM_{2.5}$ standards in December 2012 and established a target level of protection that is expected to be met through attainment of the existing secondary standards for $PM_{2.5}$.

6.1.2.2 Visibility Monitoring

In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network was originally established at 20 sites, but it has now been expanded to 110 sites that represent all but one of the 156 Mandatory Federal Class I areas across the country (see Figure 6-3). This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of Protected Visual Environments).

IMPROVE provides direct measurement of fine particles that contribute to visibility impairment. The IMPROVE network employs aerosol measurements at all sites, and optical and scene measurements at some of the sites. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon OC and EC), soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency, with adjustment for the relative humidity. The IMPROVE program utilizes both an "original" and a "revised" reconstruction formula for this purpose, with the latter explicitly accounting for sea salt concentrations. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. In addition to this indirect method of assessing light extinction, there are optical measurements which directly measure light extinction or its components. Such measurements are made principally with a nephelometer to measure light scattering, some sites also include an aethalometer for light absorption, or a few sites use a transmissometer, which measures total light extinction. Scene characteristics are typically recorded using digital or video photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Directly measured light extinction is used under the IMPROVE protocol to cross check that the aerosol-derived light extinction levels are reasonable in establishing current visibility conditions. Aerosol-derived light extinction is used to document spatial and temporal trends and to determine how changes in atmospheric constituents would affect future visibility conditions.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. Visibility is typically worse in the summer months, and the rural East generally has higher levels of impairment than remote sites in the West. Figures 9-9 through 9-11 in the PM ISA detail the percent contributions to particulate light extinction for ammonium nitrate and sulfate, EC and OC, and coarse mass and fine soil, by season.[123]

6.1.2.3 Plant and Ecosystem Effects of Ozone

The welfare effects of ozone can be observed across a variety of scales, i.e. subcellular, cellular, leaf, whole plant, population and ecosystem. Ozone effects that begin at small spatial scales, such as the leaf of an individual plant, when they occur at sufficient magnitudes (or to a sufficient degree) can result in effects being propagated along a continuum to larger and larger spatial scales. For example, effects at the individual plant level, such as altered rates of leaf gas exchange, growth and reproduction can, when widespread, result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure.[124] In those sensitive species[M], effects from repeated exposure to ozone throughout the growing season of the plant tend to accumulate, so

[M] 73 FR 16491 (March 27, 2008). Only a small percentage of all the plant species growing within the U.S. (over 43,000 species have been catalogued in the USDA PLANTS database) have been studied with respect to ozone sensitivity.

that even low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation.[125,N] Ozone damage to sensitive species includes impaired photosynthesis and visible injury to leaves. The impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to reduced crop yields, timber production, and plant productivity and growth. Impaired photosynthesis can also lead to a reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.[126] These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on areas with sensitive species could potentially lead to species shifts and loss from the affected ecosystems[O], resulting in a loss or reduction in associated ecosystem goods and services.[127] Additionally, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas and reduced use of sensitive ornamentals in landscaping.[128]

The Integrated Science Assessment (ISA) for Ozone presents more detailed information on how ozone effects vegetation and ecosystems.[129] The ISA concludes that ambient concentrations of ozone are associated with a number of adverse welfare effects and characterizes the weight of evidence for different effects associated with ozone.[P] The ISA concludes that visible foliar injury effects on vegetation, reduced vegetation growth, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops, and alteration of below-ground biogeochemical cycles are causally associated with exposure to ozone. It also concludes that reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling, and alteration of terrestrial community composition are likely to be causally associated with exposure to ozone.

6.1.2.4 Particulate Matter Deposition

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominantly from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). The following characterizations of the nature of these environmental effects are based on information contained in the 2009 PM ISA and the 2008 Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria (secondary NO_X/SO_X ISA).[130, 131]

[N] The concentration at which ozone levels overwhelm a plant's ability to detoxify or compensate for oxidant exposure varies. Thus, whether a plant is classified as sensitive or tolerant depends in part on the exposure levels being considered.

[O] Per footnote above, ozone impacts could be occurring in areas where plant species sensitive to ozone have not yet been studied or identified.

[P] The Ozone ISA evaluates the evidence associated with different ozone related health and welfare effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II of the ISA.

6.1.2.4.1 *Deposition of Nitrogen and Sulfur*

Nitrogen and sulfur interactions in the environment are highly complex as shown in Figure 6-4. Both nitrogen and sulfur are essential, and sometimes limiting, nutrients needed for growth and productivity of ecosystem components (e.g. algae, plants). In terrestrial and aquatic ecosystems excesses of nitrogen or sulfur can lead to acidification and nutrient enrichment.[132] In addition, in aquatic ecosystems, sulfur deposition can increase mercury methylation.

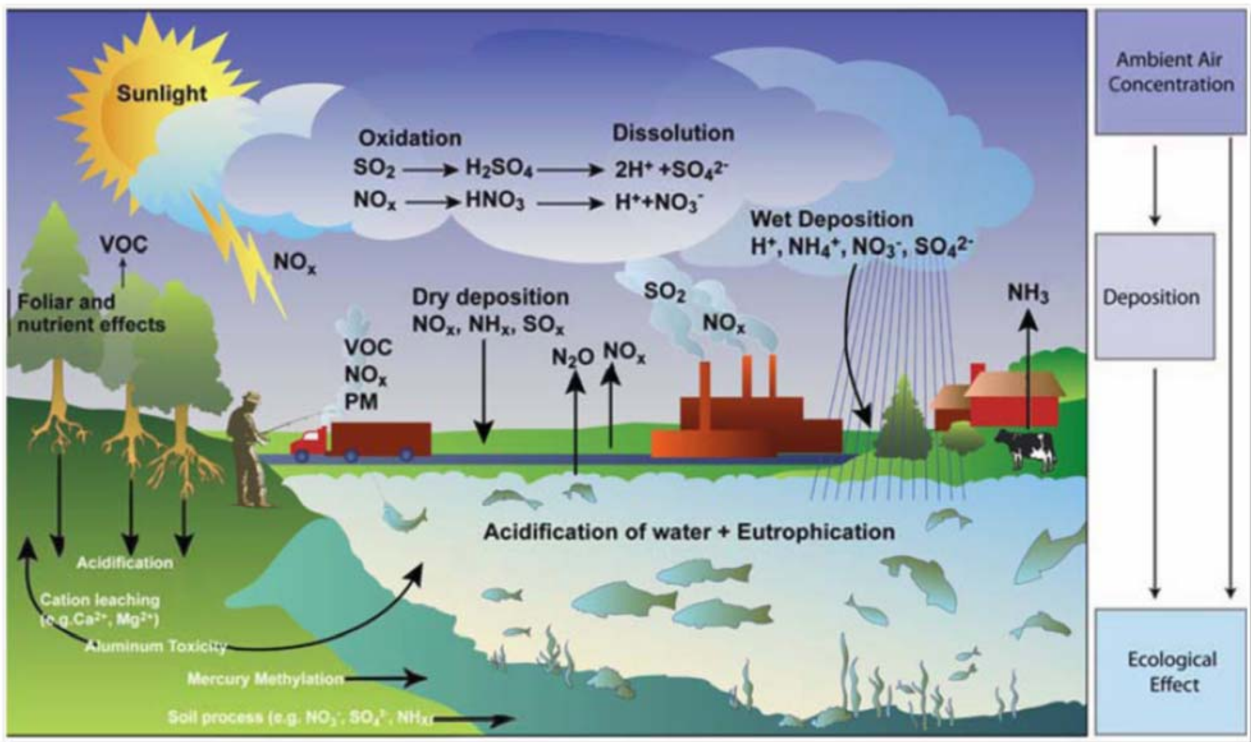

Figure 6-4 Nitrogen and Sulfur Cycling, and Interactions in the Environment

Source: U.S. EPA, 2008c

6.1.2.4.1.1 Ecological Effects of Acidification

Deposition of nitrogen and sulfur can cause acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. Soil acidification is a natural process, but is often accelerated by acidifying deposition, which can decrease concentrations of exchangeable base cations in soils.[133] Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations.[134] Decreases in the acid neutralizing capacity and increases in inorganic aluminum concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems.[135]

Geology (particularly surficial geology) is the principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition.[136] Geologic formations having low base cation supply generally underlie the watersheds of acid-sensitive lakes and streams. Other factors contribute to the sensitivity of soils and surface waters to acidifying deposition, including topography, soil chemistry, land use, and hydrologic flow path.[137]

6.1.2.4.1.1.1 Aquatic Acidification

Aquatic effects of acidification have been well studied in the U.S. and elsewhere at various trophic levels. These studies indicate that aquatic biota have been affected by acidification at virtually all levels of the food web in acid sensitive aquatic ecosystems. Effects have been most clearly documented for fish, aquatic insects, other invertebrates, and algae. Biological effects are primarily attributable to a combination of low pH and high inorganic aluminum concentrations. Such conditions occur more frequently during rainfall and snowmelt that cause high flows of water and less commonly during low-flow conditions, except where chronic acidity conditions are severe. Biological effects of episodes include reduced fish condition factor[A], changes in species composition and declines in aquatic species richness across multiple taxa, ecosystems and regions.

Because acidification primarily affects the diversity and abundance of aquatic biota, it also affects the ecosystem services that are derived from the fish and other aquatic life found in these surface waters. In the northeastern United States, the surface waters affected by acidification are a source of food for some recreational and subsistence fishermen and for other consumers with particularly high rates of self-caught fish consumption, such as the Hmong and Chippewa ethnic groups.[138,139]

6.1.2.4.1.1.2 Terrestrial Acidification

Acidifying deposition has altered major biogeochemical processes in the U.S. by increasing the nitrogen and sulfur content of soils, accelerating nitrate and sulfate leaching from soil to drainage waters, depleting base cations (especially calcium and magnesium) from soils, and increasing the mobility of aluminum. Inorganic aluminum is toxic to some tree roots. Plants affected by high levels of aluminum from the soil often have reduced root growth, which restricts the ability of the plant to take up water and nutrients, especially calcium.[140] These direct effects can, in turn, influence the response of these plants to climatic stresses such as droughts and cold temperatures. They can also influence the sensitivity of plants to other stresses, including insect pests and disease leading to increased mortality of canopy trees.[141] In the U.S., terrestrial effects of acidification are best described for forested ecosystems (especially red spruce and sugar maple ecosystems) with additional information on other plant communities, including shrubs and lichen.[142]

Both coniferous and deciduous forests throughout the eastern U.S. are experiencing gradual losses of base cation nutrients from the soil due to accelerated leaching from acidifying deposition. This change in nutrient availability may reduce the quality of forest nutrition over the long term. Evidence suggests that red spruce and sugar maple in some areas in the eastern U.S. have experienced declining health because of this deposition. For red spruce, (*Picea rubens*) dieback or decline has been observed across high elevation landscapes of the northeastern U.S., and to a lesser extent, the southeastern U.S., and acidifying deposition has been implicated as a causal factor.[143]

6.1.2.4.1.2 Ecological Effects from Nitrogen Enrichment

6.1.2.4.1.2.1 Aquatic Enrichment

Eutrophication in estuaries is associated with a range of adverse ecological effects including low dissolved oxygen (DO), harmful algal blooms (HABs), loss of submerged aquatic vegetation (SAV), and low water clarity. Low DO disrupts aquatic habitats, causing stress to fish and shellfish, which, in the short-term, can lead to episodic fish kills and, in the long-term, can damage overall growth in fish and shellfish populations. Low DO also degrades the aesthetic qualities of surface water. In addition to often being toxic to fish and shellfish, and leading to fish kills and aesthetic impairments of estuaries, HABs can, in some instances, also be harmful to human health. SAV provides critical habitat for many aquatic species in estuaries and, in some instances, can also protect shorelines by reducing wave strength; therefore, declines in SAV due to nutrient enrichment are an important source of concern. Low water clarity is in part the result of accumulations of both algae and sediments in estuarine waters. In addition to contributing to declines in SAV, high levels of turbidity also degrade the aesthetic qualities of the estuarine environment.

An assessment of estuaries nationwide by the National Oceanic and Atmospheric Administration (NOAA) concluded that 64 estuaries (out of 99 with available data) suffered from moderate or high levels of eutrophication due to excessive inputs of both N and phosphorus.[144] For estuaries in the Mid-Atlantic region, the contribution of atmospheric deposition to total N loads is estimated to range between 10 percent and 58 percent.[145] Estuaries in the eastern United States are an important source of food production, in particular fish and shellfish production. The estuaries are capable of supporting large stocks of resident commercial species, and they serve as the breeding grounds and interim habitat for several migratory species. Eutrophication in estuaries may also affect the demand for seafood after well-publicized toxic blooms, water-based recreation, and erosion protection provided by SAV.

6.1.2.4.1.2.2 Terrestrial Enrichment

Terrestrial enrichment occurs when terrestrial ecosystems receive N loadings in excess of natural background levels, through either atmospheric deposition or direct application. Atmospheric N deposition is associated with changes in the types and number of species and biodiversity in terrestrial systems. Nitrogen enrichment occurs over a long time period; as a result, it may take as much as 50 years or more to see changes in ecosystem conditions and indicators. One of the main provisioning services potentially affected by N deposition is grazing opportunities offered by grasslands for livestock production in the Central U.S. Although N deposition on these grasslands can offer supplementary nutritive value and promote overall grass production, there are concerns that fertilization may favor invasive grasses and shift the species composition away from native grasses. This process may ultimately reduce the productivity of grasslands for livestock production.

Terrestrial enrichment also affects habitats, for example the Coastal Sage Scrub (CSS) and Mixed Conifer Forest (MCF) habitats which are an integral part of the California landscape. Together the ranges of these habitats include the densely populated and valuable coastline and the mountain areas. Numerous threatened and endangered species at both the state and federal levels reside in CSS and MCF. Fire regulation is also an important regulating service that could be affected by nutrient enrichment of the CSS and MCF ecosystems by encouraging growth of more flammable grasses, increasing fuel loads, and altering the fire cycle.

6.1.2.4.1.3 Vegetation Effects Associated with Gaseous Sulfur Dioxide

Uptake of gaseous sulfur dioxide in a plant canopy is a complex process involving adsorption to surfaces (leaves, stems, and soil) and absorption into leaves. SO_2 penetrates into leaves through the stomata, although there is evidence for limited pathways via the cuticle.[146] Pollutants must be transported from the bulk air to the leaf boundary layer in order to get to the stomata. When the stomata are closed, as occurs under dark or drought conditions, resistance to gas uptake is very high and the plant has a very low degree of susceptibility to injury. In contrast, mosses and lichens do not have a protective cuticle barrier to gaseous pollutants or stomates and are generally more sensitive to gaseous sulfur and nitrogen than vascular plants.[147] Acute foliar injury usually happens within hours of exposure, involves a rapid absorption of a toxic dose, and involves collapse or necrosis of plant tissues. Another type of visible injury is termed chronic injury and is usually a result of variable SO_2 exposures over the growing season. Besides foliar injury, chronic exposure to low SO_2 concentrations can result in reduced photosynthesis, growth, and yield of plants.[148] These effects are cumulative over the season and are often not associated with visible foliar injury. As with foliar injury, these effects vary among species and growing environment. SO_2 is also considered the primary factor causing the death of lichens in many urban and industrial areas.[149]

6.1.2.4.1.4 Mercury Methylation

Mercury is a persistent, bioaccumulative toxic metal that is emitted in three forms: gaseous elemental Hg (Hg^0), oxidized Hg compounds (Hg^{+2}), and particle-bound Hg (Hg_P). Methylmercury (MeHg) is formed by microbial action in the top layers of sediment and soils, after Hg has precipitated from the air and deposited into waterbodies or land. Once formed, MeHg is taken up by aquatic organisms and bioaccumulates up the aquatic food web. Larger predatory fish may have MeHg concentrations many times, typically on the order of one million times, that of the concentrations in the freshwater body in which they live. The NO_X SO_X ISA—Ecological Criteria concluded that evidence is sufficient to infer a causal relationship between sulfur deposition and increased mercury methylation in wetlands and aquatic environments.[150] Specifically, there appears to be a relationship between SO_4^{2-} deposition and mercury methylation; however, the rate of mercury methylation varies according to several spatial and biogeochemical factors whose influence has not been fully quantified. Therefore, the correlation between SO_4^{2-} deposition and MeHg cannot yet be quantified for the purpose of interpolating the association across waterbodies or regions. Nevertheless, because changes in MeHg in ecosystems represent changes in significant human and ecological health risks, the association between sulfur and mercury cannot be neglected.[151]

6.1.2.4.2 *Deposition of Metallic and Organic Constituents of PM*

Several significant ecological effects are associated with deposition of chemical constituents of ambient PM such as metals and organics.[152] The trace metal constituents of PM include cadmium, copper, chromium, mercury, nickel, zinc, and lead. The organics include persistent organic pollutants (POPs), polyaromatic hydrocarbons (PAHs) and polybromiated diphenyl ethers (PBDEs). Exposure to PM for direct effects occur via deposition (e.g., wet, dry or occult) to vegetation surfaces, while indirect effects occur via deposition to ecosystem soils or surface waters where the deposited constituents of PM then interacts with biological organisms. While both fine and coarse-mode particles may affect plants and other organisms, more often the chemical constituents drive the ecosystem response to PM.[153] Ecological effects of PM include direct effects to metabolic processes of plant foliage; contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction; and contribution to total organics loading resulting in bioaccumulation and biomagnification.

Particulate matter can adversely impact plants and ecosystem services provided by plants by deposition to vegetative surfaces.[154] Particulates deposited on the surfaces of leaves and needles can block light, altering the radiation received by the plant. PM deposition near sources of heavy deposition can obstruct stomata limiting gas exchange, damage leaf cuticles and increase plant temperatures.[155] Plants growing on roadsides exhibit impact damage from near-road PM deposition, having higher levels of organics and heavy metals, and accumulate salt from road de-icing during winter months.[156] In addition, atmospheric PM can convert direct solar radiation to diffuse radiation, which is more uniformly distributed in a tree canopy, allowing radiation to reach lower leaves.[157] Decreases in crop yields (a provisioning service) due to reductions in solar radiation have been attributed to regional scale air pollution in other counties with especially severe regional haze.[158]

In addition to damage to plant surfaces, deposited PM can be taken up by plants from soil or foliage. Copper, zinc, and nickel have been shown to be directly toxic to vegetation under field conditions.[159] The ability of vegetation to take up heavy metals is dependent upon the amount, solubility and chemical composition of the deposited PM. Uptake of PM by plants from soils and vegetative surfaces can disrupt photosynthesis, alter pigments and mineral content, reduce plant vigor, decrease frost hardiness and impair root development.

Particulate matter can also contain organic air toxic pollutants, including PAHs, which are a class of polycyclic organic matter (POM). PAHs can accumulate in sediments and bioaccumulate in freshwater, flora and fauna. The uptake of organics depends on the plant species, site of deposition, physical and chemical properties of the organic compound and prevailing environmental conditions.[160] Different species can have different uptake rates of PAHs. For example, zucchini (Cucurbita pepo) accumulated significantly more PAHs than related plant species.[161] PAHs can accumulate to high enough concentrations in some coastal environments to pose an environmental health threat that includes cancer in fish populations, toxicity to organisms living in the sediment and risks to those (e.g., migratory birds) that consume these organisms.[162,163] Atmospheric deposition of particles is thought to be the major source of PAHs to the sediments of Lake Michigan, Chesapeake Bay, Tampa Bay and other coastal areas of the U.S.[164]

Contamination of plant leaves by heavy metals can lead to elevated concentrations in the soil. Trace metals absorbed into the plant, frequently bind to the leaf tissue, and then are lost when the leaf drops. As the fallen leaves decompose, the heavy metals are transferred into the soil.[165,166] Many of the major indirect plant responses to PM deposition are chiefly soil-mediated and depend on the chemical composition of individual components of deposited PM. Upon entering the soil environment, PM pollutants can alter ecological processes of energy flow and nutrient cycling, inhibit nutrient uptake to plants, change microbial community structure and, affect biodiversity. Accumulation of heavy metals in soils depends on factors such as local soil characteristics, geologic origin of parent soils, and metal bioavailability. Heavy metals, such as zinc, copper, and cadmium, and some pesticides can interfere with microorganisms that are responsible for decomposition of soil litter, an important regulating ecosystem service that serves as a source of soil nutrients.[167] Surface litter decomposition is reduced in soils having high metal concentrations. Soil communities have associated bacteria, fungi, and invertebrates that are essential to soil nutrient cycling processes. Changes to the relative species abundance and community composition are associated with deposited PM to soil biota.[168]

Atmospheric deposition can be the primary source of some organics and metals to watersheds. Deposition of PM to surfaces in urban settings increases the metal and organic component of storm water runoff.[169] This atmospherically-associated pollutant burden can then be toxic to aquatic biota. The contribution of atmospherically deposited PAHs to aquatic food webs was demonstrated in high elevation mountain lakes with no other anthropogenic contaminant sources.[170] Metals associated with PM deposition limit phytoplankton growth, affecting aquatic trophic structure. Long-range atmospheric transport of 47 pesticides and degradation products to the snowpack in seven national parks in the Western U.S. was recently quantified indicating PM-associated contaminant inputs to receiving waters during spring snowmelt.[171]

The recently completed Western Airborne Contaminants Assessment Project (WACAP) is the most comprehensive database on contaminant transport and PM depositional effects on sensitive ecosystems in the Western U.S.[172] In this project, the transport, fate, and ecological impacts of anthropogenic contaminants from atmospheric sources were assessed from 2002 to 2007 in seven ecosystem components (air, snow, water, sediment, lichen, conifer needles and fish) in eight core national parks. The study concluded that bioaccumulation of semi-volatile organic compounds occurred throughout park ecosystems, an elevational gradient in PM deposition exists with greater accumulation in higher altitude areas, and contaminants accumulate in proximity to individual agriculture and industry sources, which is counter to the original working hypothesis that most of the contaminants would originate from Eastern Europe and Asia.

6.1.2.4.3 *Materials Damage and Soiling*

Building materials including metals, stones, cements, and paints undergo natural weathering processes from exposure to environmental elements (e.g., wind, moisture, temperature fluctuations, sunlight, etc.). Pollution can worsen and accelerate these effects. Deposition of PM is associated with both physical damage (materials damage effects) and impaired aesthetic qualities (soiling effects). Wet and dry deposition of PM can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints and by deteriorating building materials such as stone, concrete and marble.[173] The effects of PM are exacerbated by the presence of acidic gases and can be additive or synergistic due to the complex mixture of pollutants in the air and surface characteristics of the material. Acidic deposition has been shown to have an effect on materials including zinc/galvanized steel and other metal, carbonate stone (as monuments and building facings), and surface coatings (paints).[174] The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

6.1.2.5 Environmental Effects of Air Toxics

Emissions from producing, transporting and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds (VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[175] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[176] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (e.g., acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[177]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[178,179,180] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

6.2 Air Quality Impacts of Non-GHG Pollutants

Chapter 5 of this draft RIA presents the projected emissions changes due to the proposal. Once the emissions changes are projected the next step is to look at how the ambient air quality would be impacted by those emissions changes. Although the purpose of this proposal is to address greenhouse gas emissions, this proposal would also impact emissions of criteria and hazardous air pollutants. No air quality modeling was done for this draft RIA to project the impacts of the proposal. Air quality modeling will be done for the final rulemaking, however, and those plans are discussed in Section 6.2.2.

6.2.1 Current Concentrations of Non-GHG Pollutants

6.2.1.1 Current Concentrations of Particulate Matter

As described in Chapter 6.1.1.1, PM causes adverse health effects, and EPA has set national standards to provide requisite protection against those health effects. There are two primary NAAQS for $PM_{2.5}$: an annual standard (12.0 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$) with a 98th percentile form, and two secondary NAAQS for $PM_{2.5}$: an annual standard (15.0 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$), likewise with a 98th percentile form. The initial $PM_{2.5}$ standards were set in 1997 and revisions to the standards were finalized in 2006 and in December 2012. The 2006 revision revised the level of the 24-hour standards from 65 $\mu g/m^3$ to 35 ug/m3, and the December 2012 rule revised the level of the primary annual $PM_{2.5}$ standard from 15.0 $\mu g/m^3$ to 12.0 $\mu g/m^3$.[181]

In 2005 EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 19844, April 14, 2005). As of July 2, 2014, over 47 million people lived in the 19 areas that are still designated as nonattainment for the 1997 annual $PM_{2.5}$ NAAQS. These $PM_{2.5}$ nonattainment areas are comprised of 105 full or partial counties. EPA anticipates making initial area designation decisions for the 2012 primary annual $PM_{2.5}$ NAAQS in December 2014, with those designations likely becoming effective in early 2015.[182] On November 13, 2009 and February 3, 2011, EPA designated 32 nonattainment areas for the 2006 24-hour $PM_{2.5}$ NAAQS (74 FR 58688, November 13, 2009 and 76 FR 6056, February 3, 2011). As of July 2, 2014, 24 of these areas remain designated as nonattainment, and they are composed of 74 full or partial counties, with a population of over 43 million. In total, there are currently 33 $PM_{2.5}$ nonattainment areas with a population of over 61 million people.[Q]

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into attainment in the future. Designated nonattainment areas not currently attaining the 1997 annual $PM_{2.5}$ NAAQS are required to attain the NAAQS by 2015 and will be required to maintain the 1997 annual $PM_{2.5}$ NAAQS thereafter. The 2006 24-hour $PM_{2.5}$ nonattainment areas are required to attain the 2006 24-hour $PM_{2.5}$ NAAQS in the 2015 to 2019 time frame and will be required to maintain the 2006 24-hour $PM_{2.5}$ NAAQS thereafter. Areas to be designated nonattainment for the 2012 primary annual $PM_{2.5}$ NAAQS will likely be required to attain the 2012 NAAQS in the 2021 to 2025 time frame. The heavy-duty vehicle standards proposed here first apply to model year 2021 vehicles.

6.2.1.2 Current Concentrations of Ozone

As described in Chapter 6.1.1.2.2, ozone causes adverse health effects, and EPA has set national ambient air quality standards to protect against those health effects. The primary and secondary NAAQS for ozone are 8-hour standards with a level of 0.075 ppm. The most recent revision to the ozone standards was in 2008; the previous 8-hour ozone standards, set in 1997, had a level of 0.08 ppm. In 2004, EPA designated nonattainment areas for the 1997 8-hour ozone NAAQS (69 FR 23858, April 30, 2004).[R] As of July 2, 2014, there were 37 8-hour ozone nonattainment areas for the 1997 ozone NAAQS, composed of 188 full or partial counties, with a total population of over 105 million. Nonattainment designations for the 2008 ozone standards were finalized on April 30, 2012 and May 31, 2012.[183] As of July 2, 2014, there were 46 ozone nonattainment areas for the 2008 ozone NAAQS, composed of 227 full or partial counties, with a

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[Q] Data come from Summary Nonattainment Area Population Exposure Report, current as of July 2, 2014 at: http://www.epa.gov/oar/oaqps/greenbk/popexp.html and contained in Docket EPA-HQ-OAR-2014-0827. The 61 million total is calculated by summing, without double counting, the 1997 and 2006 $PM_{2.5}$ nonattainment populations contained in the Summary Nonattainment Area Population Exposure report (http://www.epa.gov/oar/oaqps/greenbk/popexp.html). If there is a population associated with both the 1997 and 2006 nonattainment areas, and they are not the same, then the larger of the two populations is included in the sum.
[R] A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard.

population of over 123 million. As of July 2, 2014, over 134 million people are living in ozone nonattainment areas.[S]

States with ozone nonattainment areas are required to take action to bring those areas into attainment. The attainment date assigned to an ozone nonattainment area is based on the area's classification. Areas with higher 3–year design values are classified at higher levels and subject to more stringent control requirements, but they are also given more time to attain the ozone NAAQS. Most ozone nonattainment areas for the 1997 8-hour ozone NAAQS were required to attain in the 2007 to 2013 time frame and then to maintain it thereafter.[T] The attainment dates for areas designated nonattainment for the 2008 8-hour ozone NAAQS are in the 2015 to 2032 timeframe, depending on the severity of the problem in each area. In addition, EPA is currently working on a review of the ozone NAAQS.[U] If EPA revises the ozone standards pursuant to that review, the attainment dates associated with areas designated nonattainment for that NAAQS would be 5 or more years after the final rule is promulgated, depending on the severity of the problem in each area. The heavy-duty vehicle standards proposed here first apply to model year 2021 vehicles.

6.2.1.3 Current Concentrations of Nitrogen Oxides

EPA most recently completed a review of the primary NAAQS for NO_2 in January 2010. There are two primary NAAQS for NO_2: an annual standard (53 ppb) and a 1-hour standard (100 ppb). EPA promulgated area designations in the Federal Register on February 17, 2012. In this initial round of designations, all areas of the country were designated as "unclassifiable/attainment" for the 2010 NO_2 NAAQS based on data from the existing air quality monitoring network. EPA and state agencies are working to establish an expanded network of NO_2 monitors, expected to be deployed in the 2013-2017 time frame. Once three years of air quality data have been collected from the expanded network, EPA will be able to evaluate NO_2 air quality in additional locations.[184,185]

6.2.1.4 Current Concentrations of Sulfur Oxides

EPA most recently completed a review of the primary SO_2 NAAQS in June 2010. The current primary NAAQS for SO_2 is a 1-hour standard of 75 ppb. EPA finalized the initial area designations for 29 nonattainment areas in 16 states in a notice published in the Federal Register

[S] The 134 million total is calculated by summing, without double counting, the 1997 and 2008 ozone nonattainment populations contained in the Summary Nonattainment Area Population Exposure report (http://www.epa.gov/oar/oaqps/greenbk/popexp.html). If there is a population associated with both the 1997 and 2008 nonattainment areas, and they are not the same, then the larger of the two populations is included in the sum.

[T] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area and the San Joaquin Valley Air Basin 8-hour ozone nonattainment area are designated as Extreme and will have to attain before June 15, 2024. The Sacramento, Coachella Valley, Western Mojave and Houston 8-hour ozone nonattainment areas are designated as Severe and will have to attain by June 15, 2019.

[U] On November 25, 2014 EPA proposed to update both the primary ozone standard, to protect public health, and the secondary standard, to protect the public welfare. Both standards would be 8-hour standards set within a range of 65 to 70 parts per billion (ppb). EPA is seeking comment on levels for the health standard as low as 60 ppb. The agency will accept comments on all aspects of the proposal, including on retaining the existing standard. (http://www.epa.gov/glo/pdfs/20141125proposal.pdf) on August 5, 2013. In this first round of designations, EPA only designated nonattainment areas that were violating the standard based on existing air quality monitoring data provided by the states. The agency did not have sufficient information to designate any area as "attainment" or make final decisions about areas for which additional modeling or monitoring is needed (78 FR 47191, August 5, 2013). EPA anticipates designating areas for the revised SO_2 standard in multiple rounds.

6.2.1.5 Current Concentrations of Carbon Monoxide

There are two NAAQS for CO: an 8-hour standard (9 ppm) and a 1-hour standard (35 ppm). The primary NAAQS for CO were retained in August 2011. There are currently no CO nonattainment areas; as of September 27, 2010, all CO nonattainment areas were redesignated to maintenance areas. The designations were based on the existing community-wide monitoring network. EPA is making changes to the ambient air monitoring requirements for CO. The new requirements are expected to result in approximately 52 CO monitors operating near roads within 52 urban areas by January 2015 (76 FR 54294, August 31, 2011).

6.2.1.6 Current Concentrations of Diesel Exhaust PM

Because DPM is part of overall ambient PM and cannot be easily distinguished from overall PM, we do not have direct measurements of DPM in the ambient air. DPM concentrations are estimated using ambient air quality modeling based on DPM emission inventories. DPM concentrations were recently estimated as part of the 2005 NATA.[186] Ambient impacts of mobile source emissions were predicted using the Assessment System for Population Exposure Nationwide (ASPEN) dispersion model.

Concentrations of DPM were calculated at the census tract level in the 2005 NATA. Figure 6-5 below summarizes the distribution of ambient DPM concentrations at the national scale. Areas with high concentrations are clustered in the Northeast, Great Lake States, California, and the Gulf Coast States, and are also distributed throughout the rest of the U.S. Table 6-1 presents a distribution of ambient DPM concentrations around the country. The median DPM concentration calculated nationwide is 0.53 $\mu g/m^3$. Half of the DPM and diesel exhaust organic gases can be attributed to onroad diesels.

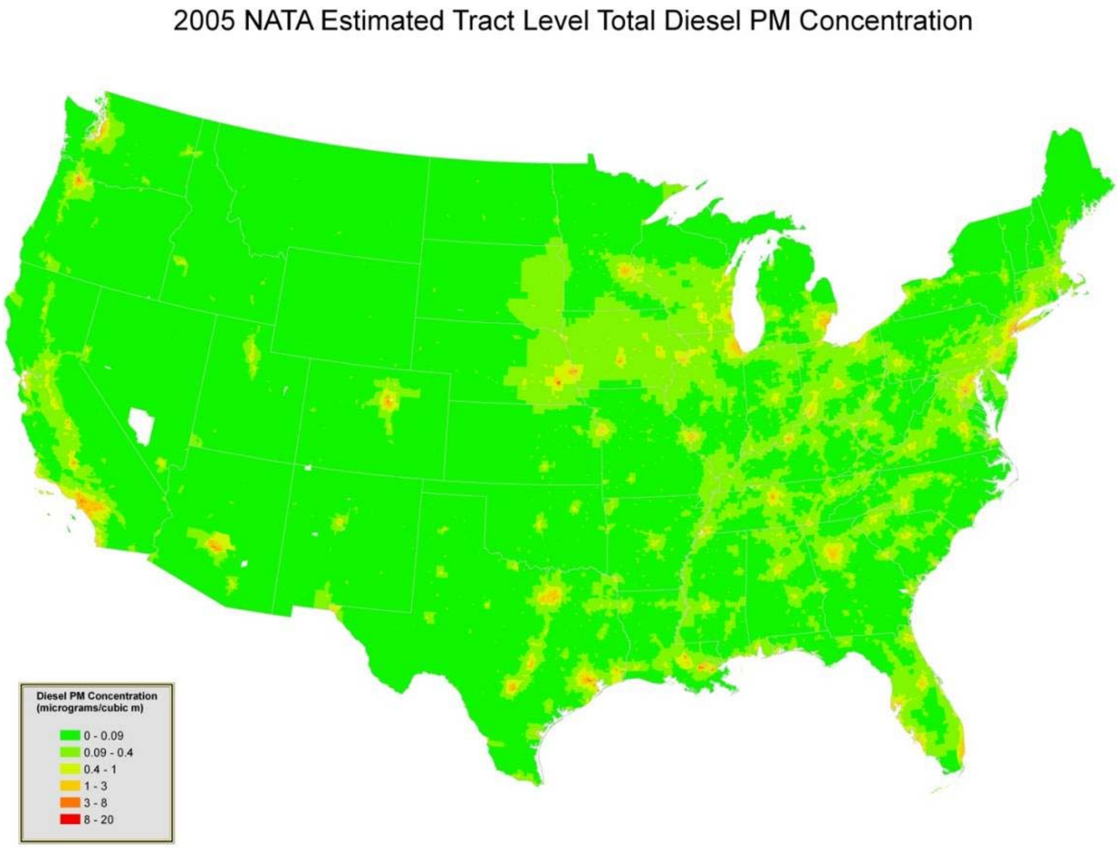

Figure 6-5 Estimated County Ambient Concentration of Diesel Particulate Matter

Table 6-1 Distribution of Census Tract Ambient Concentrations of DPM at the National Scale in 2005 NATA[a]

	AMBIENT CONCENTRATION ($\mu g/m^3$)
5^{th} Percentile	0.03
25^{th} Percentile	0.17
50^{th} Percentile	0.53
75^{th} Percentile	1.22
95th Percentile	2.91
Onroad Contribution to Median Census Tract Concentrations	50%

Note:

[a] This table is generated from data contained in the diesel particulate matter Microsoft Access database file found in the Tract-Level Pollutants section of the 2005 NATA webpage (http://www.epa.gov/ttn/atw/nata2005/tables.html).

6.2.1.7 Current Concentrations of Air Toxics

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[187] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in EPA's most recent Mobile Source Air Toxics (MSAT) Rule.[188] In order to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern, EPA conducts the National-Scale Air Toxics Assessment (NATA). The most recent NATA was conducted for calendar year 2005, and was released in March 2011.[189] NATA for 2005 includes four steps:

1) Compiling a national emissions inventory of air toxics emissions from outdoor sources

2) Estimating ambient concentrations of air toxics across the United States

3) Estimating population exposures across the United States

4) Characterizing potential public health risk due to inhalation of air toxics including both cancer and noncancer effects

According to the NATA for 2005, mobile sources were responsible for 43 percent of outdoor toxic emissions and over 50 percent of the cancer risk and noncancer hazard attributable to direct emissions from mobile and stationary sources.[V,W,190] Mobile sources are also large contributors to precursor emissions which react to form secondary concentrations of air toxics. Formaldehyde is the largest contributor to cancer risk of all 80 pollutants quantitatively assessed in the 2005 NATA, and mobile sources were responsible for over 40 percent of primary emissions of this pollutant in 2005, and are major contributors to formaldehyde precursor emissions. Benzene is also a large contributor to cancer risk, and mobile sources account for over 70 percent of ambient exposure. Over the years, EPA has implemented a number of mobile source and fuel controls which have resulted in VOC reductions, which also reduced formaldehyde, benzene and other air toxic emissions.

6.2.2 Impacts of Proposed Standards on Future Air Quality

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere.

[V] NATA also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics.
[W] NATA relies on a Gaussian plume model, Assessment System for Population Exposure Nationwide (ASPEN), to estimate toxic air pollutant concentrations.

Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis by assessing the effectiveness of control strategies. These models are applied at multiple spatial scales from local, regional, national, and global.

Full-scale photochemical air quality modeling is necessary to accurately project levels of criteria and air toxic pollutants. For the final rulemaking, national-scale air quality modeling analyses will be performed to analyze the impacts of the standards on $PM_{2.5}$, NO_2, ozone, and selected air toxics (i.e., benzene, formaldehyde, acetaldehyde, naphthalene, acrolein and 1,3-butadiene). The length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this proposal.

Section VIII of the preamble presents projections of the changes in criteria pollutant and air toxics emissions due to the proposed standards; the basis for those estimates is set out in Chapter 5 of the draft RIA. NHTSA also provides its projections in Chapter 4 of its DEIS. The atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex, and making predictions based solely on emissions changes is extremely difficult. However, based on the magnitude of the emissions changes predicted to result from the proposed standards, the agencies expect that there will be improvements in ambient air quality, pending a more comprehensive analysis for the final rulemaking.

For the final rulemaking, the agencies intend to use a 2011-based Community Multi-scale Air Quality (CMAQ) modeling platform as the tool for the air quality modeling. The CMAQ modeling system is a comprehensive three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations and deposition, and air toxics, over regional and urban spatial scales (e.g., over the contiguous U.S.).[191,192,193,194] The CMAQ model is a well-known and well-established tool and is commonly used by EPA for regulatory analyses, and by States in developing attainment demonstrations for their State Implementation Plans.[195] The CMAQ model version 5.0 was most recently peer-reviewed in September of 2011 for the U.S. EPA.

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. The agencies intend to use the most recent multi-pollutant CMAQ code available at the time of air quality modeling (CMAQ version 5.0.2; multipollutant version[X]) which reflects updates to version 5.0 to improve the underlying science algorithms as well as include new diagnostic/scientific modules which are detailed at http://www.cmascenter.org.[196,197,198] Figure 6-6 shows the geographic extent of the modeling domain that will be used for air quality modeling in these analyses. The domain covers the 48 contiguous states along with the southern portions of Canada and the northern portions of Mexico. This modeling domain contains 25 vertical layers with a top at about 17,600 meters, or 50 millibars (mb) and a horizontal resolution of 12 x 12 km.

[X] CMAQ version 5.0.2 was released in April 2014. It is available from the Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org.

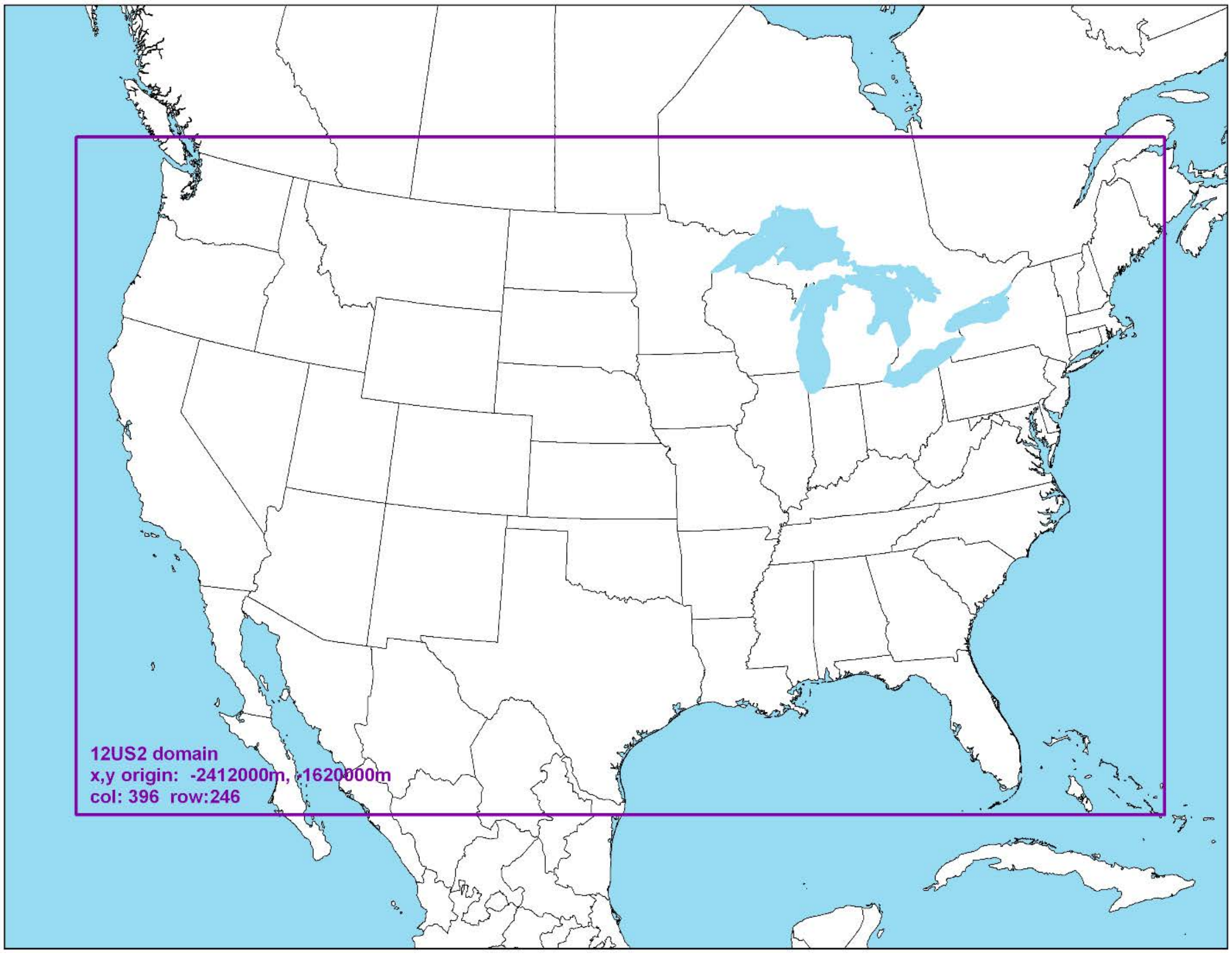

Figure 6-6 Map of the CMAQ 12-km US Modeling Domain

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The 2011 CMAQ meteorological inputs will be derived from Version 3.4 of the Weather Research Forecasting Model (WRF).[199] These inputs included hourly-varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer. Details of the annual 2011 meteorological model simulation and evaluation will be described in more detail within the final RIA, the technical support document for the final rulemaking air quality modeling, and NHTSA's Final Environmental Impact Statement.

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model[200] (standard version 8-03-02 with 8-02-01 chemistry. The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS-5; additional information available at: http://gmao.gsfc.nasa.gov/GEOS/ and http://wiki.seas.harvard.edu/geos-chem/index.php/GEOS-

5). This model was run for 2011 with a grid resolution of 2.0 degrees x 2.5 degrees (latitude-longitude). The predictions were used to provide one-way dynamic boundary conditions at one-hour intervals and an initial concentration field for the CMAQ simulations. A GEOS-Chem evaluation was conducted for the purpose of validating the 2011 GEOS-Chem simulation for predicting selected measurements relevant to their use as boundary conditions for CMAQ. This evaluation included using satellite retrievals paired with GEOS-Chem grid cells.[201] More information is available about the GEOS-CHEM model and other applications using this tool at: http://www-as.harvard.edu/chemistry/trop/geos.

6.3 Changes in Atmospheric CO_2 Concentrations, Global Mean Temperature, Sea Level Rise, and Ocean pH Associated with the Program's GHG Emissions Reductions

6.3.1 Introduction

The impact of GHG emissions on the climate has been reviewed in the 2009 Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, the 2012-2016 light-duty vehicle rulemaking, the 2014-2018 heavy-duty vehicle GHG rulemaking, and the 2017-2025 light-duty vehicle rulemaking. See 74 FR at 66496; 75 FR at 25491; 76 FR at 57294; 77 FR at 62894. This section briefly discusses again some of the climate impact context for transportation emissions.

Once emitted, GHGs that are the subject of this regulation can remain in the atmosphere for decades to millennia, meaning that 1) their concentrations become well-mixed throughout the global atmosphere regardless of emission origin, and 2) their effects on climate are long lasting. GHG emissions come mainly from the combustion of fossil fuels (coal, oil, and gas), with additional contributions from the clearing of forests, agricultural activities, cement production, and some industrial activities. Transportation activities, in aggregate, were the second largest contributor to total U.S. GHG emissions in 2010 (27 percent of total emissions).[Y]

EPA Administrator relied on thorough and peer-reviewed assessments of climate change science prepared by the Intergovernmental Panel on Climate Change ("IPCC"), the United States Global Change Research Program ("USGCRP"), and the National Research Council of the National Academies ("NRC")[Z] as the primary scientific and technical basis for the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act (74 FR 66496, December 15, 2009). These assessments comprehensively address the scientific issues EPA Administrator had to examine, providing her both data and information on a wide range of issues pertinent to the Endangerment Finding. These assessments have been rigorously reviewed by the expert community, and also by United States government agencies and scientists, including by EPA itself.

[Y] U.S. EPA (2012) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010. EPA 430-R-12-001. Available at http://epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf
[Z] For a complete list of core references from IPCC, USGCRP/CCSP, NRC and others relied upon for development of the TSD for EPA's Endangerment and Cause or Contribute Findings see Section 1(b), specifically, Table 1.1 of the TSD. (Docket EPA-HQ-OAR-2010-0799)

Based on these assessments, EPA Administrator determined that the emissions from new motor vehicles and engines contributes to elevated concentrations of greenhouse gases, that these greenhouse gases cause warming; that the recent warming has been attributed to the increase in greenhouse gases; and that warming of the climate endangers the public health and welfare of current and future generations. The D.C. Circuit has emphatically upheld the reasonableness of these findings. Coalition for Responsible Regulation v. EPA, 684 F. 3d 102, 121 (D.C. Cir. 2012) upholding all of EPA's findings and stating "EPA had before it substantial record evidence that anthropogenic emissions of greenhouse gases 'very likely' caused warming of the climate over the last several decades. EPA further had evidence of current and future effects of this warming on public health and welfare. Relying again upon substantial scientific evidence, EPA determined that anthropogenically induced climate change threatens both public health and public welfare. It found that extreme weather events, changes in air quality, increases in food- and water-borne pathogens, and increases in temperatures are likely to have adverse health effects. The record also supports EPA's conclusion that climate change endangers human welfare by creating risk to food production and agriculture, forestry, energy, infrastructure, ecosystems, and wildlife. Substantial evidence further supported EPA's conclusion that the warming resulting from the greenhouse gas emissions could be expected to create risks to water resources and in general to coastal areas as a result of expected increase in sea level.")

A number of major peer-reviewed scientific assessments have been released since the administrative record concerning the Endangerment Finding closed following EPA's 2010 Reconsideration Denial[202]. These assessments include the "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation"[203], the 2013-14 Fifth Assessment Report (AR5)[204], the 2014 National Climate Assessment report[205], the "Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean"[206], "Report on Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia"[207], "National Security Implications for U.S. Naval Forces" (National Security Implications)[208], "Understanding Earth's Deep Past: Lessons for Our Climate Future"[209], "Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future"[210], "Climate and Social Stress: Implications for Security Analysis"[211], and "Abrupt Impacts of Climate Change" (Abrupt Impacts) assessments[212].

EPA has reviewed these assessments and finds that in general, the improved understanding of the climate system they present are consistent with the assessments underlying the 2009 Endangerment Finding.

The most recent assessments to be released were the IPCC AR5 assessments between September 2013 and April 2014, the NRC Abrupt Impacts assessment in December of 2013, and the U.S. National Climate Assessment in May of 2014. The NRC Abrupt Impacts report examines the potential for tipping points, thresholds beyond which major and rapid changes occur in the Earth's climate system or other systems impacted by the climate. The Abrupt Impacts report did find less cause for concern than some previous assessments regarding some abrupt events within the next century such as disruption of the Atlantic Meridional Overturning Circulation (AMOC) and sudden releases of high-latitude methane from hydrates and permafrost, but found that the potential for abrupt changes in ecosystems, weather and climate extremes, and groundwater supplies critical for agriculture now seem more likely, severe, and imminent. The assessment found that some abrupt changes were already underway (Arctic sea ice retreat and increases in extinction risk due to the speed of climate change), but cautioned that even abrupt changes such as the AMOC disruption that are not expected in this century can have severe impacts when they happen.

The IPCC AR5 assessments are also generally consistent with the underlying science supporting the 2009 Endangerment Finding. For example, confidence in attributing recent warming to human causes has increased: the IPCC stated that it is extremely likely (>95 percent confidence) that human influences have been the dominant cause of recent warming. Moreover, the IPCC found that the last 30 years were likely (>66 percent confidence) the warmest 30 year period in the Northern Hemisphere of the past 1400 years, that the rate of ice loss of worldwide glaciers and the Greenland and Antarctic ice sheets has likely increased, that there is medium confidence that the recent summer sea ice retreat in the Arctic is larger than has been in 1450 years, and that concentrations of carbon dioxide and several other of the major greenhouse gases are higher than they have been in at least 800,000 years. Climate-change induced impacts have been observed in changing precipitation patterns, melting snow and ice, species migration, negative impacts on crops, increased heat and decreased cold mortality, and altered ranges for water-borne illnesses and disease vectors. Additional risks from future changes include death, injury, and disrupted livelihoods in coastal zones and regions vulnerable to inland flooding, food insecurity linked to warming, drought, and flooding, especially for poor populations, reduced access to drinking and irrigation water for those with minimal capital in semi-arid regions, and decreased biodiversity in marine ecosystems, especially in the Arctic and tropics, with implications for coastal livelihoods. The IPCC determined that "[c]ontinued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gases emissions."

Finally, the recently released National Climate Assessment stated, "Climate change is already affecting the American people in far reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and glaciers and Arctic sea ice to melt, and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy."

Assessments from these bodies represent the current state of knowledge, comprehensively cover and synthesize thousands of individual studies to obtain the majority conclusions from the body of scientific literature and undergo a rigorous and exacting standard of review by the peer expert community and U.S. government.

Based on modeling analysis performed by EPA, reductions in CO_2 and other GHG emissions associated with this proposed rule will affect future climate change. Since GHGs are well-mixed in the atmosphere and have long atmospheric lifetimes, changes in GHG emissions will affect atmospheric concentrations of greenhouse gases and future climate for decades to millennia, depending on the gas. This section provides estimates of the projected change in atmospheric CO_2 concentrations based on the emission reductions estimated for this proposed rule, compared to the reference case. In addition, this section analyzes the response to the changes in GHG concentrations of the following climate-related variables: global mean temperature, sea level rise, and ocean pH. See Chapter 5 in this RIA for the estimated net GHG emissions reductions over time.

6.3.2 Projected Change in Atmospheric CO_2 Concentrations, Global Mean Surface Temperature and Sea Level Rise

To assess the impact of the emissions reductions from the proposed alternative, EPA estimated changes in projected atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise to 2100 using the GCAM (Global Change Assessment Model, formerly MiniCAM), integrated assessment model[AA,213] coupled with the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[BB,214,215] GCAM was used to create the globally and temporally consistent set of climate relevant emissions required for running MAGICC. MAGICC was then used to estimate the projected change in relevant climate variables over time. Given the magnitude of the estimated emissions reductions associated with the proposal, a simple climate model such as MAGICC is appropriate for estimating the atmospheric and climate response.

6.3.2.1 Methodology

Emissions reductions associated with this proposal were evaluated with respect to a baseline reference case. An emissions scenario was developed by applying the estimated emissions reductions from the proposal's proposed alternative relative to the baseline to the GCAM reference (no climate policy) scenario (used as the basis for the Representative Concentration Pathway RCP4.5).[216] Specifically, the annual CO_2, N_2O, CH_4, NO_X and SO_2 emissions reductions estimated from this proposed rule were applied as net reductions to the GCAM global baseline net emissions for each substance. The emissions reductions past 2050 for all emissions were scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. This was chosen as a simple scale factor given that both direct and upstream emissions changes are included in the emissions reduction scenario provided. Road transport fuel consumption past 2050 does not change significantly and thus emissions reductions remain relatively constant from 2050 through 2100.

The GCAM reference scenario[217] depicts a world in which global population reaches a maximum of more than 9 billion in 2065 and then declines to 8.7 billion in 2100 while global

[AA] GCAM is a long-term, global integrated assessment model of energy, economy, agriculture and land use that considers the sources of emissions of a suite of greenhouse gases (GHG's), emitted in 14 globally disaggregated regions, the fate of emissions to the atmosphere, and the consequences of changing concentrations of greenhouse related gases for climate change. GCAM begins with a representation of demographic and economic developments in each region and combines these with assumptions about technology development to describe an internally consistent representation of energy, agriculture, land-use, and economic developments that in turn shape global emissions.

[BB] MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single framework. The framework allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), reactive gases (CO, NO_X, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO_2). MAGICC emulates the global-mean temperature responses of more sophisticated coupled Atmosphere/Ocean General Circulation Models (AOGCMs) with high accuracy.

GDP grows by an order of magnitude and global energy consumption triples. The reference scenario includes no explicit policies to limit carbon emissions, and therefore fossil fuels continue to dominate global energy consumption, despite substantial growth in nuclear and renewable energy. Atmospheric CO_2 concentrations rise throughout the century and reach 760 to 820 ppmv by 2100, depending on climatic parameters, with total radiative forcing increasing more than 5 Watts per square meter (W/m^2) above 1990 levels by 2100. Forest land declines in the reference scenario to accommodate increases in land use for food and bioenergy crops. Even with the assumed agricultural productivity increases, the amount of land devoted to crops increases in the first half of the century due to increases in population and income (higher income drives increases in land-intensive meat consumption). After 2050 the rate of growth in food demand slows, in part due to declining population. As a result the amount of cropland and also land use change (LUC) emissions decline as agricultural crop productivity continues to increase.

The GCAM reference scenario uses non-CO_2 and pollutant emissions implemented as described in Smith and Wigley (2006); land-use change emissions as described in Wise et al. (2009); and updated base-year estimates of global GHG emissions. This scenario was created as part of the Climate Change Science Program (CCSP) effort to develop a set of long-term global emissions scenarios that incorporate an update of economic and technology data and utilize improved scenario development tools compared to the IPCC *Special Report on Emissions Scenarios* (SRES) (IPCC 2000).

Using MAGICC 5.3 v2,[218] the change in atmospheric CO_2 concentrations, global mean temperature, and sea level were projected at five-year time steps to 2100 for both the reference (no climate policy) scenario and the emissions reduction scenario specific to the proposed alternative of this proposal. To capture some of the uncertainty in the climate system, the changes in projected atmospheric CO_2 concentrations, global mean temperature and sea level were estimated across a range of plausible climate sensitivities, 1.5°C to 6.0°C.[CC] The range as illustrated in Chapter 10, Box 10.2, Figure 2 of the IPCC's Working Group I is approximately consistent with the 10-90 percent probability distribution of the individual cumulative distributions of climate sensitivity.[219] Other uncertainties, such as uncertainties regarding the carbon cycle, ocean heat uptake, or aerosol forcing, were not addressed.

MAGICC calculates the forcing response at the global scale from changes in atmospheric concentrations of CO_2, CH_4, N_2O, HFCs, and tropospheric ozone. It also includes the effects of temperature changes on stratospheric ozone and the effects of CH_4 emissions on stratospheric water vapor. Changes in CH_4, NO_X, VOC, and CO emissions affect both O_3 concentrations and CH_4 concentrations. MAGICC includes the relative climate forcing effects of changes in sulfate concentrations due to changing SO_2 emissions, including both the direct effect of sulfate particles

[CC] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The most recent IPCC AR5 assessment states that climate sensitivity is "likely" to be in the range of 1.5°C to 4.5°C, "extremely unlikely" to be less than 1°C, and "very unlikely" to be greater than 6 °C ." Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

and the indirect effects related to cloud interactions. However, MAGICC does not calculate the effect of changes in concentrations of other aerosols such as nitrates, black carbon, or organic carbon, making the assumption that the sulfate cooling effect is a proxy for the sum of all the aerosol effects. Therefore, the climate effects of changes in $PM_{2.5}$ emissions and precursors (besides SO_2) presented in Chapter 5 were not included in the calculations in this chapter. MAGICC also calculates all climate effects at the global scale. This global scale captures the climate effects of the long-lived, well-mixed greenhouse gases, but does not address the fact that short-lived climate forcers such as aerosols and ozone can have effects that vary with location and timing of emissions. Black carbon in particular is known to cause a positive forcing or warming effect by absorbing incoming solar radiation, but there are uncertainties about the magnitude of that warming effect and the interaction of black carbon (and other co-emitted aerosol species) with clouds. See 77 FR 38890, 38991-993 (June 29, 2012). While black carbon is likely to be an important contributor to climate change, it would be premature to include quantification of black carbon climate impacts in an analysis of the proposal's standards at this time. See generally, EPA, Response to Comments to the Endangerment Finding Vol. 9 Section 9.1.6.1, the discussion of black carbon in the endangerment finding at 74 FR at 66520, EPA's discussion in the recent proposal to revise the PM NAAQS (77 FR at 38991-993), and the recently published EPA Report to Congress on Black Carbon. Additionally, the magnitude of $PM_{2.5}$ emissions changes (and therefore, black carbon emission changes) related to these standards are small in comparison to the changes in the pollutants which have been included in the MAGICC model simulations.

To compute the changes in atmospheric CO_2 concentration, global mean temperature, and sea level rise specifically attributable to the impacts of the proposal, the difference in emissions between the proposal and the baseline scenario was subtracted from the GCAM reference emissions scenario. As a result of the proposal's emissions reductions from the proposed alternative relative to the baseline case, by 2100 the concentration of atmospheric CO_2 is projected to be reduced by approximately 1.1 to 1.2 parts per million by volume (ppmv), the global mean temperature is projected to be reduced by approximately 0.0026 to 0.0065°C, and global mean sea level rise is projected to be reduced by approximately 0.023 to 0.057 cm. For sea level rise, the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica; including these effects would show correspondingly larger benefits of mitigation.

Figure 6-7 provides the results over time for the estimated reductions in atmospheric CO_2 concentration associated with the proposal compared to the baseline scenario. Figure 6-8 provides the estimated change in projected global mean temperatures associated with the proposal. Figure 6-9 provides the estimated reductions in global mean sea level rise associated with the proposal. The range of reductions in global mean temperature and sea level rise due to uncertainty in climate sensitivity is larger than that for CO_2 concentrations because CO_2 concentrations are only weakly coupled to climate sensitivity through the dependence on temperature of the rate of ocean absorption of CO_2, whereas the magnitude of temperature change response to CO_2 changes (and therefore sea level rise) is more tightly coupled to climate sensitivity in the MAGICC model.

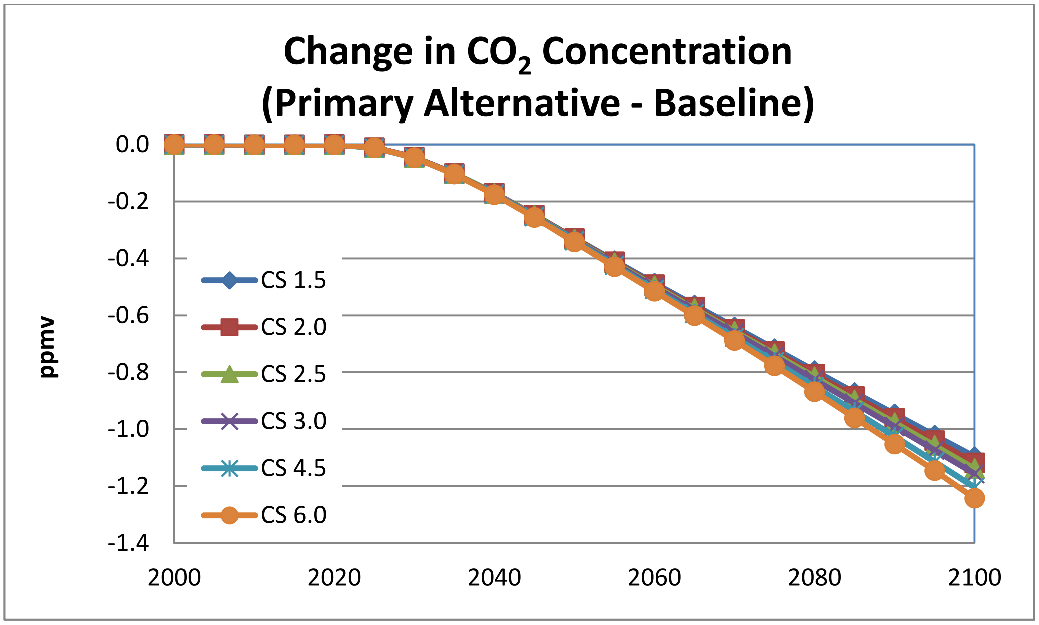

Figure 6-7 Estimated Projected Reductions in Atmospheric CO_2 Concentrations (parts per million by volume) from the Baseline for the Proposed Alternative of the Heavy-Duty Proposal (climate sensitivity (CS) cases ranging from 1.5-6°C)

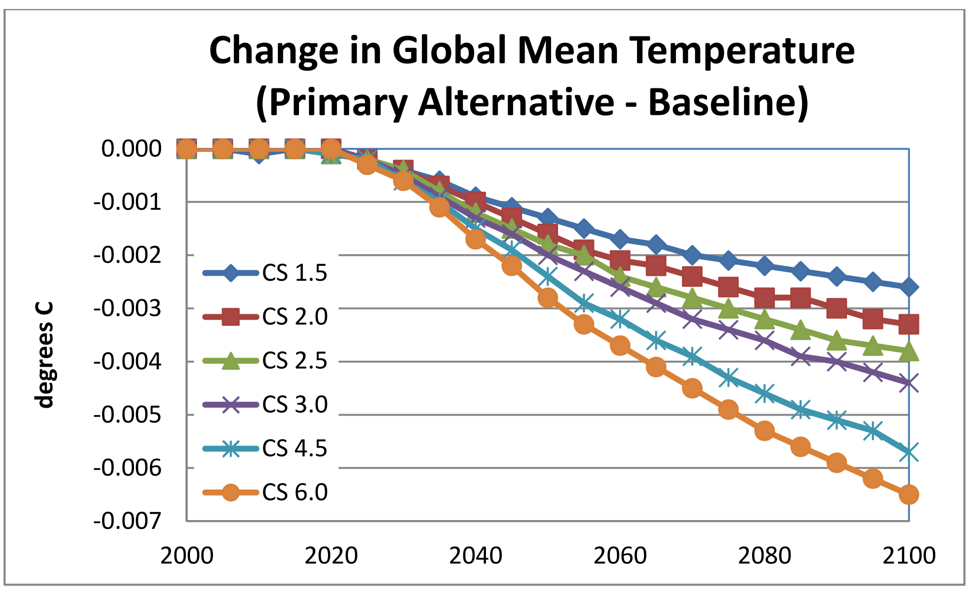

Figure 6-8 Estimated Projected Reductions in Global Mean Surface Temperatures from the Baseline for the Proposed Alternative of the Heavy-Duty Proposal (climate sensitivity (CS) cases ranging from 1.5-6°C)

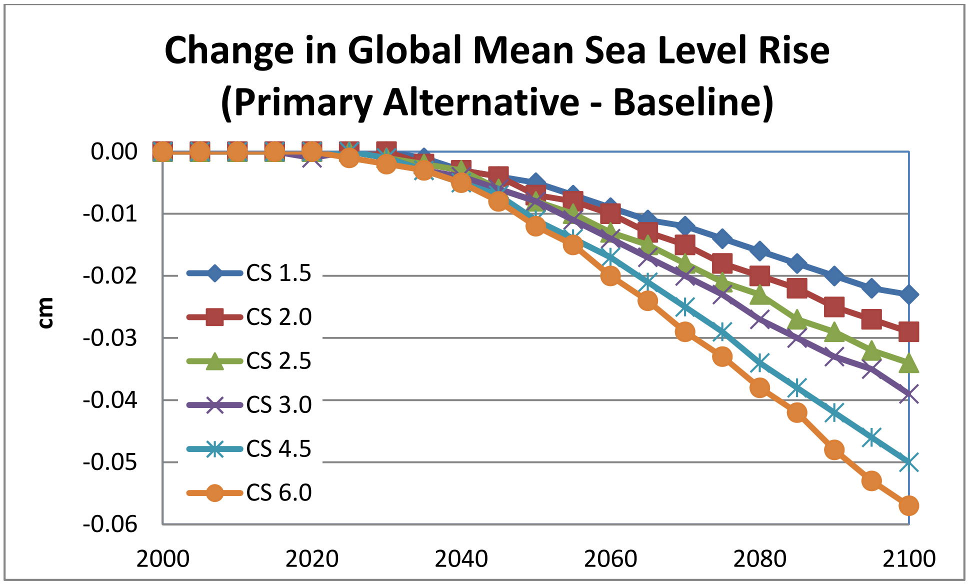

Figure 6-9 Estimated Projected Reductions in Global Mean Sea Level Rise from the Baseline for the Proposed Alternative of the Heavy-Duty Proposal (climate sensitivity (CS) cases ranging from 1.5-6°C)

The results in Figure 6-8 and Figure 6-9 show reductions in the projected global mean temperature and sea level respectively, across all climate sensitivities. The projected reductions are small relative to the change in temperature (1.8 – 4.8 ºC) and sea level rise (23 – 56 cm) from 1990 to 2100 from the MAGICC simulations for the GCAM reference case. However, this is to be expected given the magnitude of emissions reductions expected from the proposal in the context of global emissions. These reductions are quantifiable, directionally consistent, and will contribute to reducing the risks associated with climate change. Notably, these effects are occurring everywhere around the globe, so benefits that appear to be marginal for any one location, such as a reduction in sea level rise of half a millimeter, can be sizable when the effects are summed along thousands of miles of coastline. Climate change is a global phenomenon and EPA recognizes that this one national action alone will not prevent it; EPA notes this would be true for any given GHG mitigation action when taken alone or when considered in isolation. EPA also notes that a substantial portion of CO_2 emitted into the atmosphere is not removed by natural processes for millennia, and therefore each unit of CO_2 not emitted into the atmosphere due to this rule avoids essentially permanent climate change on centennial time scales. Again, it should be noted that the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica: the recent NRC report estimated a likely sea level increase for the A1B SRES scenario of 0.5 to 1.0 meters, almost double the estimate from MAGICC, so projected reductions in sea level rise may be similarly underestimated.[220] If other uncertainties besides climate sensitivity were included in the analysis, the resulting ranges of projected changes would likely be slightly larger.

6.3.3 Estimated Projected Change in Ocean pH

For this proposal, EPA analyzes another key climate-related variable and calculates projected change in ocean pH for tropical waters. For this analysis, changes in ocean pH are related to the change in the atmospheric concentration of carbon dioxide (CO_2) resulting from the emissions reductions associated with the proposed alternative. EPA used the program developed for CO_2 System Calculations CO2SYS,[221] version 1.05, a program which performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. The program was developed by Ernie Lewis at Brookhaven National Laboratory and Doug Wallace at the Institut für Meereskunde in Germany, supported by the U.S. Department of Energy, Office of Biological and Environmental Research, under Contract No. DE-ACO2-76CH00016.

The CO2SYS program uses two of the four measurable parameters of the CO_2 system [total alkalinity (TA), total inorganic CO_2 (TC), pH, and either fugacity (fCO_2) or partial pressure of CO_2 (pCO_2)] to calculate the other two parameters given a specific set of input conditions (temperature and pressure) and output conditions chosen by the user. EPA utilized the Excel version (Pierrot et al. 2006)[222] of the program to compute pH for three scenarios: the baseline scenario at a climate sensitivity of 3 degrees for which the CO_2 concentrations was calculated to be 784.87 in 2100, the proposed alternative relative to the baseline with a CO_2 concentration of 784.11, and a calculation for 1990 with a CO_2 concentration of 353.63.

Using the set of seawater parameters detailed below, EPA calculated pH levels for the three scenarios. The pH of the emissions standards relative to the baseline scenario pH was +0.0004 units (more basic). For comparison, the difference between the baseline scenario in 2100 and the pH in 1990 was -0.30 pH units (more acidic).

The CO2SYS program required the input of a number of variables and constants for each scenario for calculating the result for both the reference case and the proposal's emissions reduction baseline cases. EPA used the following inputs, with justification and references for these inputs provided in brackets:

1) Input mode: Single-input
2) Choice of constants: Mehrbach et al. (1973)[223], refit by Dickson and Millero (1987)[224]
3) Choice of fCO_2 or pCO_2: pCO_2
4) Choice of KSO4: Dickson (1990)[225] Choice of KSO4: Dickson (1990)[226]
5) Choice of pH scale: Total scale Choice of pH scale: Total scale
6) $[B]_T$ value: Uppstrom, 1974

The program provides several choices of constants for saltwater that are needed for the calculations. EPA calculated pH values using all choices and found that in all cases the choice had an indistinguishable effect on the results. In addition, EPA ran the model using a variety of other required input values to test whether the model was sensitive to these inputs. EPA found the model was not sensitive to these inputs in terms of the incremental change in pH calculated for each climate sensitivity case. The input values are derived from certified reference materials of sterilized natural sea water (Dickson, 2003, 2005, and 2009).[227] Based on the projected atmospheric CO_2 concentration reductions that would result from this proposal's baseline case (1.2 ppmv for a climate sensitivity of 3.0), the modeling program calculates an increase in ocean pH of approximately 0.0006 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from the proposed alternative yields an increase in ocean pH. Table 6-2 contains the projected changes in ocean pH based the change in atmospheric CO_2 concentrations which were derived from the MAGICC modeling.

Table 6-2 Impact of the Proposal's GHG Emissions Reductions on Ocean pH

CLIMATE SENSITIVITY	DIFFERENCE IN CO_2[A]	YEAR	PROJECTED CHANGE
3.0	-1.2 ppmv	2100	0.0006

Note:
[a] Represents the change in atmospheric CO_2 concentrations in 2100 based on the difference from the proposed alternative relative to the base case from the GCAM reference scenario used in the MAGICC modeling.

6.3.4 Summary of Climate Analyses

EPA's analysis of the impact of the proposal's emissions reductions on global climate conditions is intended to quantify these potential reductions using the best available science. While EPA's modeling results of the impact of this proposal alone show small differences in climate effects (CO_2 concentration, global mean temperature, sea level rise, and ocean pH), in comparison to the total projected changes, they yield results that are repeatable and directionally consistent within the modeling frameworks used. The results are summarized in Table 6-3, Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with the Proposal.

These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for this proposal, a reduction in projected global mean temperature and sea level rise implies a reduction in the risks associated with climate change. The figures for these variables illustrate that across a range of climate sensitivities projected global mean temperature and sea level rise increase less in the proposed alternative scenario than in the reference (no climate policy) case. The benefits of GHG emissions reductions can be characterized both qualitatively and quantitatively, some of which can be monetized (see Chapter 9). There are substantial uncertainties in modeling the global risks of climate change, which complicates quantification and cost-benefits assessments. Changes in climate variables are a meaningful proxy for changes in the risk of all potential impacts--including those that can be monetized, and those that have not been monetized but can be quantified in physical terms (e.g., water availability), as well as those that have not yet been quantified or are extremely difficult to quantify (e.g., forest disturbance and catastrophic events such as collapse of large ice sheets and subsequent sea level rise).

Table 6-3 Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with the Proposal (Based on a Range of Climate Sensitivities from 1.5-6°C)

VARIABLE	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-1.1 to -1.2
Global Mean Surface Temperature	ºC	2100	-0.0026 to -0.0065
Sea Level Rise	cm	2100	-0.023 to -0.057
Ocean pH	pH units	2100	+0.0006[a]

Note:
[a] The value for projected change in ocean pH is based on a climate sensitivity of 3.0.

References

[1] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[2] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F.
[3] 78 FR 3086 (January 15, 2013) pages 3103-3104.
[4] 77 FR 38890 (June 29, 2012) pages 38906-38911.
[5] 78 FR 3086 (January 15, 2013) pages 3103-3104.
[6] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Chapter 6 (Section 6.5) and Chapter 7 (Section 7.6).
[7] 78 FR 3103 (January 15, 2013).
[8] 78 FR 3103 (January 15, 2013).
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Chapter 7: Vehicle-Related Costs, Fuel Savings & Maintenance Costs

In this chapter, the agencies present our estimates of the vehicle -related costs associated with the proposed standards along with corresponding fuel savings and maintenance costs. For this rule, the agencies conducted coordinated and complementary analyses using two analytical methods for the heavy-duty pick up and van segment by employing both DOT's CAFE model and EPA's MOVES model. The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engine that powers the tractor), and vocational vehicles (including the engine that powers the vehicle). Additional calculations were performed to determine corresponding monetized program costs and benefits. For heavy-duty pickups and vans, the agencies performed complementary analyses, which we refer to as "Method A" and "Method B". In Method A, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative and the estimated effects on fuel consumption, emissions, benefits and costs. In Method B, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative, along with resultant impacts on per vehicle costs, and the MOVES model was used to calculate corresponding changes in total fuel consumption and annual emissions. Additional calculations were performed to determine corresponding monetized program costs and benefits. NHTSA considered Method A as its central analysis and Method B as a supplemental analysis. EPA considered the results of both methods. The agencies concluded that both methods led the agencies to the same conclusions and the same selection of the proposed standards. Throughout this Chapter and in later chapters presenting program-related costs and benefits, engine costs are included along with vehicle-related costs.

7.1 Vehicle Costs, Fuel Savings and Maintenance Costs vs. the Dynamic Baseline and Using Method A

The agencies joint analysis of the potential costs of the proposed standards combines DOT CAFE model calculations of HD pickup and van costs with EPA MOVES modeling of vocational vehicle, tractor and trailer fuel consumption along with EPA analysis of vocational vehicle, tractor and trailer costs. The analysis includes costs for fuel-saving technology that manufacturers could add in response to the proposed standards, EPA estimates of the additional compliance and R&D costs for vocational vehicles and combination tractor trailers, and some additional maintenance costs.

7.1.1 Vehicle Program Costs

In this section, the agencies present our estimate of the vehicle- -related costs associated with the proposed program versus Alternative 1b using the CAFE model analysis of HD pickups and vans. The presentation here summarizes the costs associated with new technology the agencies estimate manufacturers could add to meet the proposed GHG and fuel consumption standards. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis and on a MY lifetime basis. In Chapter 7.2, where the agencies present the Method B analysis, the analogous information is presented along with costs on an annual, or calendar year, basis for all segments. For details behind the cost estimates associated with individual technologies, the reader is directed to Sections III through VI of the proposed preamble and to Chapter 2 of the draft RIA.

Note that all discounted costs presented in this chapter, whether in the Calendar Year (or annual) analysis or the Model Year Lifetime analysis, are discounted back to 2015 at the discount rate shown in the table(s).

7.1.1.1 Technology Costs

For the HD pickup trucks and vans, the agencies have used a methodology consistent with that used for our recent 2017-2025 light-duty joint rulemaking since most of the technologies expected for HD pickup trucks and vans are consistent with those expected for the larger light-duty trucks. The cost estimates presented in the recent light-duty joint rulemaking were then scaled upward to account for the larger weight, towing capacity, and work demands of the trucks in these heavier classes. For details on that scaling process and the resultant costs for individual technologies, the reader is directed to Chapter 2.6 and 2.12 of this draft RIA. Note also that all cost estimates have been updated to 2012 dollars for this analysis while the 2017-2025 light-duty joint rulemaking was presented in 2010 dollars.[1]

For vocational vehicles, tractors and trailers, consistent with the Phase 1 rule, the agencies have estimated costs using a different methodology than that employed in the recent light-duty joint rulemaking establishing fuel economy and GHG standards. In the recent light-duty joint rulemaking, all fixed costs were included in the hardware costs via an indirect cost multiplier. As such, the hardware costs presented in that analysis included both the actual hardware and the associated fixed costs. For the vocational, tractor and trailer segments in this analysis, some of the fixed costs are estimated separately and are presented separately from the technology costs. As noted above, all costs are presented in 2012 dollars.

The estimates of vehicle costs are generated relative to two unique “no action” baselines. The first of these (alternative 1a, presented below in Chapter 7.2) representing generally flat fuel consumption improvements, or a fleet of vehicles meeting the Phase 1 heavy-duty requirements. The second of these (alternative 1b and presented here) representing dynamic fuel consumption improvements, or a fleet of vehicles with improving fuel consumption despite the lack of regulatory drivers. See Section X of the preamble and Chapter 11 of this draft RIA for more detail on these two baselines. As such, costs to comply with the Phase 1 standards are not included in the estimates here. In fact, in the methodology used for vocational vehicles, tractors and trailers, there are cases where Phase 1 technologies are being removed in favor of Phase 2 technologies – that is, the technology basis for the Phase 2 proposed standards involves removing certain of the Phase 1 technologies. In those cases, savings are associated with the removal of the Phase 1 technology. The details of which technologies and where such savings occur are presented in Chapter 2.12 of the draft RIA.

For HD pickups and vans, as described in Chapter 2 of this draft RIA, the agencies used NHTSA’s CAFE model to estimate the cost per vehicle associated with the proposed (and possible alternative) standards.[A] That model has the capability to look ahead at future standards when making determinations of how vehicles should be changed to comply. It does this because redesign cycles do not always line up well with regulatory implementation schedules, so a manufacturer may choose to redesign a vehicle in MY2018 in preparation for upcoming MY2021-2025 standards if that particular vehicle is not scheduled for another redesign until, say, MY2026. The result being new technology costs in years prior to implementation of the standards. The CAFE model's output would show such costs occurring in years prior to MY2021. On the other hand, the CAFE model also estimates the potential that credits generated in earlier model years might be carried forward (i.e., "banked") and then used in later model years, potentially reducing costs in some model years covered by the analysis.

Table 7-1 presents the average incremental technology costs per vehicle for the proposed program relative to alternative 1b. These tables include both engine and vehicle technologies. For HD pickups and vans, costs begin with new standards in MY2018, as technology is utilized in vehicles with early redesign cycles. The costs jump in MY2021 as more complex technologies are utilized, then generally increase through the remainder of the analysis period. For vocational vehicles, the costs begin in MY2021, then decrease slightly through MY2023, with an increase in MY2024, decreasing slightly through MY2026, and followed by a large increase in costs from MY2027 until the end of the analysis period. For tractor/trailers, the costs begin in MY2018 as trailers begin adding new technology to meet the 2018 trailer standards. Costs then increase in MY2021 as the tractor standards begin through 2027. After 2027, costs begin to decrease due to learning effects. All costs shown in the table represent the weighted average cost of all vehicles within the category shown in the heading.

[A] The CAFE model also provides a full benefit-cost analysis associated with proposed standards, and the agencies have used this analysis as part of Method A to provide estimates of the costs and benefits of today's proposed standards. The full benefit-cost analysis for Method A is presented in Chapters 9 and 10 of this draft RIA. The full benefit-cost analysis for Method B is presented in Chapter 8 of this draft RIA.

Table 7-1 Estimated Technology Costs per Vehicle for the Preferred Alternative versus the Dynamic Baseline and using Method A (2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS
2018	$98	$0	$639
2019	$92	$0	$548
2020	$95	$0	$478
2021	$493	$1,152	$7,445
2022	$485	$1,128	$7,273
2023	$766	$1,037	$6,790
2024	$896	$1,766	$10,690
2025	$1,149	$1,731	$10,476
2026	$1,248	$1,695	$10,206
2027	$1,366	$3,381	$12,487
2028	$1,356	$3,323	$12,292
2029	$1,357	$3,271	$12,178
2030	$1,348	$3,222	$12,070
2050	$1,348	$3,232	$11,981

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

As noted in the text, MYs 2018-2020 include costs for trailers only, and in MYs 2021 and later the costs include both tractor and trailer costs. Detailed technology and package costs for all segments can be found in Chapter 2 of this draft RIA (notably, see Sections 2.12 and 2.13).

Table 7-2 presents the model year lifetime costs for new technology discounted at 3 percent using Method A. And Table 7-3 presents the model year lifetime costs for new technology discounted at 7 percent using Method A.

Table 7-2 Discounted MY Lifetime New Technology Costs of the Preferred Alternative Vs. the Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$61	$0	$104	$165
2019	$55	$0	$99	$154
2020	$55	$0	$95	$150
2021	$280	$488	$1,013	$1,781
2022	$269	$468	$976	$1,713
2023	$412	$421	$898	$1,731
2024	$479	$719	$1,412	$2,610
2025	$608	$705	$1,396	$2,709
2026	$654	$689	$1,369	$2,712
2027	$704	$1,363	$1,676	$3,743
2028	$688	$1,321	$1,642	$3,651
2029	$677	$1,279	$1,618	$3,574
Sum	$4,942	$7,452	$12,299	$24,693

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-3 Discounted MY Lifetime New Technology Costs of the Preferred Alternative Vs. the Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$54	$0	$91	$145
2019	$47	$0	$84	$131
2020	$46	$0	$77	$123
2021	$223	$381	$791	$1,395
2022	$206	$352	$734	$1,292
2023	$304	$305	$650	$1,259
2024	$340	$501	$984	$1,825
2025	$415	$473	$936	$1,824
2026	$430	$445	$884	$1,759
2027	$446	$847	$1,041	$2,334
2028	$419	$790	$982	$2,191
2029	$397	$736	$932	$2,065
Sum	$3,327	$4,829	$8,186	$16,342

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.2 Compliance Costs

As noted above, some fixed costs were estimated separately from the hardware costs. As such, not all fixed costs are included in the tables presented in Section 7.1.1.1. The agencies have estimated additional and/or new compliance costs associated with the proposed standards. Normally, compliance program costs would be considered part of the indirect costs and, therefore, would be accounted for via the markup applied to direct manufacturing costs. However, since the agencies are proposing new compliance elements that were not present during development of the indirect cost markups used in this analysis, additional compliance program costs are being accounted for via a separate "line-item" here. Note that, for HD pickups and vans, compliance elements were present during development of the indirect cost markups used; as such, these costs are already included as part of the technology costs described above.

There are three elements to the compliance costs estimated in this analysis. The first is for construction of new, or upgrades to existing, test facilities for conducting powertrain testing. The second costs are for conducting the powertrain tests themselves. And the third is for reporting of compliance data to EPA and NHTSA. We estimated these latter costs in the Phase 1 rule as $0.24 million, $0.9 million and $1.1 million for HD pickups and vans, vocational and tractors, respectively, for a total of $2.3 million per year (2009$).[2] All of these are industry-wide, annual costs.

We have estimated new reporting costs in this Phase 2 proposal associated with new powertrain testing within the vocational vehicle program, the increased level of reporting in the tractor program and an all new compliance program where none has existed to date within the trailer program. We have estimated those costs at $95,000 and $240,000 for vocational and tractor programs, and at $1.2 million in the trailer program, all in 2012$. All of these are industry-wide, annual costs.

For powertrain testing facility upgrades and construction, we have estimated that 6 manufacturers would upgrade and 5 would construct new facilities at an upgrade cost of $1.2 million and a new construction cost of $1.9 million, all in 2012$. The result being an industry-wide (but vocational program only) cost of $16.6 million (2012$). This cost would occur once which we have attributed to CY2021, what would be the first year of the Phase 2 vocational standards.[B]

Lastly, the vocational program is also estimated to incur costs associated with conducting powertrain testing. We have estimated the cost of testing at $69,000 per test and expect three large manufacturers to conduct 20 tests/year for a total of $4.1 million/year.[C]

[B] Note that, in alternative 2, we expect no manufacturers would conduct powertrain testing so none would construct or upgrade facilities.

[C] Note that, in alternative 2, we expect no powertrain testing so no testing costs; in alternative 4, we expect 4 large manufacturers to conduct the testing for an annual cost of $5.5 million.

Table 7-4 and Table 7-5 present the MY lifetime costs for new compliance program elements at 3 percent and 7 percent, respectively.

Table 7-4 Discounted MY Lifetime Compliance Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0
2021	$13.7	$1.2	$14.9
2022	$3.4	$1.1	$4.5
2023	$3.3	$1.1	$4.4
2024	$3.2	$1.1	$4.3
2025	$3.1	$1.0	$4.1
2026	$3.0	$1.0	$4.0
2027	$2.9	$1.0	$3.9
2028	$2.8	$1.0	$3.8
2029	$2.8	$0.9	$3.7
Sum	$38.3	$9.4	$47.7

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-5 Discounted MY Lifetime Compliance Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0
2021	$10.7	$0.9	$11.6
2022	$2.5	$0.9	$3.4
2023	$2.4	$0.8	$3.2
2024	$2.2	$0.7	$3.0
2025	$2.1	$0.7	$2.8
2026	$1.9	$0.7	$2.6
2027	$1.8	$0.6	$2.4
2028	$1.7	$0.6	$2.3
2029	$1.6	$0.5	$2.1
Sum	$27.0	$6.4	$33.4

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.3 Research & Development Costs

Much like the compliance program costs described above, EPA has estimated additional engine, vocational vehicle and tractor R&D associated with the proposed standards that is not accounted for via the indirect cost markups used in this analysis for those segments. The necessary R&D for HD pickups and vans is covered by the indirect costs included as part of the technology costs described above. In the Phase 1 rule, the agencies estimated the engine R&D costs at $6.8 million (2009$) per engine class per manufacturer per year for five years. In this Phase 2 analysis, EPA has estimated this same level of R&D and has assumed 12 heavy-heavy and 12 medium-heavy HD engine R&D programs would be conducted for a total of $214 million/year (2012$). In this analysis, EPA has assumed those costs would occur annually for 4 years, MYs 2021-2024. The total being $857 million (2012$) over 4 years (by comparison, the Phase 1 rule estimated a total of $852 million (2009$) over 5 years). To this, EPA has estimated an additional $6 million/year spent by vocational vehicle manufacturers and $20 million/year spent by tractor manufacturers. In the end, EPA is estimating a total of $961 million in R&D spending above and beyond the level included in the markups used to estimate indirect costs for these segments. Under alternative 4, due to the accelerated implementation of technology, EPA has estimated even more R&D—an additional $6.5 million per year or $26 million total spent by vocational vehicle and tractor manufacturers. Importantly, EPA estimates that these costs would occur during normal R&D and vehicle design cycles for both alternatives 3 and 4. EPA has not included any *additional* R&D would be spent by trailer manufacturers since our cost estimates include R&D conducted by trailer parts suppliers which are subsequently included in the prices charged by those suppliers to the trailer manufacturer. Additionally, the markups we have applied to cover indirect costs (see Chapter 2.12 of this draft RIA) include costs associated with R&D incurred by the trailer manufacturer.

Table 7-6 through Table 7-7 present the model year lifetime R&D costs discounted at 3 percent and 7 percent, respectively.

Table 7-6 Discounted MY Lifetime R&D Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0
2021	$93.4	$104.9	$198.3
2022	$90.6	$101.9	$192.5
2023	$88.0	$98.9	$186.9
2024	$85.4	$96.0	$181.5
2025	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0
Sum	$357.5	$401.7	$759.2

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-7 Discounted MY Lifetime R&D Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0
2021	$72.9	$81.9	$154.9
2022	$68.1	$76.6	$144.7
2023	$63.7	$71.6	$135.3
2024	$59.5	$66.9	$126.4
2025	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0
Sum	$264.3	$297.0	$561.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.4 Summary of Vehicle-Related Costs of the Proposed Program using Method A

Table 7-8 presents the model year lifetime costs associated with the preferred alternative discounted at 3 percent relative to the dynamic baseline and using Method A. Table 7-9 presents the model year lifetime costs associated with the preferred alternative discounted at 7 percent relative to the dynamic baseline and using Method A.

Table 7-8 Discounted MY Lifetime Vehicle-Related Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$61	$0	$104	$165
2019	$55	$0	$99	$154
2020	$55	$0	$95	$150
2021	$280	$595	$1,119	$1,994
2022	$269	$563	$1,079	$1,911
2023	$412	$512	$998	$1,922
2024	$479	$807	$1,509	$2,795
2025	$608	$708	$1,397	$2,713
2026	$654	$692	$1,370	$2,716
2027	$704	$1,366	$1,677	$3,747
2028	$688	$1,324	$1,643	$3,655
2029	$677	$1,282	$1,619	$3,578
Sum	$4,942	$7,848	$12,710	$25,500

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-9 Discounted MY Lifetime Vehicle-Related Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$54	$0	$91	$145
2019	$47	$0	$84	$131
2020	$46	$0	$77	$123
2021	$223	$465	$874	$1,562
2022	$206	$423	$811	$1,440
2023	$304	$371	$722	$1,397
2024	$340	$562	$1,051	$1,953
2025	$415	$475	$937	$1,827
2026	$430	$446	$885	$1,761
2027	$446	$849	$1,042	$2,337
2028	$419	$792	$983	$2,194
2029	$397	$738	$932	$2,067
Sum	$3,327	$5,121	$8,489	$16,937

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.2 Changes in Fuel Consumption and Savings

7.1.2.1 Changes in Fuel Consumption

The proposed standards would result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles would see corresponding savings associated with reduced fuel expenditures. The agencies have estimated the impacts on fuel consumption for the proposed standards. More detail behind these changes in fuel consumption is presented in Chapter 5 and Chapter 10 of this draft RIA. The expected impacts on fuel consumption are shown in Table 7-10 as reductions from the dynamic baseline reference case (i.e., positive values represent fewer gallons consumed) and using Method A. The gallons shown in this table include any increased consumption resulting from the rebound effect.

Table 7-10 MY Lifetime Fuel Consumption Reductions due to the Preferred Alternative Vs. The Dynamic Baseline and using Method A (Million Gallons) [a]

	GASOLINE REDUCTIONS [b]				DIESEL REDUCTIONS			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	44	0	0	44	25	0	934	959
2019	41	0	0	41	20	0	870	890
2020	42	0	0	42	20	0	840	860
2021	172	54	0	226	136	340	4,091	4567
2022	173	54	0	227	136	340	4,057	4533
2023	265	54	0	319	246	340	3,958	4544
2024	306	127	0	433	283	705	6,289	7277
2025	678	130	0	808	309	722	6,330	7361
2026	782	133	0	915	315	738	6,359	7412
2027	884	297	0	1181	323	1,193	7,350	8866
2028	894	300	0	1194	326	1,210	7,417	8953
2029	910	303	0	1213	330	1,222	7,563	9115

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Gasoline reductions include reductions in Ethanol85.

7.1.2.2 Changes in Fuel Expenditures

Using the fuel consumption reductions presented above, the agencies have calculated the fuel expenditure changes associated with the proposed standards, subcategory by subcategory. To do this, reduced fuel consumption is multiplied in each year by the corresponding estimated average fuel price in that year, using the reference case fuel prices from AEO 2014. For the Method A analysis, the AEO 2014 early release reference case was used for the vocational vehicles and tractor/trailers; the AEO 2014 final release reference case was used for HD pickups and vans. As the AEO fuel price projections go through 2040 and not beyond, fuel prices beyond 2040 were set equal to the 2040 values for vocational vehicles and tractor/trailers. For the Method A

HD pickups and vans, the retail price of gasoline was projected to rise at 0.2 percent per year for gasoline and 0.7 percent for diesel. These estimates do not account for the significant uncertainty in future fuel prices; the monetized fuel savings would be understated if actual fuel prices are higher (or overstated if fuel prices are lower) than estimated. The Annual Energy Outlook (AEO) is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. This has been done using both the pre-tax and post-tax fuel prices. Since the post-tax fuel prices are the prices paid at fuel pumps, the fuel expenditure changes calculated using these prices represent the changes fuel purchasers would see. The pre-tax fuel savings are those that society would see. Assuming no change in fuel tax rates, the difference between these two columns represents the reduction in fuel tax revenues that would be received by state and federal governments. The MY lifetime fuel savings for the preferred alternative relative to the dynamic baseline and using Method A are shown in Table 7-11 using a 3 percent discount rate and in Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-12 using a 7 percent discount rate. Note that in Chapters 8 and 11 of this draft RIA, the overall benefits and costs of the rulemaking are presented and only the pre-tax fuel expenditure impacts are presented there.

Table 7-11 Discounted MY Lifetime Reductions in Fuel Expenditures of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (3% Discount Rate, Millions of 2012$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$181	$0	$2,744	$2,925	$161	$0	$2,435	$2,596
2019	$157	$0	$2,515	$2,672	$140	$0	$2,238	$2,378
2020	$160	$0	$2,386	$2,547	$143	$0	$2,130	$2,273
2021	$794	$1,082	$11,422	$13,297	$711	$966	$10,222	$11,898
2022	$782	$1,064	$11,139	$12,984	$701	$952	$9,991	$11,645
2023	$1,281	$1,044	$10,675	$13,000	$1,151	$937	$9,596	$11,684
2024	$1,446	$2,156	$16,663	$20,264	$1,303	$1,937	$15,008	$18,248
2025	$2,294	$2,167	$16,460	$20,922	$2,066	$1,951	$14,855	$18,872
2026	$2,494	$2,172	$16,217	$20,883	$2,247	$1,959	$14,663	$18,870
2027	$2,686	$3,617	$18,381	$24,684	$2,423	$3,267	$16,650	$22,340
2028	$2,664	$3,591	$18,164	$24,419	$2,407	$3,250	$16,482	$22,138
2029	$2,654	$3,555	$18,144	$24,352	$2,402	$3,222	$16,491	$22,115
Sum	$17,592	$20,446	$144,911	$182,949	$15,854	$18,442	$130,760	$165,056

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-12 Discounted MY Lifetime Reductions in Fuel Expenditures of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (7% Discount Rate, Millions of 2012$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$130	$0	$1,954	$2,084	$116	$0	$1,729	$1,845
2019	$109	$0	$1,721	$1,830	$97	$0	$1,528	$1,625
2020	$107	$0	$1,566	$1,673	$95	$0	$1,395	$1,490
2021	$510	$689	$7,197	$8,395	$455	$614	$6,426	$7,495
2022	$483	$653	$6,766	$7,902	$433	$583	$6,056	$7,072
2023	$762	$617	$6,249	$7,628	$684	$553	$5,605	$6,842
2024	$828	$1,227	$9,401	$11,457	$745	$1,101	$8,451	$10,297
2025	$1,265	$1,188	$8,945	$11,399	$1,138	$1,068	$8,058	$10,264
2026	$1,324	$1,147	$8,487	$10,957	$1,191	$1,033	$7,661	$9,884
2027	$1,373	$1,840	$9,264	$12,476	$1,236	$1,660	$8,378	$11,274
2028	$1,311	$1,758	$8,810	$11,879	$1,183	$1,589	$7,982	$10,753
2029	$1,257	$1,676	$8,472	$11,406	$1,136	$1,517	$7,690	$10,343
Sum	$9,459	$10,796	$78,832	$99,087	$8,508	$9,717	$70,958	$89,184

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.3 Maintenance Costs

The agencies have estimated increased maintenance costs associated with installation of lower rolling resistance tires. We expect that, when replaced, the lower rolling resistance tires would be replaced by equivalent performing tires throughout the vehicle lifetime. As such, the incremental increases in costs for lower rolling resistance tires would be incurred throughout the vehicle lifetime at intervals consistent with current tire replacement intervals. Those intervals are difficult to quantify given the variety of vehicles and operating modes within the HD industry. For HD pickups and vans, we have chosen a tire replacement interval of 40,000 miles. We have done the same for all vocational vehicles which is probably overly conservative as more frequent intervals results in higher maintenance costs. For tractors and trailers, we have used a maintenance interval of 200,000 miles. The presence of tire inflation management systems, and the increased use of those systems expected due to this proposed rule, should serve to improve tire maintenance intervals.

In evaluating maintenance costs associated with the proposal relative to the less dynamic baseline, EPA has used the maintenance intervals noted above, the MOVES policy case VMT, and the MOVES population of specific MY vehicles in future calendar years to estimate the increased maintenance costs associated with the proposal, again for each subcategory. Note that, in the context of the benefit-cost analysis, EPA has estimated maintenance costs using the policy case VMT which, by definition, includes rebound VMT (see Section IX of the preamble and

Chapter 8 of this draft RIA for a discussion of rebound VMT). In evaluating maintenance costs associated with the proposal relative to Alternative 1b, NHTSA has used, for HD pickups and vans, the integrated analysis performed using the CAFE modeling system. For vocational vehicles, tractors and trailers, NHTSA has used the MOVES-based approach outlined above.

Table 7-13 shows the incremental increased costs associated with lower rolling resistance tires for HD pickups and vans, vocational vehicles, tractors, trailers and tractor/trailers relative to the dynamic baseline.

Table 7-13 Increased Maintenance Costs at Maintenance Intervals Associated with the Preferred Alternative Vs. The Dynamic Baseline using Method A (2012$/event) [a,b]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR	TRAILER	TRACTOR/ TRAILER
2018	$0.00	$0.00	$0.00	$79.92	$67.16
2019	$0.00	$0.00	$0.00	$77.77	$65.36
2020	$0.00	$0.00	$0.00	$75.69	$63.60
2021	$1.72	$6.99	$33.16	$78.81	$99.38
2022	$3.45	$6.91	$32.53	$75.98	$96.39
2023	$5.17	$8.12	$31.66	$71.17	$91.46
2024	$6.90	$17.66	$33.50	$73.97	$95.66
2025	$8.62	$17.47	$32.92	$72.02	$93.43
2026	$8.62	$13.50	$30.01	$70.72	$89.44
2027	$8.62	$21.34	$32.27	$69.44	$90.62
2028	$8.62	$20.26	$31.52	$68.18	$88.81
2029 & later	$8.62	$15.99	$31.22	$66.27	$86.91

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The maintenance category includes only the incremental expenditure required to assure that low rolling resistance, rather than conventional, tires are used throughout the useful life of the vehicle. The agencies request comment and information on other relevant maintenance costs

Table 7-14 presents the model year lifetime in-use maintenance costs—versus the dynamic baseline and using Method A— discounted at 3 percent. Table 7-15 presents the model year lifetime in-use maintenance costs—versus the dynamic baseline and using Method A—discounted at 7 percent.

Table 7-14 Discounted MY Lifetime Maintenance Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$51.2	$51.2
2019	$0.0	$0.0	$49.2	$49.2
2020	$0.0	$0.0	$47.5	$47.5
2021	$3.3	$14.1	$72.6	$90.0
2022	$6.5	$13.5	$69.0	$88.9
2023	$9.4	$15.4	$64.0	$88.8
2024	$12.3	$33.3	$66.6	$112.2
2025	$15.1	$32.7	$65.1	$112.9
2026	$15.0	$25.0	$62.1	$102.1
2027	$14.7	$38.9	$62.3	$115.9
2028	$14.4	$36.2	$60.2	$110.7
2029	$14.0	$27.9	$57.9	$99.8
Sum	$104.6	$237.0	$727.6	$1,069.2

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-15 Discounted MY Lifetime Maintenance Costs of the Preferred Alternative Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$35.8	$35.8
2019	$0.0	$0.0	$33.2	$33.2
2020	$0.0	$0.0	$30.9	$30.9
2021	$2.1	$8.9	$45.5	$56.6
2022	$3.9	$8.3	$41.7	$53.9
2023	$5.5	$9.1	$37.3	$51.9
2024	$6.9	$18.9	$37.4	$63.2
2025	$8.3	$17.8	$35.2	$61.3
2026	$7.9	$13.1	$32.4	$53.4
2027	$7.4	$19.7	$31.3	$58.5
2028	$7.0	$17.7	$29.2	$53.9
2029	$6.6	$13.1	$27.1	$46.8
Sum	$55.7	$126.6	$417.2	$599.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.4 Analysis of Payback Periods

An important metric to vehicle purchasers is the payback period that can be expected on any new purchase. In other words, there is greater willingness to pay for new technology if that new technology "pays back" within an acceptable period of time. We make no effort to define the acceptable period of time here, but seek to estimate the payback period for others to make the decision themselves. We define the payback period as the point at which reduced fuel expenditures outpace increased vehicle costs. For example, a new MY2027 HD pickup truck is estimated to cost roughly $1,400 more (on average, in 2012$, and relative to the reference case vehicle) due to the addition of new fuel consumption improving and GHG reducing technology. This new technology would result in lower fuel consumption and, therefore, reduced fuel expenditures. But how many months or years would pass before the reduced fuel expenditures would surpass the increased costs?

To estimate the costs, we have considered not only the cost of the new technology, but also the taxes paid on the incrementally higher purchase expense, the slightly higher insurance expenses on the slightly higher value vehicle, the increased finance cost, and the increased maintenance costs associated with the new technology. Taxes and fees paid were estimated as 5.46 percent of the final MSRP. Financing was estimated to be 15.32 percent of final MSRP, and for insurance costs, the model uses an estimate of 19.23 percent of the final MSRP of a vehicle as the cost of insurance. For maintenance costs, the results shown in Table 7-16 express the average incremental maintenance costs associated with new technology added to an average HD pickup or van which drives an average amount of miles each year. These calculations do not represent specific vehicle classes or specific use cases so should not be seen as being applicable to any particular individual's situation. However, the payback periods do provide a general sense, on average, of what sort of payback periods are likely at a national, societal perspective.

Table 7-16 presents the discounted annual increased vehicle costs and fuel expenditure impacts associated with owning a new MY2027 HD pickup or van using both 3 percent and 7 percent discount rates. The results in this table use Method A. As shown in the table, the payback for HD pickups and vans occurs late in the 3rd year of ownership (the year in which cumulative expenditures become negative) using a 3 percent discount rate and in the early part of the 4th year using a 7 percent discount rate. For other classes of vehicles, including vehicle types such as refuse trucks and transit buses, refer to the Method B analysis of payback periods presented in Chapter 7.2.4.

Table 7-16 Discounted Owner Expenditures & Payback Period for MY2027 HD Pickups & Vans under the Preferred Alternative Vs. The Dynamic Baseline and using Method A 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$1,855	$0	-$522	$1,333	$1,779	$0	-$501	$1,278
2	$0	$0	-$513	$820	$0	$0	-$471	$806
3	$0	$0	-$467	$353	$0	$0	-$411	$395
4	$0	$0	-$429	-$76	$0	$0	-$363	$32
5	$0	$0	-$408	-$484	$0	$0	-$330	-$298
6	$0	$0	-$369	-$852	$0	$0	-$286	-$584
7	$0	$0	-$325	-$1,177	$0	$0	-$242	-$826
8	$0	$0	-$282	-$1,459	$0	$0	-$201	-$1,027

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

7.2 Vehicle Costs, Fuel Savings and Maintenance Costs vs. the Less Dynamic Baseline and using Method B

As noted in the introduction to Chapter 7.1, the agencies joint analysis of the potential costs of the proposed standards combines EPA MOVES modeling of vocational vehicle, tractor and trailer fuel consumption, EPA analysis of vocational vehicle, tractor and trailer costs, along with DOT CAFE model calculations of HD pickup and van costs per vehicle. The analysis includes costs for fuel-saving technology that manufacturers could add in response to the proposed standards, EPA estimates of the additional compliance and R&D costs for vocational vehicles and combination tractor trailers, and some additional maintenance costs.[3]

7.2.1 Vehicle Program Costs

In this section, the agencies present our estimate of the vehicle-related costs associated with the preferred alternative (Alternative 3) versus the less dynamic baseline (Alternative 1a) using the MOVES analysis of HD pickups and vans as well as vocational vehicle, tractors and trailers. The presentation here summarizes the costs associated with new technology the agencies estimate manufacturers could add to meet the proposed GHG and fuel consumption standards. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis, on a MY lifetime basis and on an annual basis. For details behind the cost estimates associated with individual technologies, the reader is directed to Sections III through VI of the proposed preamble and to Chapter 2 of the draft RIA. The analysis here also includes a look at payback periods—the time at which cumulative fuel savings outweigh increased costs associated with new, more fuel efficient vehicles. And finally, the analysis here includes a look at the cost per ton of GHG emissions reduced by the addition of new technology.

Note that all discounted costs presented in this chapter, whether in the Calendar Year (or annual) analysis or the Model Year Lifetime analysis, are discounted back to 2015 at the discount rate shown in the table(s).

7.2.1.1 Technology Costs

For the HD pickups and vans, the agencies have used a methodology consistent with that used for our recent 2017-2025 light-duty joint rulemaking since most of the technologies expected for HD pickups and vans are consistent with those expected for the larger light-duty trucks. The cost estimates presented in the recent light-duty joint rulemaking were then scaled upward to account for the larger weight, towing capacity, and work demands of the trucks in these heavier classes. For details on that scaling process and the resultant costs for individual technologies, the reader is directed to Chapter 2.12 of this draft RIA. Note also that all cost estimates have been updated to 2012 dollars for this analysis while the 2017-2025 light-duty joint rulemaking was presented in 2010 dollars.[4]

For vocational vehicles, tractors and trailers, consistent with the Phase 1 rule, the agencies have estimated costs using a different methodology than that employed in the recent light-duty joint rulemaking establishing fuel economy and GHG standards. In the recent light-duty joint rulemaking, all fixed costs were included in the hardware costs via an indirect cost multiplier. As such, the hardware costs presented in that analysis included both the actual hardware and the associated fixed costs. For the vocational, tractor and trailer segments in this analysis, some of the fixed costs are estimated separately and are presented separately from the technology costs. As noted above, all costs are presented in 2012 dollars.

The estimates of vehicle costs are generated relative to two unique “no action” baselines. The first of these (alternative 1a, presented here) representing generally flat or less dynamic fuel consumption improvements, or a fleet of vehicles meeting the Phase 1 heavy-duty requirements. The second of these (alternative 1b and presented in detail in Chapter 7.1) representing dynamic fuel consumption improvements, or a fleet of vehicles with improving fuel consumption despite the lack of regulatory drivers. See Section X of the preamble and Chapter 11 of this draft RIA for more detail on these two baselines. As such, costs to comply with the Phase 1 standards are not included in the estimates here. In fact, in the methodology used for vocational vehicles, tractors and trailers, there are cases where Phase 1 technologies are being removed in favor of Phase 2 technologies – that is, the technology basis for the Phase 2 proposed standards involves removing certain of the Phase 1 technologies. In those cases, savings are associated with the removal of the Phase 1 technology. The details of which technologies and where such savings occur are presented in Chapter 2.12 of the draft RIA.

For HD pickups and vans, as described in Chapter 2 of this draft RIA, the agencies used NHTSA’s CAFE model to estimate the cost per vehicle associated with the preferred and possible alternative standards.[D] That model has the capability to look ahead at future standards

[D] The CAFE model also provides a full benefit-cost analysis associated with the HD pickup and van portion of the proposed and alternative standards, and the agencies have used this analysis as part of Method A to provide estimates of the costs and benefits of today’s proposed standards. The full benefit-cost analysis for Method A is when making determinations of how vehicles should be changed to comply. It does this because redesign cycles do not always line up well with regulatory implementation schedules, so a manufacturer may choose to redesign a vehicle in MY2018 in preparation for upcoming MY2021-2025 standards if that particular vehicle is not scheduled for another redesign until, say, MY2026. The result being new technology costs in years prior to implementation of the standards. The CAFE model's output would show such costs occurring in years prior to MY2021. On the other hand, the CAFE model also estimates the potential that credits generated in earlier model years might be carried forward (i.e., "banked") and then used in later model years, potentially reducing costs in some model years covered by the analysis. In Table 7-17, EPA has taken those early costs and spread them over the years 2021 through 2026 so that those costs can be fully realized while showing them occurring during the expected years of implementation.

Table 7-17 presents the average incremental technology costs per vehicle for the preferred alternative relative to the less dynamic baseline and using Method B (the MOVES analysis for all vehicle categories). These tables include both engine and vehicle technologies. For HD pickups and vans, costs begin with new standards in MY2021 then generally increase through MY2027 after which time they begin to decrease as vehicles continue to meet the MY2027 standards at ever decreasing cost due to learning effects. The trend is similar for vocational vehicles. For tractor/trailers, the costs begin in MY2018 as trailers begin adding new technology to meet the 2018 trailer standards. Costs then increase in MY2021 as the tractor standards begin through 2027. After 2027, costs begin to decrease due to learning effects. All costs shown in the table represent the weighted average cost of all vehicles within the category shown in the heading.

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presented in Chapters 9 and 10 of this draft RIA. The full benefit-cost analysis for Method B is presented in Chapter 8 of this draft RIA.

Table 7-17 Estimated Technology Costs per Vehicle for the Preferred Alternative versus the Less Dynamic Baseline and using Method B (2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS
2018	$0	$0	$639
2019	$0	$0	$613
2020	$0	$0	$592
2021	$558	$1,152	$7,606
2022	$551	$1,128	$7,482
2023	$834	$1,037	$7,016
2024	$991	$1,766	$10,947
2025	$1,204	$1,731	$10,763
2026	$1,267	$1,695	$10,513
2027	$1,342	$3,381	$12,849
2028	$1,332	$3,323	$12,655
2029	$1,334	$3,271	$12,548
2030	$1,324	$3,222	$12,439
2050	$1,324	$3,232	$12,415

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

As noted in the text, MYs 2018-2020 include costs for trailers only, and in MYs 2021 and later the costs include both tractor and trailer costs, inclusive of engine-related costs. Detailed technology and package costs for all segments can be found in Chapter 2 of this draft RIA (notably, see Sections 2.12 and 2.13). Also, for HD pickups and vans, EPA has taken early costs and spread them over the years 2021 through 2026 so that those costs can be fully realized while showing them occurring during the expected years of implementation.

Table 7-18 presents the annual costs—versus the less dynamic baseline and using Method B—for new engine- and vehicle-related technology along with net present values at 3 percent and 7 percent. Table 7-19 presents the model year lifetime costs—versus the less dynamic baseline and using Method B—for new technology discounted at 3 percent. Table 7-20 presents the model year lifetime costs—versus the less dynamic baseline and using Method B—for new technology discounted at 7 percent.

Table 7-18 Annual Technology Costs and Net Present Values Associated with the Preferred Alternative vs. the Less Dynamic Baseline and using Method B ($Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$116	$116
2019	$0	$0	$113	$113
2020	$0	$0	$112	$112
2021	$328	$591	$1,254	$2,173
2022	$324	$585	$1,252	$2,161
2023	$491	$541	$1,192	$2,224
2024	$590	$951	$1,913	$3,455
2025	$731	$961	$1,955	$3,647
2026	$788	$967	$1,980	$3,736
2027	$844	$1,972	$2,493	$5,309
2028	$847	$1,969	$2,519	$5,334
2029	$854	$1,963	$2,559	$5,376
2030	$855	$1,956	$2,589	$5,399
2035	$892	$2,076	$2,888	$5,856
2040	$935	$2,204	$3,177	$6,316
2050	$1,024	$2,414	$3,548	$6,987
NPV, 3%	$13,475	$29,183	$43,268	$85,926
NPV, 7%	$6,461	$13,502	$20,553	$40,516

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-19 Discounted MY Lifetime New Technology Costs of the Preferred Alternative Vs. the Less Dynamic Baseline and using Method B (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$104	$104
2019	$0	$0	$99	$99
2020	$0	$0	$95	$95
2021	$271	$488	$1,035	$1,794
2022	$260	$468	$1,003	$1,731
2023	$382	$421	$927	$1,730
2024	$446	$719	$1,445	$2,610
2025	$536	$705	$1,434	$2,674
2026	$561	$689	$1,410	$2,660
2027	$583	$1,363	$1,723	$3,670
2028	$568	$1,321	$1,690	$3,580
2029	$556	$1,279	$1,667	$3,502
Sum	$4,164	$7,452	$12,632	$24,248

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-20 Discounted MY Lifetime New Technology Costs of the Preferred Alternative Vs. the Less Dynamic Baseline and using Method B (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$91	$91
2019	$0	$0	$84	$84
2020	$0	$0	$77	$77
2021	$212	$381	$808	$1,401
2022	$195	$352	$754	$1,302
2023	$276	$305	$671	$1,252
2024	$311	$501	$1,007	$1,818
2025	$360	$473	$961	$1,793
2026	$362	$445	$910	$1,717
2027	$363	$847	$1,071	$2,280
2028	$340	$790	$1,011	$2,141
2029	$320	$736	$960	$2,017
Sum	$2,738	$4,829	$8,405	$15,973

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.2 Compliance Costs

As noted above, some fixed costs were estimated separately from the hardware costs. As such, not all fixed costs are included in the tables presented in Section 7.2.1.1. The agencies have estimated additional and/or new compliance costs associated with the proposed standards. Normally, compliance program costs would be considered part of the indirect costs and, therefore, would be accounted for via the markup applied to direct manufacturing costs. However, since the agencies are proposing new compliance elements that were not present during development of the indirect cost markups used in this analysis, additional compliance program costs are being accounted for via a separate "line-item" here. Note that, for HD pickups and vans, compliance elements were present during development of the indirect cost markups used; as such, these costs are already included as part of the technology costs described above.

There are three elements to the compliance costs estimated in this analysis. The first is for construction of new, or upgrades to existing, test facilities for conducting powertrain testing. The second costs are for conducting the powertrain tests themselves. And the third is for reporting of compliance data to EPA and NHTSA. We estimated these latter costs in the Phase 1 rule as $0.24 million, $0.9 million and $1.1 million for HD pickups and vans, vocational and tractors, respectively, for a total of $2.3 million per year (2009$).[5] All of these are industry-wide, annual costs.

We have estimated new reporting costs in this Phase 2 proposal associated with new powertrain testing within the vocational vehicle program, the increased level of reporting in the tractor program and an all new compliance program where none has existed to date within the trailer program. We have estimated those costs at $95,000 and $240,000 for vocational and tractor programs, and at $1.2 million in the trailer program, all in 2012$. All of these are industry-wide, annual costs.

For powertrain testing facility upgrades and construction, we have estimated that 6 manufacturers would upgrade and 5 would construct new facilities at an upgrade cost of $1.2 million and a new construction cost of $1.9 million, all in 2012$. The result being an industry-wide (but vocational program only) cost of $16.6 million (2012$). This cost would occur once which we have attributed to CY2021, what would be the first year of the Phase 2 vocational standards.[E]

Lastly, the vocational program is also estimated to incur costs associated with conducting powertrain testing. We have estimated the cost of testing at $69,000 per test and expect three large manufacturers to conduct 20 tests/year for a total of $4.1 million/year.[F]

[E] Note that, in alternative 2, we expect no manufacturers would conduct powertrain testing so none would construct or upgrade facilities.

[F] Note that, in alternative 2, we expect no powertrain testing so no testing costs; in alternative 4, we expect 4 large manufacturers to conduct the testing for an annual cost of $5.5 million.

Table 7-21 through Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-23 present the annual costs for new compliance program elements along with net present values at 3 percent and 7 percent, and the model year lifetime compliance costs discounted at 3 percent and 7 percent, respectively.

Table 7-21 Annual Compliance Costs and Net Present Values Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B ($Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$16.6	$1.4	$18.1
2022	$0.0	$4.2	$1.4	$5.7
2023	$0.0	$4.2	$1.4	$5.7
2024	$0.0	$4.2	$1.4	$5.7
2025	$0.0	$4.2	$1.4	$5.7
2026	$0.0	$4.2	$1.4	$5.7
2027	$0.0	$4.2	$1.4	$5.7
2028	$0.0	$4.2	$1.4	$5.7
2029	$0.0	$4.2	$1.4	$5.7
2030	$0.0	$4.2	$1.4	$5.7
2035	$0.0	$4.2	$1.4	$5.7
2040	$0.0	$4.2	$1.4	$5.7
2050	$0.0	$4.2	$1.4	$5.7
NPV, 3%	$0.0	$80.8	$23.7	$104.4
NPV, 7%	$0.0	$44.2	$12.1	$56.4

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-22 Discounted MY Lifetime Compliance Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$13.7	$1.2	$14.9
2022	$0.0	$3.4	$1.1	$4.5
2023	$0.0	$3.3	$1.1	$4.4
2024	$0.0	$3.2	$1.1	$4.3
2025	$0.0	$3.1	$1.0	$4.1
2026	$0.0	$3.0	$1.0	$4.0
2027	$0.0	$2.9	$1.0	$3.9
2028	$0.0	$2.8	$1.0	$3.8
2029	$0.0	$2.8	$0.9	$3.7
Sum	$0.0	$38.3	$9.4	$47.7

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-23 Discounted MY Lifetime Compliance Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$10.7	$0.9	$11.6
2022	$0.0	$2.5	$0.9	$3.4
2023	$0.0	$2.4	$0.8	$3.2
2024	$0.0	$2.2	$0.7	$3.0
2025	$0.0	$2.1	$0.7	$2.8
2026	$0.0	$1.9	$0.7	$2.6
2027	$0.0	$1.8	$0.6	$2.4
2028	$0.0	$1.7	$0.6	$2.3
2029	$0.0	$1.6	$0.5	$2.1
Sum	$0.0	$27.0	$6.4	$33.4

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.3 Research & Development Costs

Much like the compliance program costs described above, EPA has estimated additional engine, vocational vehicle and tractor R&D associated with the proposed standards that is not accounted for via the indirect cost markups used in this analysis for those segments. The necessary R&D for HD pickups and vans is covered by the indirect costs included as part of the technology costs described above. In the Phase 1 rule, the agencies estimated the engine R&D costs at $6.8 million (2009$) per engine class per manufacturer per year for five years. In this Phase 2 analysis, EPA has estimated this same level of R&D and has assumed 12 heavy-heavy and 12 medium-heavy HD engine R&D programs would be conducted for a total of $214 million/year (2012$). In this analysis, EPA has assumed those costs would occur annually for 4 years, MYs 2021-2024. The total being $857 million (2012$) over 4 years (by comparison, the Phase 1 rule estimated a total of $852 million (2009$) over 5 years). To this, EPA has estimated an additional $6 million/year spent by vocational vehicle manufacturers and $20 million/year spent by tractor manufacturers. In the end, EPA is estimating a total of $961 million in R&D spending above and beyond the level included in the markups used to estimate indirect costs for these segments. Under alternative 4, due to the accelerated implementation of technology, EPA has estimated even more R&D—an additional $6.5 million per year or $26 million total spent by vocational vehicle and tractor manufacturers. Importantly, EPA estimates that these costs would occur during normal R&D and vehicle design cycles for both alternatives 3 and 4. EPA has not included any *additional* R&D would be spent by trailer manufacturers since our cost estimates include R&D conducted by trailer parts suppliers which are subsequently included in the prices charged by those suppliers to the trailer manufacturer. Additionally, the markups we have applied to cover indirect costs (see Chapter 2.12 of this draft RIA) include costs associated with R&D incurred by the trailer manufacturer.

Table 7-24 through Table 7-26 present the annual costs for R&D spending along with net present values at 3 percent and 7 percent, and the model year lifetime R&D costs discounted at 3 percent and 7 percent, respectively.

Table 7-24 Annual R&D Costs and Net Present Values Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B ($Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$113.1	$127.1	$240.3
2022	$0.0	$113.1	$127.1	$240.3
2023	$0.0	$113.1	$127.1	$240.3
2024	$0.0	$113.1	$127.1	$240.3
2025	$0.0	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0	$0.0
2030	$0.0	$0.0	$0.0	$0.0
2035	$0.0	$0.0	$0.0	$0.0
2040	$0.0	$0.0	$0.0	$0.0
2050	$0.0	$0.0	$0.0	$0.0
NPV, 3%	$0.0	$357.5	$401.7	$759.2
NPV, 7%	$0.0	$264.3	$297.0	$561.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-25 Discounted MY Lifetime R&D Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$93.4	$104.9	$198.3
2022	$0.0	$90.6	$101.9	$192.5
2023	$0.0	$88.0	$98.9	$186.9
2024	$0.0	$85.4	$96.0	$181.5
2025	$0.0	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0	$0.0
Sum	$0.0	$357.5	$401.7	$759.2

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-26 Discounted MY Lifetime R&D Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.0	$72.9	$81.9	$154.9
2022	$0.0	$68.1	$76.6	$144.7
2023	$0.0	$63.7	$71.6	$135.3
2024	$0.0	$59.5	$66.9	$126.4
2025	$0.0	$0.0	$0.0	$0.0
2026	$0.0	$0.0	$0.0	$0.0
2027	$0.0	$0.0	$0.0	$0.0
2028	$0.0	$0.0	$0.0	$0.0
2029	$0.0	$0.0	$0.0	$0.0
Sum	$0.0	$264.3	$297.0	$561.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.4 Summary of Vehicle-Related Costs of the Program using Method B

Table 7-27 presents the annual new vehicle costs (including engine-related costs) associated with the preferred alternative for HD pickups and vans, vocational vehicles, and tractor and trailer programs along with net present values at 3 percent and 7 percent. This table presents costs relative to the less dynamic baseline and using the MOVES analysis of all vehicle categories (Method B). Table 7-28 presents the model year lifetime costs associated with the preferred alternative discounted at 3 percent relative to the less dynamic baseline and using Method B. Table 7-29 presents the model year lifetime costs associated with the preferred alternative discounted at 7 percent relative to the less dynamic baseline and using Method B.

Table 7-27 Annual Vehicle-Related Costs and Net Present Values Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B ($Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$116	$116
2019	$0	$0	$113	$113
2020	$0	$0	$112	$112
2021	$328	$721	$1,382	$2,432
2022	$324	$702	$1,381	$2,407
2023	$491	$659	$1,320	$2,470
2024	$590	$1,069	$2,042	$3,701
2025	$731	$965	$1,956	$3,653
2026	$788	$972	$1,982	$3,742
2027	$844	$1,976	$2,495	$5,315
2028	$847	$1,973	$2,520	$5,340
2029	$854	$1,967	$2,560	$5,381
2030	$855	$1,960	$2,591	$5,405
2035	$892	$2,080	$2,890	$5,862
2040	$935	$2,209	$3,179	$6,322
2050	$1,024	$2,418	$3,550	$6,992
NPV, 3%	$13,475	$29,621	$43,693	$86,789
NPV, 7%	$6,461	$13,810	$20,862	$41,133

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-28 Discounted MY Lifetime Vehicle-Related Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$104	$104
2019	$0	$0	$99	$99
2020	$0	$0	$95	$95
2021	$271	$595	$1,141	$2,007
2022	$260	$563	$1,106	$1,928
2023	$382	$512	$1,027	$1,921
2024	$446	$807	$1,542	$2,795
2025	$536	$708	$1,435	$2,678
2026	$561	$692	$1,411	$2,664
2027	$583	$1,366	$1,724	$3,673
2028	$568	$1,324	$1,691	$3,583
2029	$556	$1,282	$1,668	$3,506
Sum	$4,164	$7,848	$13,044	$25,055

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-29 Discounted MY Lifetime Vehicle-Related Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$91	$91
2019	$0	$0	$84	$84
2020	$0	$0	$77	$77
2021	$212	$465	$891	$1,567
2022	$195	$423	$832	$1,450
2023	$276	$371	$743	$1,390
2024	$311	$562	$1,074	$1,947
2025	$360	$475	$962	$1,796
2026	$362	$446	$911	$1,719
2027	$363	$849	$1,072	$2,283
2028	$340	$792	$1,012	$2,143
2029	$320	$738	$960	$2,019
Sum	$2,738	$5,121	$8,709	$16,568

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.2 Changes in Fuel Consumption and Savings

7.2.2.1 Changes in Fuel Consumption

The proposed standards would result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles would see corresponding savings associated with reduced fuel expenditures. The agencies have estimated the impacts on fuel consumption for the proposed standards. More detail behind these changes in fuel consumption is presented in Chapter 5 of this draft RIA. The expected impacts on fuel consumption are shown in Table 7-30 as reductions from the less dynamic baseline reference case (i.e., positive values represent fewer gallons consumed) and using the MOVES analysis of all vehicle categories (Method B). The gallons shown in this table include any increased consumption resulting from the rebound effect.

Table 7-30 Annual Fuel Consumption Reductions due to the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (Million Gallons) [a]

	GASOLINE REDUCTIONS				DIESEL REDUCTIONS			
CALENDAR YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0	0	0	0	0	0	74	74
2019	0	0	0	0	0	0	150	150
2020	0	0	0	0	0	0	227	227
2021	5	5	0	10	5	29	489	523
2022	19	10	0	29	20	58	817	894
2023	42	15	0	57	43	86	1,147	1,276
2024	73	26	0	99	76	146	1,674	1,895
2025	113	37	0	151	117	205	2,202	2,523
2026	161	48	0	210	167	263	2,722	3,152
2027	217	74	0	291	224	357	3,308	3,890
2028	270	99	0	369	280	449	3,871	4,600
2029	321	123	0	445	333	538	4,407	5,278
2030	370	147	0	516	383	622	4,918	5,924
2035	561	240	0	801	579	962	6,975	8,517
2040	674	294	0	968	690	1,169	8,349	10,209
2050	783	343	0	1,127	803	1,390	10,117	12,310

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-31 MY Lifetime Fuel Consumption Reductions due to the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (Million Gallons) [a]

	GASOLINE REDUCTIONS				DIESEL REDUCTIONS			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0	0	0	0	0	0	754	754
2019	0	0	0	0	0	0	745	745
2020	0	0	0	0	0	0	738	738
2021	58	54	0	113	59	340	4,025	4,424
2022	162	54	0	216	164	340	4,064	4,568
2023	263	54	0	317	267	340	4,096	4,703
2024	366	127	0	493	373	705	6,551	7,628
2025	472	130	0	602	481	722	6,763	7,967
2026	582	133	0	714	593	738	6,958	8,289
2027	685	297	0	982	699	1,193	8,092	9,984
2028	692	300	0	992	707	1,210	8,265	10,181
2029	696	303	0	999	712	1,222	8,427	10,360

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.2.2 Changes in Fuel Expenditures

Using the fuel consumption reductions presented above, the agencies have calculated the fuel expenditure changes associated with the proposed standards, subcategory by subcategory. To do this, reduced fuel consumption is multiplied in each year by the corresponding estimated average fuel price in that year, using the reference case fuel prices from AEO 2014. As the AEO fuel price projections go through 2040 and not beyond, fuel prices beyond 2040 were set equal to the 2040 values. These estimates do not account for the significant uncertainty in future fuel prices; the monetized fuel savings would be understated if actual fuel prices are higher (or overstated if fuel prices are lower) than estimated. The Annual Energy Outlook (AEO) is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. This has been done using both the pre-tax and post-tax fuel prices. Since the post-tax fuel prices are the prices paid at fuel pumps, the fuel expenditure changes calculated using these prices represent the changes fuel purchasers would see. The pre-tax fuel savings are those that society would see. Assuming no change in fuel tax rates, the difference between these two columns represents the reduction in fuel tax revenues that would be received by state and federal governments, or about $240 million in 2021 and $5.2 billion by 2050 as shown in Table 7-32. Table 7-33 presents the model year lifetime fuel savings—versus the less dynamic baseline and using Method B—discounted at 3 percent. Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-34 presents the model year lifetime costs fuel savings—versus the less dynamic baseline and using Method B—discounted at 7 percent. Note that in Chapters 8 and 11 of this draft RIA, the overall benefits and costs of the rulemaking are presented and only the pre-tax fuel expenditure impacts are presented there.

Table 7-32 Annual Reductions in Fuel Expenditures and Net Present Values due to the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
CALENDAR YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$261	$261	$0	$0	$227	$227
2019	$0	$0	$540	$540	$0	$0	$472	$472
2020	$0	$0	$834	$834	$0	$0	$731	$731
2021	$36	$124	$1,830	$1,989	$31	$109	$1,610	$1,750
2022	$137	$251	$3,117	$3,505	$120	$222	$2,753	$3,095
2023	$303	$381	$4,435	$5,119	$267	$337	$3,928	$4,532
2024	$536	$656	$6,558	$7,750	$474	$581	$5,824	$6,879
2025	$838	$937	$8,756	$10,531	$742	$833	$7,797	$9,372
2026	$1,206	$1,218	$10,953	$13,378	$1,071	$1,085	$9,777	$11,934
2027	$1,643	$1,708	$13,508	$16,859	$1,462	$1,525	$12,089	$15,076
2028	$2,062	$2,182	$15,937	$20,181	$1,837	$1,952	$14,289	$18,079
2029	$2,478	$2,658	$18,349	$23,485	$2,213	$2,383	$16,487	$21,083
2030	$2,877	$3,120	$20,677	$26,675	$2,574	$2,803	$18,616	$23,993
2035	$4,633	$5,175	$31,160	$40,968	$4,190	$4,698	$28,354	$37,242
2040	$5,896	$6,681	$39,501	$52,078	$5,385	$6,122	$36,276	$47,783
2050	$6,859	$7,917	$47,862	$62,638	$6,264	$7,255	$43,955	$57,474
NPV, 3%	$59,038	$66,542	$418,711	$544,290	$53,537	$60,566	$381,492	$495,595
NPV, 7%	$24,187	$27,169	$176,228	$227,584	$21,881	$24,670	$160,096	$206,646

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-33 Discounted MY Lifetime Reductions in Fuel Expenditures of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (3% Discount Rate, Millions of 2012$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$2,183	$2,183	$0	$0	$1,937	$1,937
2019	$0	$0	$2,123	$2,123	$0	$0	$1,890	$1,890
2020	$0	$0	$2,066	$2,066	$0	$0	$1,844	$1,844
2021	$296	$1,066	$11,074	$12,436	$263	$952	$9,911	$11,126
2022	$813	$1,048	$10,995	$12,856	$724	$938	$9,862	$11,525
2023	$1,296	$1,029	$10,888	$13,212	$1,157	$923	$9,787	$11,867
2024	$1,774	$2,124	$17,103	$21,001	$1,587	$1,909	$15,405	$18,901
2025	$2,246	$2,136	$17,330	$21,712	$2,013	$1,923	$15,640	$19,577
2026	$2,712	$2,140	$17,490	$22,342	$2,436	$1,931	$15,814	$20,180
2027	$3,135	$3,564	$19,944	$26,643	$2,821	$3,220	$18,065	$24,106
2028	$3,104	$3,539	$19,949	$26,592	$2,798	$3,202	$18,101	$24,101
2029	$3,064	$3,503	$19,925	$26,493	$2,767	$3,175	$18,109	$24,052
Sum	$18,440	$20,149	$151,070	$189,659	$16,567	$18,173	$136,364	$171,105

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-34 Discounted MY Lifetime Reductions in Fuel Expenditures of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (7% Discount Rate, Millions of 2012$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$1,529	$1,529	$0	$0	$1,352	$1,352
2019	$0	$0	$1,428	$1,428	$0	$0	$1,267	$1,267
2020	$0	$0	$1,331	$1,331	$0	$0	$1,185	$1,185
2021	$186	$666	$6,848	$7,701	$165	$594	$6,115	$6,874
2022	$492	$631	$6,555	$7,678	$437	$564	$5,867	$6,869
2023	$755	$597	$6,255	$7,607	$673	$535	$5,611	$6,819
2024	$995	$1,187	$9,472	$11,654	$889	$1,065	$8,515	$10,469
2025	$1,213	$1,149	$9,244	$11,607	$1,086	$1,033	$8,328	$10,447
2026	$1,410	$1,109	$8,986	$11,505	$1,265	$999	$8,111	$10,374
2027	$1,570	$1,780	$9,868	$13,218	$1,411	$1,605	$8,924	$11,940
2028	$1,496	$1,701	$9,500	$12,697	$1,347	$1,537	$8,607	$11,490
2029	$1,423	$1,621	$9,135	$12,179	$1,283	$1,468	$8,291	$11,041
Sum	$9,540	$10,442	$80,151	$100,134	$8,555	$9,399	$72,174	$90,128

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.3 Maintenance Costs

The agencies have estimated increased maintenance costs associated with installation of lower rolling resistance tires. We expect that, when replaced, the lower rolling resistance tires would be replaced by equivalent performing tires throughout the vehicle lifetime. As such, the incremental increases in costs for lower rolling resistance tires would be incurred throughout the vehicle lifetime at intervals consistent with current tire replacement intervals. Those intervals are difficult to quantify given the variety of vehicles and operating modes within the HD industry. For HD pickups and vans, we have chosen a tire replacement interval of 40,000 miles. We have done the same for all vocational vehicles which is probably overly conservative as more frequent intervals results in higher maintenance costs. For tractors and trailers, we have used a maintenance interval of 200,000 miles. The presence of tire inflation management systems, and the increased use of those systems expected due to this proposed rule, should serve to improve tire maintenance intervals.

In evaluating maintenance costs associated with the proposal relative to the less dynamic baseline, EPA has used the maintenance intervals noted above, the MOVES policy case VMT, and the MOVES population of specific MY vehicles in future calendar years to estimate the increased maintenance costs associated with the proposal, again for each subcategory. Note that, in the context of the benefit-cost analysis, EPA has estimated maintenance costs using the policy case VMT which, by definition, includes rebound VMT (see Section IX of the preamble and Chapter 8 of this draft RIA for a discussion of rebound VMT). In contrast, in the context of the payback analysis discussed below, EPA estimates maintenance costs using the reference case VMT which, by definition, excludes rebound VMT. EPA does this for reasons explained in the payback discussion presented in Chapter 0 of this draft RIA.

Table 7-35 shows the incremental increased costs associated with lower rolling resistance tires for HD pickups and vans, vocational vehicles, tractors, trailers and tractor/trailers relative to the less dynamic baseline and using Method B. Table 7-36 shows the lifetime maintenance intervals for MY2018 through MY2029.

Table 7-35 Increased Maintenance Costs at Maintenance Intervals Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (2012$/event) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR	TRAILER	TRACTOR/ TRAILER
2018	$0.00	$0.00	$0.00	$79.92	$67.16
2019	$0.00	$0.00	$0.00	$77.77	$65.36
2020	$0.00	$0.00	$0.00	$75.69	$63.60
2021	$1.72	$6.99	$33.16	$78.81	$99.38
2022	$3.45	$6.91	$32.53	$76.74	$97.02
2023	$5.17	$8.12	$31.66	$71.17	$91.46
2024	$6.90	$17.66	$33.50	$73.97	$95.66
2025	$8.62	$17.47	$32.92	$72.02	$93.43
2026	$8.62	$13.50	$30.01	$70.72	$89.44
2027	$8.62	$21.34	$32.27	$69.44	$90.62
2028	$8.62	$20.26	$31.52	$68.85	$89.37
2029 & later	$8.62	$15.99	$31.22	$68.27	$88.59

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-36 Lifetime Maintenance Intervals for the Indicated Model Years Vs. The Less Dynamic Baseline and using Method B [a, b]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILER
2018	7.19	7.89	7.74
2019	7.18	7.85	7.74
2020	7.16	7.82	7.73
2021	7.24	7.93	7.74
2022	7.23	7.90	7.74
2023	7.23	7.88	7.74
2024	7.23	7.87	7.75
2025	7.23	7.86	7.77
2026	7.25	7.87	7.80
2027	7.28	7.88	7.85
2028	7.32	7.90	7.90
2029 & later	7.37	7.93	7.97

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[b] Includes rebound vehicle miles traveled (VMT).

Table 7-37 presents the annual in-use maintenance costs associated with the preferred alternative along with net present values at 3 percent and 7 percent. This table presents costs relative to the less dynamic baseline and using the MOVES analysis for all vehicle categories (Method B). Table 7-38 presents the model year lifetime in-use maintenance costs—versus the less dynamic baseline and using Method B— discounted at 3 percent. Table 7-39 presents the model year lifetime in-use maintenance costs—versus the less dynamic baseline and using Method B—discounted at 7 percent.

Table 7-37 Annual Increased Maintenance Costs and Net Present Values Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B ($Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$5.5	$5.5
2019	$0.0	$0.0	$11.0	$11.0
2020	$0.0	$0.0	$16.5	$16.5
2021	$0.4	$1.8	$25.4	$27.6
2022	$1.3	$3.5	$33.8	$38.6
2023	$2.5	$5.6	$41.5	$49.6
2024	$4.2	$10.2	$49.3	$63.8
2025	$6.3	$14.7	$56.8	$77.8
2026	$8.4	$18.1	$63.4	$90.0
2027	$10.4	$23.6	$69.8	$103.7
2028	$12.3	$28.5	$75.5	$116.3
2029	$14.1	$32.0	$80.7	$126.8
2030	$14.1	$32.0	$80.7	$126.8
2035	$14.1	$32.0	$80.7	$126.8
2040	$14.1	$32.0	$80.7	$126.8
2050	$14.1	$32.0	$80.7	$126.8
NPV, 3%	$183.5	$417.8	$1,194.7	$1,796.0
NPV, 7%	$83.7	$191.1	$585.4	$860.2

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-38 Discounted MY Lifetime Maintenance Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (3% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$51.2	$51.2
2019	$0.0	$0.0	$49.2	$49.2
2020	$0.0	$0.0	$47.5	$47.5
2021	$3.3	$14.1	$72.6	$90.0
2022	$6.5	$13.5	$69.4	$89.4
2023	$9.4	$15.4	$64.0	$88.8
2024	$12.3	$33.3	$66.6	$112.2
2025	$15.1	$32.7	$65.1	$112.9
2026	$15.0	$25.0	$62.1	$102.1
2027	$14.7	$38.9	$62.3	$115.9
2028	$14.4	$36.2	$60.6	$111.1
2029	$14.0	$27.9	$59.1	$101.0
Sum	$104.6	$237.0	$729.5	$1,071.2

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-39 Discounted MY Lifetime Maintenance Costs of the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B (7% Discount Rate, $Millions of 2012$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$35.8	$35.8
2019	$0.0	$0.0	$33.2	$33.2
2020	$0.0	$0.0	$30.9	$30.9
2021	$2.1	$8.9	$45.5	$56.6
2022	$3.9	$8.3	$42.0	$54.2
2023	$5.5	$9.1	$37.3	$51.9
2024	$6.9	$18.9	$37.4	$63.2
2025	$8.3	$17.8	$35.2	$61.3
2026	$7.9	$13.1	$32.4	$53.4
2027	$7.4	$19.7	$31.3	$58.5
2028	$7.0	$17.7	$29.4	$54.0
2029	$6.6	$13.1	$27.6	$47.3
Sum	$55.7	$126.6	$418.2	$600.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.4 Analysis of Payback Periods

An important metric to vehicle purchasers is the payback period that can be expected on any new purchase. In other words, there is greater willingness to pay for new technology if that new technology "pays back" within an acceptable period of time. We make no effort to define the acceptable period of time here, but seek to estimate the payback period for others to make the decision themselves. We define the payback period as the point at which reduced fuel expenditures outpace increased vehicle costs. For example, a new MY2027 tractor with trailer is estimated to cost roughly $12,850 more (on average, including an "average" trailer, in 2012$, and relative to the reference case vehicle) due to the addition of new GHG reducing/fuel consumption improving technology. This new technology would result in lower fuel consumption and, therefore, reduced fuel expenditures. But how many months or years would pass before the reduced fuel expenditures would surpass the increased costs?

To estimate the costs, we have considered not only the cost of the new technology, but also the taxes paid on the incrementally higher purchase expense, the slightly higher insurance expenses on the slightly higher value vehicle, and the increased maintenance costs associated with the new technology. Taxes paid were estimated as 6 percent sales tax in all regulated sectors and a 12 percent excise tax applicable in the tractor/trailer and vocational sectors. As such, the vehicle costs presented here are slightly higher than those presented elsewhere in this draft RIA. For insurance costs, we have estimated the collision insurance to be 2 percent of the purchase price of a vehicle consistent with the approach taken in our 2017-2025 light-duty GHG/CAFE rule.[6] Therefore, increased insurance costs would equal 2 percent of the increased technology costs, and would be incurred every year going forward. But, since collision insurance is tied to vehicle value, we have also included a depreciation rate consisting of straight-line depreciation of 3 percent each year through the 25th year of ownership at which time we have flat-lined the depreciation and held vehicle value constant (see Table 7-59 in Chapter 7.3, below). For maintenance costs, we have used the same method described above (see Chapter 0 of this draft RIA) except that we have used reference case VMT for the calculation rather than policy case VMT (i.e., we exclude rebound miles here) because typical payback considerations generally do not account for possible increased miles driven. Also, here we use retail fuel prices since those are the prices paid by owners of these vehicles.

We have conducted this payback analysis for HD pickups and vans, vocational vehicles and for tractor/trailers (including the engines used in each of these subcategories). All calculations are for the average vehicle, or average tractor/trailer combination, that drives the average number of miles each year. The calculations do not represent specific vehicle classes or specific use cases so should not be seen as being applicable to any particular individual's situation. However, the payback periods do provide a general sense, on average, of what sort of payback periods are likely at a national, societal perspective.

Table 7-40 presents the discounted annual increased vehicle costs and fuel expenditure impacts associated with owning a new MY2027 HD pickup or van using both 3 percent and 7 percent discount rates. The results in this table use Method B. As shown in the table, the payback for HD pickups and vans occurs late in the 3rd year of ownership (the year in which cumulative expenditures become negative) using a 3 percent discount rate and in the early part of the 3rd year using a 7 percent discount rate.

Table 7-40 Discounted Owner Expenditures & Payback Period for MY2027 HD Pickups & Vans under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$1,587	$4	-$759	$832	$1,558	$3	-$745	$817
2	$25	$3	-$734	$126	$23	$3	-$694	$150
3	$23	$3	-$714	-$561	$21	$3	-$649	-$476
4	$22	$3	-$693	-$1,229	$19	$3	-$606	-$1,060
5	$20	$3	-$651	-$1,857	$17	$2	-$549	-$1,590
6	$19	$3	-$611	-$2,446	$15	$2	-$496	-$2,067
7	$18	$2	-$571	-$2,997	$14	$2	-$446	-$2,497
8	$16	$2	-$536	-$3,514	$12	$2	-$403	-$2,886

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

Table 7-41 and Table 7-42 show the same information for a MY2027 vocational vehicle and a tractor/trailer, respectively. As shown, payback for vocational vehicles occurs in the 5th year of ownership (using 3 percent discounting and in the 6th year using 7 percent discounting) while payback for tractor/trailers occurs early in the 2nd year of ownership.

Table 7-41 Discounted Owner Expenditures & Payback Period for MY2027Vocational Vehicles under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$3,998	$10	-$965	$3,043	$3,924	$10	-$947	$2,987
2	$63	$9	-$937	$2,178	$59	$9	-$885	$2,169
3	$59	$9	-$914	$1,331	$53	$8	-$832	$1,399
4	$55	$9	-$891	$504	$48	$8	-$780	$675
5	$51	$8	-$829	-$265	$43	$7	-$699	$27
6	$48	$7	-$771	-$981	$39	$6	-$625	-$554
7	$45	$7	-$716	-$1,645	$35	$5	-$559	-$1,073
8	$42	$6	-$667	-$2,264	$31	$5	-$501	-$1,538

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

Table 7-42 Discounted Owner Expenditures & Payback Period for MY2027Tractor/Trailers under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance[b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$15,194	$48	-$14,649	$593	$14,914	$47	-$14,379	$582
2	$238	$46	-$14,204	-$13,327	$225	$43	-$13,421	-$12,571
3	$223	$44	-$13,809	-$26,869	$203	$40	-$12,561	-$24,889
4	$209	$42	-$13,416	-$40,034	$183	$37	-$11,746	-$36,415
5	$195	$39	-$12,391	-$52,191	$164	$33	-$10,443	-$46,661
6	$182	$35	-$11,411	-$63,385	$148	$29	-$9,258	-$55,743
7	$170	$32	-$10,511	-$73,694	$133	$25	-$8,209	-$63,794
8	$158	$29	-$9,704	-$83,211	$119	$22	-$7,295	-$70,949

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

The fuel expenditure column uses retail fuel prices specific to gasoline and diesel fuel as projected in AEO2014 Early Release. This payback analysis does not include other private impacts, such as reduced refueling events, or other societal impacts, such as the potential rebound miles driven or the value of driving those rebound miles, or noise, congestion and accidents. It also does not include societal impacts such as co-pollutant environmental benefits or benefits associated with reduced GHG emissions. We use retail fuel prices and exclude these other private and social impacts because the focus is meant to be on those factors that buyers think about most while considering a new vehicle purchase and those factors that result in more or fewer dollars in their pockets.

In an effort to provide further information on payback, we have also looked at the payback periods for more specific vehicle subcategories. For example, while the tractor/trailer payback shown in Table 7-42 occurs early in the 2nd year, the payback for a Class 8 sleeper cab would occur within the first year of ownership as shown in Table 7-43.

Table 7-43 Discounted Owner Expenditures & Payback Period for MY2027 Sleeper Cab with Trailer under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$16,541	$60	-$20,087	-$3,486	$16,236	$59	-$19,717	-$3,422
2	$259	$58	-$19,477	-$22,646	$244	$55	-$18,403	-$21,526
3	$243	$56	-$18,936	-$41,285	$221	$50	-$17,224	-$38,479
4	$227	$53	-$18,396	-$59,401	$199	$47	-$16,107	-$54,341
5	$212	$49	-$17,053	-$76,193	$179	$41	-$14,373	-$68,494
6	$198	$45	-$15,768	-$91,718	$161	$36	-$12,793	-$81,090
7	$185	$41	-$14,591	-$106,083	$144	$32	-$11,395	-$92,309
8	$172	$37	-$13,538	-$119,412	$129	$28	-$10,178	-$102,330

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

Given the variety in the vocational market, the subcategory analysis becomes more interesting. For example, Table 7-44 shows the payback for an intercity bus. Table 7-45 shows the same information for a transit bus, while Table 7-46 shows this information for a school bus. These tables highlight how much the payback period can vary depending on the level of technology cost and fuel consumption improvement versus the number of miles driven. The high VMT intercity bus (~80,000 miles/year) and transit bus (~60,000 miles/year) payback in the 1st and 3rd year, respectively, despite first year costs exceeding $4,000 and $8,000, respectively. By contrast, the lower VMT school bus (~13,000 miles/year) pays back in the 11th year (or 14th year with 7 percent discounting) despite first year costs under $6,000.

Table 7-44 Discounted Owner Expenditures & Payback Period for MY2027 Intercity Bus under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$4,863	$57	-$8,388	-$3,469	$4,773	$56	-$8,234	-$3,405
2	$76	$55	-$8,203	-$11,541	$72	$52	-$7,751	-$11,032
3	$71	$53	-$8,046	-$19,462	$65	$48	-$7,318	-$18,237
4	$67	$52	-$7,881	-$27,225	$58	$45	-$6,901	-$25,034
5	$62	$50	-$7,734	-$34,846	$53	$42	-$6,518	-$31,457
6	$58	$49	-$7,593	-$42,332	$47	$39	-$6,160	-$37,530
7	$54	$47	-$7,459	-$49,689	$42	$37	-$5,826	-$43,277
8	$51	$46	-$7,357	-$56,950	$38	$34	-$5,531	-$48,735

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

Table 7-45 Discounted Owner Expenditures & Payback Period for MY2027Transit Bus under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$8,718	$45	-$4,328	$4,435	$8,558	$44	-$4,248	$4,353
2	$136	$42	-$4,098	$516	$129	$40	-$3,872	$650
3	$128	$40	-$3,892	-$3,209	$116	$36	-$3,540	-$2,738
4	$120	$37	-$3,689	-$6,741	$105	$33	-$3,230	-$5,830
5	$112	$35	-$3,503	-$10,097	$94	$29	-$2,953	-$8,659
6	$104	$33	-$3,330	-$13,290	$85	$27	-$2,702	-$11,249
7	$97	$31	-$3,170	-$16,332	$76	$24	-$2,476	-$13,625
8	$91	$29	-$3,026	-$19,238	$68	$22	-$2,275	-$15,810

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

Table 7-46 Discounted Owner Expenditures & Payback Period for MY2027School Bus under the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	$5,687	$7	-$675	$5,019	$5,582	$7	-$662	$4,926
2	$89	$7	-$660	$4,455	$84	$6	-$623	$4,393
3	$83	$6	-$647	$3,897	$76	$6	-$589	$3,886
4	$78	$6	-$634	$3,348	$68	$6	-$555	$3,405
5	$73	$6	-$622	$2,805	$62	$5	-$524	$2,948
6	$68	$6	-$611	$2,268	$55	$5	-$495	$2,512
7	$63	$6	-$600	$1,737	$50	$4	-$469	$2,098
8	$59	$6	-$592	$1,210	$44	$4	-$445	$1,701

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

We could present tables for each MOVES subcategory, but since all are calculated using the same methodology, the detailed tables seem unnecessary. Instead, we provide Table 7-47 which summarizes the payback period for each MOVES subcategory at both 3 percent and 7 percent discount rates and for each fuel type.

Table 7-47 Payback Periods Associated with the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B for MY2027 Vehicle Subcategories at 3% and 7% Discount Rates Payback occurs in Year Shown [a]

Subcategory	3% Discount Rate			7% Discount Rate		
	Gasoline	Diesel	All	Gasoline	Diesel	All
HD Pickups & Vans (MY2027)	3	2	3	3	2	3
Vocational (MY2027 for each)						
Intercity bus	N/A	1	1	N/A	1	1
Transit bus	3	3	3	3	3	3
School bus	13	11	11	18	13	14
Refuse truck	N/A	4	4	N/A	4	4
Single unit short haul	4	5	5	4	5	5
Single unit long haul	N/A	3	3	N/A	3	3
Motor home	>23	>23	>23	>23	>23	>23
All	5	5	5	5	6	6
Tractor/Trailer (MY2027 for each)						
Combination short haul	N/A	2	2	N/A	2	2
Combination long haul	N/A	1	1	N/A	1	1
All	N/A	2	2	N/A	2	2

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
N/A denotes no such vehicles in this segment.

7.2.5 Cost per Ton of CO_2 Equivalent Reduced vs. the Less Dynamic Baseline and using Method B

The agencies have calculated the cost per ton of GHG (CO_2-equivalent, or CO_2eq) reductions associated with this rulemaking using the costs presented in Chapter 7.2.1 and 7.2.2, and the GHG emissions reductions described in Chapter 5 of this draft RIA. These costs per ton-reduction values are presented in Table 7-48 through Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

Table 7-51 for HD pickups & vans, vocational vehicles, tractor/trailers and all segments, respectively. The cost per metric ton of GHG emissions reductions in 2050 represents the long-term cost per ton of the emissions reduced. The agencies have also calculated the cost per metric ton of GHG emission reductions including the savings associated with reduced fuel consumption.

The calculations presented here include all engine-related costs but do not include benefits associated with the preferred alternative such as those associated with criteria pollutant reductions or energy security benefits (discussed in Chapter 8 of this draft RIA). By including the fuel savings, the cost per ton-reduction is less than $0 since the estimated value of fuel savings outweighs the program costs.

Table 7-48 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B HD Pickups and Vans only (dollar values are 2012$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$0.3	$0.0	0	$2,600	$2,400
2024	$0.6	$0.5	2	$330	$67
2027	$0.9	$1.5	5	$160	-$110
2030	$0.9	$2.6	9	$95	-$190
2035	$0.9	$4.2	14	$65	-$240
2040	$0.9	$5.4	17	$57	-$270
2050	$1.0	$6.3	19	$54	-$270

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

Table 7-49 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B Vocational Vehicles only (dollar values are 2012$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$0.7	$0.1	0	$1,500	$1,300
2024	$1.1	$0.6	2	$460	$210
2027	$2.0	$1.5	6	$340	$81
2030	$2.0	$2.8	10	$190	-$78
2035	$2.1	$4.7	16	$130	-$160
2040	$2.2	$6.1	20	$110	-$200
2050	$2.5	$7.3	23	$110	-$210

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see

Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

Table 7-50 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B Tractor/Trailers only (dollar values are 2012$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$1.4	$1.6	7	$210	-$30
2024	$2.1	$5.8	23	$90	-$160
2027	$2.6	$12.1	46	$56	-$210
2030	$2.7	$18.6	69	$39	-$230
2035	$3.0	$28.4	97	$31	-$260
2040	$3.3	$36.3	116	$28	-$280
2050	$3.6	$44.0	141	$26	-$290

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

Table 7-51 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Preferred Alternative Vs. The Less Dynamic Baseline and using Method B All Vehicle Segments (dollar values are 2012$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$2.5	$1.7	7	$330	$96
2024	$3.8	$6.9	28	$140	-$110
2027	$5.4	$15.1	57	$94	-$170
2030	$5.5	$24.0	88	$63	-$210
2035	$6.0	$37.2	127	$47	-$250
2040	$6.4	$47.8	152	$42	-$270
2050	$7.1	$57.5	183	$39	-$270

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

For comparison, Table 7-52 through Table 7-55 show the same information as it was presented in Chapter 7 of the final RIA for the Phase 1 HD rule.[7]

Table 7-52 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule HD Pickups and Vans only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$0,8	$0.9	3	$240	-$30
2030	$0.9	$3.0	10	$90	-$200
2040	$1.0	$4.3	14	$70	-$240
2050	$1.2	$5.5	16	$80	-$270

Table 7-53 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule Vocational Vehicles only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$0.2	$1.1	4	$50	-$210
2030	$0.2	$2.4	9	$20	-$250
2040	$0.3	$3.5	12	$30	-$270
2050	$0.4	$4.7	14	$30	-$310

Table 7-54 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule Tractor/Trailers only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$1.0	$7.7	32	$30	-$210
2030	$1.1	$15.3	57	$20	-$250
2040	$1.4	$20.2	68	$20	-$280
2050	$1.8	$26.4	78	$20	-$320

Table 7-55 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule All Vehicle Segments (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$2.0	$9.6	39	$50	-$190
2030	$2.2	$20.6	76	$30	-$240
2040	$2.7	$28.0	94	$30	-$270
2050	$3.3	$36.5	108	$30	-$310

7.3 Key Parameters Used in the Estimation of Costs and Fuel Savings

This section presents some of the parameters used in generating expenditure impacts associated with the program. Table 7-56 presents estimated sales of complying vehicles by calendar year. Table 7-57 presents AEO 2014 early release reference case fuel prices. Note that AEO projects fuel prices out to 2040. Table 7-58 presents AEO 2014 final reference case fuel prices which are used in Method A for analysis of HD pickups and vans. For that analysis, the retail (post-tax) prices are increased for each year after 2040 by 0.2 percent for gasoline and 0.7 percent for diesel. For years beyond 2040, EPA has kept fuel prices at the 2040 level rather than growing those fuel prices at a rate consistent with years prior to 2040. Table 7-59 shows the depreciation rates used in the payback period analysis presented in Chapter 0. Table 7-60 through Table 7-62 show the policy and reference case VMT values used in MOVES modeling.

Table 7-56 Estimated Calendar Year Sales by Vehicle Type using Method B [a, b]

Calendar Year	HD Pickup & Vans	Vocational Vehicles	Tractors	Semi-trailers
2018	601,428	508,986	152,323	181,264
2019	592,824	508,189	155,452	184,988
2020	588,718	511,308	159,221	189,473
2021	588,166	513,187	161,198	191,826
2022	588,277	518,192	163,719	194,826
2023	588,468	522,188	166,094	197,652
2024	595,880	538,609	171,770	204,406
2025	607,607	555,144	178,532	212,453
2026	622,297	570,707	185,102	220,271
2027	629,008	583,170	190,777	227,025
2028	635,564	592,507	195,631	232,801
2029	640,235	600,238	200,434	238,516
2030	645,344	606,945	204,610	243,486
2031	650,635	613,681	208,775	248,442
2032	656,130	620,670	213,612	254,198
2033	660,463	625,768	217,695	259,057
2034	665,671	633,244	222,677	264,986
2035	673,795	643,148	228,335	271,719
2036	680,860	651,588	233,285	277,609
2037	688,683	660,629	238,296	283,572
2038	697,131	670,643	243,855	290,187
2039	702,434	676,957	247,759	294,833
2040	706,025	682,097	251,554	299,349
2041	711,730	682,945	247,952	295,063
2042	718,283	689,604	251,409	299,177
2043	724,911	696,394	254,917	303,351
2044	731,657	703,351	258,472	307,582
2045	738,470	710,389	262,079	311,874
2046	745,352	717,507	265,734	316,223
2047	752,303	724,711	269,440	320,634
2048	759,313	731,984	273,199	325,107
2049	766,385	739,323	277,009	329,641
2050	773,523	746,732	280,872	334,238

Notes:

[a] Sales are estimated using population data contained in MOVES. See Chapter 5 of this draft RIA for a description of the MOVES modeling done in support of this proposal.

[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-57 AEO 2014 Early Release Reference Case Fuel Prices (2012$/gallon)

	Pre-Tax		Post-Tax	
Calendar Year	Gasoline	Diesel	Gasoline	Diesel
2018	$2.61	$3.07	$3.02	$3.53
2019	$2.62	$3.15	$3.03	$3.61
2020	$2.67	$3.22	$3.08	$3.67
2021	$2.71	$3.29	$3.12	$3.74
2022	$2.77	$3.37	$3.17	$3.82
2023	$2.82	$3.43	$3.22	$3.87
2024	$2.86	$3.48	$3.26	$3.92
2025	$2.89	$3.54	$3.29	$3.98
2026	$2.92	$3.59	$3.32	$4.02
2027	$2.96	$3.65	$3.36	$4.08
2028	$2.98	$3.69	$3.37	$4.12
2029	$3.01	$3.74	$3.40	$4.16
2030	$3.04	$3.79	$3.43	$4.20
2031	$3.08	$3.84	$3.46	$4.25
2032	$3.12	$3.89	$3.50	$4.30
2033	$3.16	$3.95	$3.54	$4.36
2034	$3.24	$4.02	$3.61	$4.43
2035	$3.27	$4.06	$3.65	$4.47
2036	$3.32	$4.11	$3.69	$4.51
2037	$3.36	$4.15	$3.73	$4.54
2038	$3.40	$4.19	$3.77	$4.58
2039	$3.47	$4.26	$3.83	$4.65
2040	$3.54	$4.34	$3.90	$4.73
2041	$3.54	$4.34	$3.90	$4.73
2042	$3.54	$4.34	$3.90	$4.73
2043	$3.54	$4.34	$3.90	$4.73
2044	$3.54	$4.34	$3.90	$4.73
2045	$3.54	$4.34	$3.90	$4.73
2046	$3.54	$4.34	$3.90	$4.73
2047	$3.54	$4.34	$3.90	$4.73
2048	$3.54	$4.34	$3.90	$4.73
2049	$3.54	$4.34	$3.90	$4.73
2050	$3.54	$4.34	$3.90	$4.73

Table 7-58 AEO 2014 Final Reference Case Fuel Prices Used in Method A Analysis for HD Pickups and Vans (2012$/gallon)

	Pre-Tax		Post-Tax	
Calendar Year	Gasoline	Diesel	Gasoline	Diesel
2018	$2.63	$3.10	$3.02	$3.53
2019	$2.64	$3.19	$3.03	$3.61
2020	$2.69	$3.25	$3.08	$3.67
2021	$2.74	$3.32	$3.12	$3.74
2022	$2.79	$3.41	$3.17	$3.82
2023	$2.84	$3.46	$3.22	$3.87
2024	$2.88	$3.51	$3.26	$3.92
2025	$2.92	$3.58	$3.29	$3.98
2026	$2.95	$3.62	$3.32	$4.02
2027	$2.99	$3.68	$3.36	$4.08
2028	$3.00	$3.73	$3.37	$4.12
2029	$3.03	$3.77	$3.40	$4.16
2030	$3.07	$3.81	$3.43	$4.20
2031	$3.10	$3.87	$3.46	$4.25
2032	$3.14	$3.92	$3.50	$4.30
2033	$3.18	$3.98	$3.54	$4.36
2034	$3.27	$4.06	$3.62	$4.43
2035	$3.30	$4.10	$3.65	$4.47
2036	$3.34	$4.14	$3.69	$4.51
2037	$3.38	$4.18	$3.73	$4.54
2038	$3.43	$4.22	$3.77	$4.58
2039	$3.49	$4.29	$3.83	$4.65
2040	$3.56	$4.38	$3.90	$4.73
2041	$3.57	$4.41	$3.91	$4.76
2042	$3.58	$4.44	$3.92	$4.80
2043	$3.59	$4.48	$3.93	$4.83
2044	$3.59	$4.51	$3.93	$4.86
2045	$3.60	$4.54	$3.94	$4.90
2046	$3.61	$4.58	$3.95	$4.93
2047	$3.62	$4.61	$3.96	$4.97
2048	$3.63	$4.65	$3.97	$5.00
2049	$3.63	$4.68	$3.97	$5.04
2050	$3.64	$4.72	$3.98	$5.07

Table 7-59 Depreciation Schedule used in Payback Analysis for Method B [a]

Age	Depreciation
0	0%
1	3%
2	7%
3	10%
4	13%
5	17%
6	20%
7	23%
8	27%
9	30%
10	33%
11	37%
12	40%
13	43%
14	47%
15	50%
16	53%
17	57%
18	60%
19	63%
20	67%
21	70%
22	73%
23	77%
24	80%
25	83%
26	83%
27	83%
28	83%
29	83%
30	83%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-60 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Preferred Alternative relative to the Less Dynamic Baseline using Method B Gasoline & Diesel Fueled HD Pickups and Vans [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	115,829,944,373	115,829,944,373	0
2019	113,678,239,954	113,678,239,954	0
2020	112,489,612,844	112,489,612,844	0
2021	111,945,040,889	113,266,026,805	1,320,985,916
2022	111,677,755,878	112,995,512,359	1,317,756,481
2023	111,450,161,386	112,765,269,187	1,315,107,801
2024	112,709,425,730	114,039,351,705	1,329,925,975
2025	114,748,238,188	116,102,258,642	1,354,020,454
2026	117,275,813,888	118,659,694,470	1,383,880,582
2027	118,386,726,732	119,783,672,794	1,396,946,063
2028	119,534,232,399	120,944,733,432	1,410,501,033
2029	120,302,585,242	121,722,263,013	1,419,677,771

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-61 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Preferred Alternative relative to the Less Dynamic Baseline using Method B Gasoline & Diesel Fueled Vocational Vehicles [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	118,450,357,579	118,450,357,579	0
2019	116,749,449,396	116,749,449,396	0
2020	116,127,003,082	116,127,003,082	0
2021	115,248,392,233	117,357,427,520	2,109,035,287
2022	115,272,965,194	117,382,447,329	2,109,482,135
2023	115,175,262,339	117,282,914,481	2,107,652,142
2024	117,884,442,538	120,041,702,114	2,157,259,576
2025	120,740,410,310	122,949,989,775	2,209,579,465
2026	123,305,465,962	125,561,901,338	2,256,435,376
2027	125,295,415,305	127,588,325,885	2,292,910,580
2028	126,961,637,088	129,285,065,704	2,323,428,616
2029	128,161,021,270	130,506,385,592	2,345,364,323

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-62 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Preferred Alternative relative to the Less Dynamic Baseline using Method B Gasoline & Diesel Fueled Tractor/Trailer [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	205,633,186,090	206,868,892,110	1,235,706,020
2019	208,901,077,400	210,286,134,790	1,385,057,390
2020	212,879,741,190	214,425,143,290	1,545,402,100
2021	214,192,002,054	215,883,987,009	1,691,984,954
2022	216,140,641,720	217,848,264,966	1,707,623,246
2023	217,755,803,295	219,476,052,250	1,720,248,954
2024	223,503,856,041	225,269,560,066	1,765,704,025
2025	230,652,945,572	232,475,299,910	1,822,354,338
2026	237,271,789,952	239,146,338,666	1,874,548,714
2027	242,810,503,298	244,728,847,129	1,918,343,832
2028	247,759,768,627	249,716,945,459	1,957,176,832
2029	252,434,280,992	254,428,339,577	1,994,058,585

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

References

[1] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rulemaking 75 Fed. Reg. 25323 (May 7, 2010).
[2] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.
[3] All of EPA's calculations of costs and benefits (monetized) along with paybacks can be found in the docket as "GHGHD2 NPRM Package Costs.xlsb," "GHGHD2 NPRM BCA.xlsb," and "GHGHD2 NPRM Payback.xlsb."
[4] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rulemaking 75 Fed. Reg. 25323 (May 7, 2010).
[5] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.
[6] Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, Regulatory Impact Analysis, EPA-420-R-12-016, August 2012.
[7] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.

Chapter 8. Economic and Other Impacts

8.1 Framework for Benefits and Costs

This Chapter presents the costs, benefits and other economic impacts of the proposed Phase 2 standards. It is important to note that NHTSA's proposed fuel consumption standards and EPA's proposed GHG standards would both be in effect, and each would lead to average fuel efficiency increases and GHG emission reductions.

The net benefits of the proposed Phase 2 standards consist of the effects of the program on:

- the vehicle program costs (costs of complying with the vehicle CO_2 and fuel consumption standards),
- changes in fuel expenditures associated with reduced fuel use resulting from more efficient vehicles and increased fuel use associated with the "rebound" effect, both of which result from the program,
- the economic value of reductions in GHGs,
- the economic value of reductions in other non-GHG pollutants,
- costs associated with increases in noise, congestion, and accidents resulting from increased vehicle use,
- savings in drivers' time from less frequent refueling,
- benefits of increased vehicle use associated with the "rebound" effect,
- the economic value of improvements in U.S. energy security.

The benefits and costs of these rules are analyzed using 3 percent and 7 percent discount rates, consistent with current OMB guidance.[A] These rates are intended to represent consumers' preference for current over future consumption (3 percent), and the real rate of return on private investment (7 percent) which indicates the opportunity cost of capital. However, neither of these rates necessarily represents the discount rate that individual decision-makers use.

The program may also have other economic effects that are not included here. In particular, as discussed in Chapter 2 of the draft RIA, the technology cost estimates developed here take into account the costs to hold other vehicle attributes, such as size and performance, constant. With these assumptions, and because welfare losses represent monetary estimates of how much buyers would have to be compensated to be made as well off as they would have been in the absence of this regulation,[B] price increases for new vehicles measure the welfare losses to

[A] The range of Social Cost of Carbon (SCC) values uses several discount rates because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). Refer to Section F.1 for more information.

[B] This approach describes the economic concept of compensating variation, a payment of money after a change that would make a consumer as well off after the change as before it. A related concept, equivalent variation, estimates the vehicle buyers.[C] If the full technology cost gets passed along to the buyer as an increase in price, the technology cost thus measures the primary welfare loss of the standards, including impacts on buyers. Increasing fuel efficiency would have to lead to other changes in the vehicles that buyers find undesirable for there to be additional welfare losses that are not included in the technology costs.

As the 2012-2016 and 2017-2025 light-duty GHG/CAFE rules discussed, if other vehicle attributes are not held constant, then the technology cost estimates do not capture the losses to vehicle buyers associated with these changes.[1] The light-duty rules also discussed other potential issues that could affect the calculation of the welfare impacts of these types of changes, such as aspects of buyers' behavior that might affect the demand for technology investments, uncertainty in buyers' investment horizons, and the rate at which truck owners trade off higher vehicle purchase price against future fuel savings. The agencies seek comments, including supporting data and quantitative analyses, of any additional impacts of the proposed standards on vehicle attributes and performance, or other potential aspects that could positively or negatively affect the welfare implications of this proposed rulemaking.

Where possible, we identify the uncertain aspects of these economic impacts and attempt to quantify them (e.g., sensitivity ranges associated with quantified and monetized GHG impacts; range of dollar-per-ton values to monetize non-GHG health benefits; uncertainty with respect to learning and markups). For HD pickups and vans, the agencies explicitly analyzed the uncertainty surrounding its estimates of the economic impacts from requiring higher fuel efficiency in Chapter 7. The agencies have also examined the sensitivity of our estimates of savings in fuel expenditures to alternative assumptions about future fuel prices; results of this sensitivity analysis can be found in Chapter 8.12 of this draft RIA. NHTSA's draft EIS also characterizes the uncertainty in economic impacts associated with the HD national program. For other impacts, however, there is inadequate information to inform a thorough, quantitative assessment of uncertainty. EPA and NHTSA continue to work toward developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key elements of its analyses and we will continue to work to refine these uncertainty analyses in the future as time and resources permit.

This and other chapters of the draft RIA address Section 317 of the Clean Air Act on economic analysis. Chapter 8.11 addresses Section 321 of the Clean Air Act on employment analysis. The total monetized benefits and costs of the program are summarized in Section 8.10 for the preferred alternative and in Chapter 9 for all alternatives.

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the income change that would be an alternative to the change taking place. The difference between them is whether the consumer's point of reference is her welfare before the change (compensating variation) or after the change (equivalent variation). In practice, these two measures are typically very close together.

[C] Indeed, it is likely to be an overestimate of the loss to the consumer, because the buyer has choices other than buying the same vehicle with a higher price; she could choose a different vehicle, or decide not to buy a new vehicle. The buyer would choose one of those options only if the alternative involves less loss than paying the higher price. Thus, the increase in price that the buyer faces would be the upper bound of loss of consumer welfare, unless there are other changes to the vehicle due to the fuel efficiency improvements that make the vehicle less desirable to consumers.

8.2 Conceptual Framework for Evaluating Impacts

The HD Phase 2 proposed standards would implement both the 2007 Energy Independence and Security Act requirement that NHTSA establish fuel efficiency standards for medium- and heavy-duty vehicles and the Clean Air Act requirement that EPA adopt technology-based standards to control pollutant emissions from motor vehicles and engines contributing to air pollution that endangers public health and welfare. NHTSA's statutory mandate is intended to further the agency's long-standing goals of reducing U.S. consumption and imports of petroleum energy to improve the nation's energy security.

From an economics perspective, government actions to improve our nation's energy security and to protect our nation from the potential threats of climate change address "externalities," or economic consequences of decisions by individuals and businesses that extend beyond those who make these decisions. For example, users of transportation fuels increase the entire U.S. economy's risk of having to make costly adjustments due to rapid increases in oil prices, but these users generally do not consider such costs when they decide to consume more fuel.

Similarly, consuming transportation fuel also increases emissions of greenhouse gases and other more localized air pollutants that occur when fuel is refined, distributed, and consumed. Some of these emissions increase the likelihood and severity of potential climate-related economic damages, and others cause economic damages by adversely affecting human health. The need to address these external costs and other adverse effects provides a well-established economic rationale that supports the statutory direction given to government agencies to establish regulatory programs that reduce the magnitude of these adverse effects at reasonable costs.

The proposed Phase 2 standards would require manufacturers of new heavy-duty vehicles, including trailers (HDVs), to improve the fuel efficiency of the products that they produce. As HDV users purchase and operate these new vehicles, they would consume significantly less fuel, in turn reducing U.S. petroleum consumption and imports as well as emissions of GHGs and other air pollutants. Thus as a consequence of the agencies' efforts to meet NHTSA statutory obligations to improve U.S. energy security and EPA's obligation to issue standards "to regulate emissions of the deleterious pollutant… from motor vehicles" that endangers public health and welfare,[2] the proposed fuel efficiency and GHG emission standards would also reduce HDV operators' outlays for fuel purchases. These fuel savings are one measure of the proposed rule's effectiveness in promoting NHTSA's statutory goal of conserving energy, as well as EPA's obligation to assess the cost of standards under section 202 (a) (1) and (2) of the Clean Air Act. Although these savings are not the agencies' primary motivation for adopting higher fuel efficiency standards, these substantial fuel savings represent significant additional economic benefits of this proposal.

Potential savings in fuel costs would appear to offer HDV buyers strong incentives to pay higher prices for vehicles that feature technology or equipment that reduces fuel consumption. These potential savings would also appear to offer HDV manufacturers similarly strong incentives to produce more fuel-efficient vehicles. Economic theory suggests that interactions between vehicle buyers and sellers in a normally-functioning competitive market would lead

HDV manufacturers to incorporate all technologies that contribute to lower net costs into the vehicles they offer, and buyers to purchase them willingly. Nevertheless, many readily available technologies that appear to offer cost-effective increases in HDV fuel efficiency (when evaluated over their expected lifetimes using conventional discount rates) have not been widely adopted, despite their potential to repay buyers' initial investments rapidly.

This economic situation is commonly known as the "energy efficiency gap" or "energy paradox." This situation is perhaps more challenging to understand with respect to the heavy-duty sector versus the light-duty vehicle sector. Unlike light-duty vehicles – which are purchased and used mainly by individuals and households – the vast majority of HDVs are purchased and operated by profit-seeking businesses for which fuel costs represent a substantial operating expense. Nevertheless, on the basis of evidence reviewed below, the agencies believe that a significant number of fuel efficiency improving technologies would remain far less widely adopted in the absence of these proposed standards.

Economic research offers several possible explanations for why the prospect of these apparent savings might not lead HDV manufacturers and buyers to adopt technologies that would be expected to reduce HDV operating costs. Some of these explanations involve failures of the HDV market for reasons other than the externalities caused by producing and consuming fuel. These include situations where information about the performance of fuel economy technologies is incomplete, costly to obtain, or available only to one party to a transaction (or "asymmetrical"), as well as behavioral rigidities in either the HDV manufacturing or HDV-operating industries, such as standardized or inflexibly administered operating procedures, or requirements of other regulations on HDVs. Other explanations for the limited use of apparently cost-effective technologies that do not involve market failures include HDV operators' concerns about the performance, reliability, or maintenance requirements of new technology under the demands of everyday use, uncertainty about the fuel savings they will actually realize, and questions about possible effects on carrying capacity or other aspects of HDVs' utility.

In the HD Phase 1 rulemaking (which, in contrast to these proposed standards, did not apply to trailers), the agencies raised five hypotheses that might explain this energy efficiency gap or paradox:

- Imperfect information in the new vehicle market: information available to prospective buyers about the effectiveness of some fuel-saving technologies for new vehicles may be inadequate or unreliable. If reliable information on their effectiveness in reducing fuel consumption is unavailable or difficult to obtain, HDV buyers will understandably be reluctant to pay higher prices to purchase vehicles equipped with unproven technologies.

- Imperfect information in the resale market: buyers in the used vehicle market may not be willing to pay adequate premiums for more fuel efficient vehicles when they are offered for resale to ensure that buyers of new vehicles can recover the remaining value of their original investment in higher fuel efficiency. The prospect of an inadequate return on their original owners' investments in higher fuel efficiency may contribute to the short payback periods that buyers of new vehicles appear to demand.[3]

- Principal-agent problems causing split incentives: an HDV buyer may not be directly responsible for its future fuel costs, or the individual who will be responsible for fuel costs may not participate in the HDV purchase decision. In these cases, the signal to invest in higher fuel efficiency normally provided by savings in fuel costs may not be transmitted effectively to HDV buyers, and the incentives of HDV buyers and fuel buyers will diverge, or be "split." The trailers towed by heavy-duty tractors, which are typically not supplied by the tractor manufacturer or seller, present an obvious potential situation of split incentives that was not addressed in the HD Phase 1 rulemaking, but it may apply in this rulemaking. If there is inadequate pass-through of price signals from trailer users to their buyers, then low adoption of fuel-saving technologies may result.

- Uncertainty about future fuel cost savings: HDV buyers may be uncertain about future fuel prices, or about maintenance costs and reliability of some fuel efficiency technologies. Buyers may react to this uncertainty by implicitly discounting potential future savings at rates above discount rates used in this analysis. In contrast, the costs of fuel-saving or maintenance-reducing technologies are immediate and thus not subject to discounting. In this situation, potential variability about buyers' expected returns on capital investments to achieve higher fuel efficiency may shorten the payback period – the time required to repay those investments – they demand in order to make them.

- Adjustment and transactions costs: potential resistance to new technologies – stemming, for example, from drivers' reluctance or slowness to adjust to changes in the way vehicles operate – may slow or inhibit new technology adoption. If a conservative approach to new technologies leads HDV buyers to adopt them slowly, then successful new technologies would be adopted over time without market intervention, but only with potentially significant delays in achieving the fuel saving, environmental, and energy security benefits they offer. There also may be costs associated with training drivers to realize potential fuel savings enabled by new technologies, or with accelerating fleet operators' scheduled fleet turnover and replacement to hasten their acquisition of vehicles equipped with these technologies.

Some of these explanations imply failures in the private market for fuel-saving technology beyond the externalities caused by producing and consuming fuel, while others suggest that complications in valuing or adapting to technologies that reduce fuel consumption may partly explain buyers' hesitance to purchase more fuel-efficient vehicles. In either case, adopting this proposed rule would provide regulatory certainty and thus generate important economic benefits in addition to reducing externalities.

Since the HD Phase 1 rulemaking, new research has provided further insight into potential barriers to adoption of fuel-saving technologies. Several studies utilized focus groups and interviews involving small numbers of participants, who were people with time and inclination to join such studies, rather than selected at random.[4] As a result, the information from these groups is not necessarily representative of the industry as a whole. While these studies cannot provide conclusive evidence about how all HDV buyers make their decisions, they do describe issues that arise for those that participated.

One common theme that emerges from these studies is the inability of HDV buyers to obtain reliable information about the fuel savings, reliability, and maintenance costs of technologies that improve fuel efficiency. In many product markets, such as consumer electronics, credible reviews and tests of product performance are readily available to potential buyers. In the trucking industry, however, the performance of fuel-saving technology is likely to depend on many firm-specific attributes, including the intensity of HDV use, the typical distance and routing of HDV trips, driver characteristics, road conditions, regional geography and traffic patterns.

As a result, businesses that operate HDVs have strong preferences for testing fuel-saving technologies "in-house" because they are concerned that their patterns of vehicle use may lead to different results from those reported in published information. Businesses with less capability to do in-house testing often seek information from peers, yet often remain skeptical of its applicability due to differences in the nature of their operations. One source of imperfect information is the lack of availability of certain technologies from preferred suppliers. HDV buyers often prefer to have technology or equipment installed by their favored original equipment manufacturers. However, some technologies may not be available through these preferred sources, or may be available only as after-market installations from third parties (Aarnink et al. 2012, Roeth et al. 2013).

Although these studies appear to show that information in the new HDV market is often limited or viewed as unreliable, the evidence for imperfect information in the market for used HDVs is mixed. On the one hand, some studies noted that fuel-saving technology is often not valued or demanded in the used vehicle market, because of imperfect information about its benefits, or greater mistrust of its performance among buyers in the used vehicle market than among buyers of new vehicles. The lack of demand might also be due to the intended use of the used HDV, which may not require or reward the presence of certain fuel-saving technologies. In other cases, however, fuel-saving technology can lead to a premium in the used market, as for instance to meet the more stringent requirements for HDVs operating in California.

All of the recent research identifies split incentives, or principal-agent problems, as a potential barrier to technology adoption. These occur when those responsible for investment decisions are different from the main beneficiaries of the technology. For instance, businesses that own and lease trailers to HDV operators may not have an incentive to invest in trailer-specific fuel-saving technology, since they do not collect the savings from the lower fuel costs that result. Vernon and Meier (2012) estimate that 23 percent of trailers may be exposed to this kind of principal-agent problem, although they do not quantify its financial significance.[5]

Split incentives can also exist when the HDV driver is not responsible for paying fuel costs. Some technologies require additional effort, training, or changes in driving behavior to achieve their promised fuel savings; drivers who do not pay for fuel may be reluctant to undertake those changes, thus reducing the fuel-saving benefits from the perspective of the individual or company paying for the fuel. For instance, drivers might not consistently deploy boat-tails equipped on trailers to improve vehicle aerodynamics.[D] Vernon and Meier also calculate that 91 percent of HDV fuel use is subject to this form of principal-agent problem, although they do not estimate how much it might reduce fuel savings to those who are paying for the fuel.

The studies based on focus groups and interviews (Klemick et al. 2013, Aarnink et al. 2012, Roeth et al. 2013) provide mixed evidence on the severity of the split-incentive problem. Focus groups often do identify diverging incentives between drivers and the decision-makers responsible for purchasing vehicles, and economics literature recognizes that this split incentive can be a barrier to adopting new technology. Aarnink et al. (2012) and Roeth et al. (2013) cite examples of split incentives involving trailers and fuel surcharges, although the latter also cites other examples where these same issues do not lead to split incentives.

In an effort to minimize problems that can arise form split incentives, many businesses that operate HDVs also train drivers in the use of specific technologies or to modify their driving behavior in order to improve fuel efficiency, while some also offer financial incentives to their drivers to conserve fuel. All of these options can help to reduce the split incentive problem, although they may not be effective where it arises from different ownership of combination tractors and trailers.

Uncertainty about future costs for fuel and maintenance, or about the reliability of new technology, also appears to be a significant obstacle that can slow the adoption of fuel-saving technologies. These examples illustrate the problem of uncertain or unreliable information about the actual performance of fuel efficiency technology discussed above. In addition, businesses that operate HDVs may be concerned about how reliable new technologies will prove to be on the road, and whether significant additional maintenance costs or equipment malfunctions that result in costly downtime could occur. Roeth et al. (2013) and Klemick et al. (2013) both document the short payback periods that HDV buyers require on their investments -- usually about 2 years -- which may be partly attributable to these uncertainties.

These studies also provide some support for the view that adjustment and transactions costs may impede HDV buyers from investing in higher fuel efficiency. As discussed above, several studies note that HDV buyers are less likely to select new technology when it is not available from their preferred manufacturers. Some technologies are only available as after-market additions, which can add other costs to adopting them.

Some studies also cite driver acceptance of new equipment or technologies as a barrier to their adoption. HDV driver turnover is high in the U.S., and businesses that operate HDVs are concerned about retaining their best drivers. Therefore, they may avoid technologies that require significant new training or adjustments in driver behavior. For some technologies that can be used to meet the proposed standards, such as automatic tire inflation systems, training costs are likely to be minimal. Other technologies such as stop-start systems, however, may require

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[D] Some boat-tails are being developed with technology to open them automatically when the trailer reaches a suitable speed, to reduce this problem.

drivers to adjust their expectations about vehicle operation, and it is difficult for the agencies to anticipate how drivers will respond to such changes.[E]

In addition to these factors, the studies considered other possible explanations for HDV buyers' apparent reluctance or slowness to invest in fuel-saving equipment or technology. Financial constraints – access to lending sources willing to finance purchases of more expensive vehicles – do not appear to be a problem for the medium- and large-sized businesses participating in Klemick et al.'s (2013) study. However, Roeth et al. (2013) noted that access to capital can be a significant challenge to smaller or independent businesses, and that price is always a concern to buyers. In general, businesses that operate HDVs face a range of competing uses for available capital other than investing in fuel-saving technologies, and may assign higher priority to these other uses, even when investing in higher fuel efficiency HDVs appears to promise adequate financial returns.

Other potentially important barriers to the adoption of measures that improve fuel efficiency may arise from "network externalities," where the benefits to new users of a technology depend on how many others have already adopted it. One example where network externalities seem likely to arise is the market for natural gas-fueled HDVs: the limited availability of refueling stations may reduce potential buyers' willingness to purchase natural gas-fueled HDVs, while the small number of such HDVs in-use does not provide sufficient economic incentive to construct more natural gas refueling stations.

Some businesses that operate HDVs may also be concerned about the difficulty in locating repair facilities or replacement parts, such as single-wide tires, wherever their vehicles operate. When a technology has been widely adopted, then it is likely to be serviceable even in remote or rural places, but until it becomes widely available, its early adopters may face difficulties with repairs or replacements. By accelerating the widespread adoption of these technologies, the proposed standards may assist in overcoming these difficulties.

As discussed previously, the lack of availability of fuel-saving technologies from preferred manufactures can also be a significant barrier to adoption (Roeth et al. 2013). Manufacturers may be hesitant to offer technologies for which there is not strong demand, especially if the technologies require significant research and development expenses and other costs of bringing the technology to a market of uncertain demand.

Roeth et al. (2013) also noted that it can take years, and sometimes as much as a decade, for a specific technology to become available from all manufacturers. Many manufacturers prefer to observe the market and follow other manufacturers rather than be the first to market with a specific technology. The "first-mover disadvantage" has been recognized in other research where the "first-mover" pays a higher proportion of the costs of developing technology, but loses the long-term advantage when other businesses follow quickly.[6] In this way, there may

[E] The distinction between simply requiring drivers (or mechanics) to adjust their expectations and compromises in vehicle performance or utility is subtle. While the former may not impose significant compliance costs in the long run, the latter would represent additional economic costs of complying with the standard.

be barriers to innovation on the supply side that result in lower adoption rates of fuel-efficiency technology than would be optimal.

In summary, the agencies recognize that businesses that operate HDVs are under competitive pressure to reduce operating costs, which should compel HDV buyers to identify and rapidly adopt cost-effective fuel-saving technologies. Outlays for labor and fuel generally constitute the two largest shares of HDV operating costs, depending on the price of fuel, distance traveled, type of HDV, and commodity transported (if any), so businesses that operate HDVs face strong incentives to reduce these costs.[7,8]

However, the short payback periods that buyers of new HDVs appear to require suggest that some combination of uncertainty about future cost savings, transactions costs, and imperfectly functioning markets impedes this process. Markets for both new and used HDVs may face these problems, although it is difficult to assess empirically the degree to which they actually do. Even if the benefits from widespread adoption of fuel-saving technologies exceed their costs, their use may remain limited or spread slowly because their early adopters bear a disproportionate share of those costs. In this case, the proposed standards may help to overcome such barriers by ensuring that these measures would be widely adopted.

Providing information about fuel-saving technologies, offering incentives for their adoption, and sharing HDV operators' real-world experiences with their performance through voluntary programs such as EPA's SmartWay Transport Partnership should assist in the adoption of new cost-saving technologies. Nevertheless, other barriers that impede the diffusion of new technologies are likely to remain. Buyers who are willing to experiment with new technologies expect to find cost savings, but those savings may be difficult to verify or replicate. As noted previously, because benefits from employing these technologies are likely to vary with the characteristics of individual routes and traffic patterns, buyers of new HDVs may find it difficult to identify or verify the effects of fuel-saving technologies in their operations. Risk-averse buyers may also avoid new technologies out of concerns over the possibility of inadequate returns on their investments, or with other possible adverse impacts.

Some HDV manufacturers may delay in investing in the development and production of new technologies, instead waiting for other manufacturers to bear the risks of those investments first. Competitive pressures in the HDV freight transport industry can provide a strong incentive to reduce fuel consumption and improve environmental performance. However, not every HDV operator has the requisite ability or interest to access and utilize the technical information, or the resources necessary to evaluate this information within the context of his or her own operations.

As discussed previously, whether the technologies available to improve HDVs' fuel efficiency would be adopted widely in the absence of the program is challenging to assess. To the extent that these technologies would be adopted in its absence, neither their costs nor their benefits would be attributed to the program. To account for this possibility, the agencies analyzed the proposed standards and the regulatory alternatives against two reference cases, or baselines, as described in Section X.

The first case uses a baseline that projects some improvement in fuel efficiency for new trailers, but no improvement in fuel efficiency for other vehicle segments in the absence of new

Phase 2 standards. This first case is referred to as the less dynamic baseline, or Alternative 1a. The second case uses a baseline that projects some improvement in vehicle fuel efficiency for tractors, trailers, pickup trucks, and vans but not for vocational vehicles. This second case is referred to as the more dynamic baseline, or Alternative 1b.

The agencies will continue to explore reasons for the slow adoption of readily available and apparently cost-effective technologies for improving fuel efficiency. We also will review any comments we receive on our hypotheses about its causes, as well as data or other information that can inform our understanding of why this situation seems to persist.

8.3 Analysis of the Rebound Effect

The "rebound effect" has been defined a number of ways in the literature, and one common definition states that the rebound effect is the increase in demand for an energy service when the cost of the energy service is reduced due to efficiency improvements.[9,10,11] In the context of heavy-duty vehicles (HDVs), this can be interpreted as an increase in HDV fuel consumption resulting from more intensive vehicle use in response to increased vehicle fuel efficiency.[F] Although much of this vehicle use increase is likely to take the form of increases in the number of miles vehicles are driven, it can also take the form of increases in the loaded weight at which vehicles operate or changes in traffic and road conditions vehicles encounter as operators alter their routes and schedules in response to improved fuel efficiency. Because this more intensive use consumes fuel and generates emissions, it reduces the fuel savings and avoided emissions that would otherwise be expected to result from the increases in fuel efficiency this rulemaking proposes.

Unlike the light-duty vehicle (LDV) rebound effect, the HDV rebound effect has not been extensively studied. According to a 2010 HDV report published by the National Research Council of the National Academies (NRC)[12], it is "not possible to provide a confident measure of the rebound effect," yet NRC concluded that a HDV rebound effect probably exists and that, "estimates of fuel savings from regulatory standards will be somewhat misestimated if the rebound effect is not considered." Although we believe the HDV rebound effect needs to be studied in more detail, we have nevertheless attempted to capture its potential effect in our analysis of these proposed rules, rather than to await further study. We have elected to do so because the magnitude of the rebound effect is an important determinant of the actual fuel savings and emission reductions that are likely to result from adopting stricter fuel efficiency and GHG emission standards.

In our analysis and discussion below, we focus on one widely-used metric to estimate the rebound effect associated with all types of more intensive vehicle use, the increase in vehicle miles traveled (VMT) that results from improved fuel efficiency. VMT can often provide a reasonable approximation for all types of more intensive vehicle use. For simplicity, we refer to

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[F] We discuss other potential rebound effects in section 8.3.3, such as the indirect and economy-wide rebound effects. Note also that there is more than one way to measure HDV energy services and vehicle use. The agencies' analyses use VMT as a measure (as discussed below); other potential measures include ton-miles, cube-miles, and fuel consumption.

this as “the VMT rebound effect” or “VMT rebound” throughout this section, although we acknowledge that it is an approximation to the rebound effect associated with all types of more intensive vehicle use. The agencies use our VMT rebound estimates to generate VMT inputs that are then entered into the EPA MOVES national emissions inventory model and the Volpe Center’s HD CAFE model. Both of these models use these inputs along with many others to generate projected emissions and fuel consumption changes resulting from each of the regulatory alternatives analyzed.

Using VMT rebound to approximate the fuel consumption impact from all types of more intensive vehicle use may not be completely accurate. Many factors other than distance traveled – for example, a vehicle’s loaded weight – play a role in determining its fuel consumption, so it is also important to consider how changes in these factors are correlated with variation in vehicle miles traveled. Empirical estimates of the effect of weight on HDV fuel consumption vary, but universally show that loaded weight has some effect on fuel consumption that is independent of distance traveled. Therefore, the product of vehicle payload and miles traveled, which typically is expressed in units of “ton-miles” or “ton-kilometers”, has also been considered as a metric to approximate the rebound effect. Because this metric’s value depends on both payload and distance, it is important to note that changes in these two variables can have different impacts on HDV fuel consumption. This is because the fuel consumed by HDV freight transport is determined by several vehicle attributes including engine and accessory efficiencies, aerodynamic characteristics, tire rolling resistance and total vehicle mass—including payload carried, if any.

Other factors such as vehicle route and traffic patterns can also affect how each of these vehicle attributes contributes to the overall fuel consumption of a vehicle. While it seems intuitive that if all of these other conditions remain constant, a vehicle driving the same route and distance twice will consume twice as much fuel as driving that same route once. However, because of the other vehicle attributes, it is less intuitive how a change in vehicle payload would affect vehicle fuel consumption.

Because the factors influencing HDV VMT rebound are generally different from those affecting LDV VMT rebound, much of the research on the LDV sector is likely to not apply to the HDV sector. For example, the owners and operators of LDVs may respond to the costs and benefits associated with changes in their personal vehicle’s fuel efficiency very differently than a HDV fleet owner or operator would view the costs and benefits (e.g., profits, offering more competitive prices for services) associated with changes in their HDVs’ fuel efficiency. To the extent the response differs, such differences may be smaller for HD pickups and vans, which share some similarities with LDVs. As discussed in the 2010 NRC HD report, one difference from the LDV case is that when calculating the change in HDV costs that causes the rebound effect, it is more important to consider all components of HDV operating costs. The costs of labor and fuel generally constitute the two largest shares of HDV operating costs, depending on the price of petroleum, distance traveled, type of vehicle, and commodity transported (if any).[13,14] Equipment depreciation costs associated with the purchase or lease of an HDV are another significant component of total operating costs (Figure 8-1). Even when HDV purchases involve upfront, one-time payments, HDV operators must recover the depreciation in the value of their vehicles resulting from their use, so this is likely to be considered as an operating cost they will attempt to pass on to final consumers of HDV operator services.

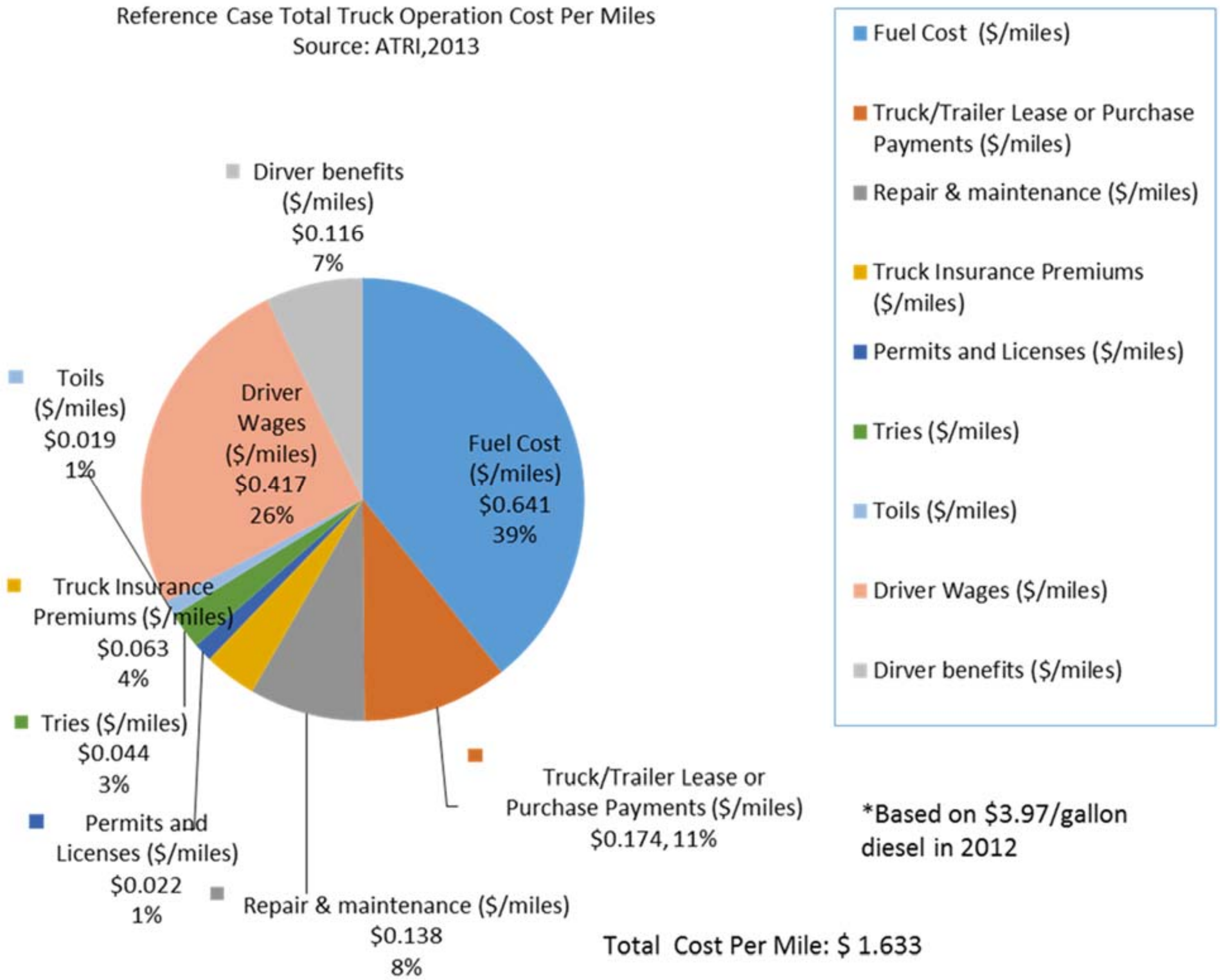

Figure 8-1 Average Truck Operation Costs

Estimates of the impact of fuel efficiency standards on HDV VMT, and hence fuel consumption, should account for changes in all of these components of HDV operating costs. The higher the net savings in total operating costs is, the higher the expected rebound effect would be. Conversely, if higher HDV purchase costs outweigh future cost savings and total operating costs increase, HDV costs could rise, which would likely result in a decrease in HDV VMT. In theory, other cost changes resulting from any requirement to achieve higher fuel efficiency, such as changes in maintenance costs or insurance rates, should also be taken into account, although information on these elements of HDV operating costs is extremely limited. In this analysis, the agencies adapt estimates of the VMT rebound effect to project the response of HDV use to the estimated changes in total operating costs that result from the proposed Phase 2 standards.

Since businesses are profit-driven, one would expect their decisions to be based on the costs and benefits of different operating decisions, both in the near-term and long-term. Specifically, one would expect commercial HDV operators to take into account changes in overall operating costs per mile when making decisions about HDV use and setting rates they charge for their services. If demand for those services is sensitive to the rates HDV operators charge, HDV VMT could change in response to the effect of higher fuel efficiency on the rates HDV operators charge. If demand for HDV services is insensitive to price (e.g., due to lack of good substitutes), however, or if changes in HDV operating costs due to the proposed standards are not passed on to final consumers of HDV operator services, the proposed standards may have a limited impact on HDV VMT.

The following sections describe the factors affecting the magnitude of HDV VMT rebound; review the econometric and other evidence related to HDV VMT rebound; and summarize how we estimated the HDV rebound effect for this proposal.

8.3.1 Factors Affecting the Magnitude of HDV VMT Rebound

The magnitude and timing of HDV VMT rebound result from the interaction of many different factors.[15] Fuel savings resulting from fuel efficiency standards may cause HDV operators and their customers to change their patterns of HDV use and fuel consumption in a variety of ways. For example, HDV operators may pass on the fuel cost savings to their customers by decreasing prices for shipping products or providing services, which in turn could stimulate more demand for those products and services (e.g., increases in freight output), and result in higher VMT. As discussed later in this section, HDV VMT rebound estimates determined via other proxy elasticities vary widely, but in no case has there been an estimate that fully offsets the fuel saved due to efficiency improvements (i.e., no rebound effect greater than or equal to 100 percent).

If fuel cost savings are passed on to the HDV operators' customers (e.g., logistics businesses, manufacturers, retailers, municipalities, utilities consumers), those customers might reorganize their logistics and distribution networks over time to take advantage of lower operating costs. For example, customers might order more frequent shipments or choose products that entail longer shipping distances, while freight carriers might divert some shipments to trucks from other shipping modes such as rail, barge or air. In addition, customers might choose to reduce their number of warehouses, reduce shipment rates or make smaller but more frequent shipments, all of which could lead to an increase in HDV VMT. Ultimately, fuel cost savings could ripple through the entire economy, thus increasing demand for goods and services shipped by trucks, and therefore increase HDV VMT due to increased gross domestic product (GDP).

Conversely, if fuel efficiency standards lead to net increases in the total costs of HDV operation because fuel cost savings do not fully offset the increase in HDV purchase prices and associated depreciation costs, then the price of HDV services could rise. This is likely to spur a decrease in HDV VMT, and perhaps a shift to alternative shipping modes. These effects could also ripple through the economy and affect GDP. Note, however, that we project fuel cost savings will offset technology costs in our analysis supporting our proposed standards.

It is also important to note that any increase in VMT on HDVs impacted by our proposed standards may be offset, to some extent, by a decrease in VMT on older HDVs. This may occur if lower fuel costs resulting from our standards cause multi-vehicle fleet operators to shift VMT to newer, more efficient HDVs in their fleet or cause operators with newer, more efficient HDVs to be more successful at winning contracts than operators with older HDVs.

Also, as discussed in Chapter 8.3.3 of this Draft RIA, the magnitude of the rebound effect is likely to be influenced by the extent of any market failures that affect the demand for more fuel efficient HDVs, as well as by HDV operators' responses to their perception of the tradeoff between higher upfront HDV purchase costs versus lower but uncertain future expenditures on fuel.

8.3.2 Econometric and Other Evidence Related to HDV VMT Rebound

As discussed above, HDV VMT rebound is defined as the change in HDV VMT that occurs in response to an increase in HDV fuel efficiency. We are not aware of any studies that directly estimate this elasticity[G] for the U.S. This section discusses econometric analyses of other related elasticities that could potentially be used as a proxy for measuring HDV VMT rebound, as well as other analyses that may provide insight into the magnitude of HDV VMT rebound.

One of the challenges to developing robust econometric analyses of HDV VMT rebound in the U.S. is data limitations. For example, the main source of time-series HDV fuel efficiency data in the U.S. is derived from aggregate fuel consumption and HDV VMT data. This may introduce interdependence or "simultaneity" between measures of HDV VMT and HDV fuel efficiency, because estimates of HDV fuel efficiency are derived partly from HDV VMT. This mutual interdependence makes it difficult to isolate the causal effect of HDV fuel efficiency on HDV VMT and to measure the response of HDV VMT to changes in HDV fuel efficiency.

Data on other important determinants of HDV VMT, such as freight shipping rates, shipment sizes, HDV payloads, and congestion levels on key HDV routes is also limited, of questionable reliability, or unavailable. Additionally, data on HDVs and their use is usually only available at an aggregate level, making it difficult to evaluate potential differences in determinants of VMT for different types of HDV operations (e.g., long-haul freight vs. regional delivery operations) or vehicle sub-classes (e.g., utility vehicles vs. school buses).

Another challenge inherent in using econometric techniques to measure the response of HDV VMT to HDV fuel efficiency is developing model specifications that incorporate the mathematical form and range of explanatory variables necessary to produce reliable estimates of HDV VMT rebound. Many different factors can influence HDV VMT, and the complex relationships among those factors should be considered when measuring the rebound effect.[16]

In practice, however, most studies have employed simplified models. Many use price variables (e.g., price per gallon of fuel, or fuel cost per mile driven) and some measure of

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[G] Elasticity is the measurement of how responsive an economic variable is to a change in another. For example: *price elasticity of demand* is a measure used in economics to show the responsiveness, or elasticity, of the quantity demanded of a good or service to a change in its price. More precisely, it gives the percentage change in quantity demanded in response to a one percent change in price.

aggregate economic activity, such as GDP. However, some of these studies exclude potentially important variables such as the amount of road capacity (which affects travel speeds and may be related to other important characteristics of highway infrastructure), or the price or availability of competing forms of freight transport such as rail or barge (i.e., characteristics of the overall freight transport network).

8.3.2.1 Fuel Price and Fuel Cost Elasticities

This sub-section reviews econometric analyses of the change in HDV use (measured in VMT, ton-mile, or fuel consumption) in response to changes in fuel price ($/gallon) or fuel cost ($/mile or $/ton-mile). The studies presented below attempt to estimate these elasticities in the HDV sector using varying approaches and data sources.

Gately (1990) employed an econometric analysis of U.S. data for the years 1966 – 1988 to examine the relationship between HDV VMT and average fuel cost per mile, real Gross National Product (GNP), and variables capturing the effects of fuel shortages in 1974 and 1979.[17] The study found no statistically significant relationship between HDV VMT and fuel cost per mile. Gately's estimates of the elasticity of HDV VMT with respect to fuel cost per mile were -0.035 with and -0.029 without the fuel shortage variables, but both estimates had large standard errors. However, Gately's study was beset by numerous statistical problems, which raise serious questions about the reliability of its results.[H]

More recently, Matos and Silva (2011) analyzed road freight transportation sector data for the years 1987 – 2006 in Portugal to identify the determinants of demand for HDV freight transportation.[18] Using a reduced-form equation relating HDV use (measured in ton-km) to economic activity (GDP) and the energy cost of HDV use (measured in fuel cost per ton-km carried), these authors estimated the elasticity of HDV ton-km with respect to energy costs to be -0.241. An important strength of Matos and Silva's study is that it also estimated this same elasticity using a procedure that accounted for the effect of potential mutual causality between HDV ton-km and energy costs, and arrived at an identical value.

Differences between HDV use and the level of highway service in Portugal and in the U.S. might limit the applicability of Matos and Silva's result to the U.S. The volume and mix of commodities could differ between the two nations, as could the levels of congestion on their respective highway networks, transport distances, the extent of intermodal competition, and the characteristics of HDVs themselves. HDVs also operate over a more limited highway network in Portugal than in the United States. Unfortunately, it is difficult to anticipate how these differences might cause Matos and Silva's elasticity estimates to differ from what we might find in the U.S. Finally, their analysis focused on HDV freight transport and did not consider non-

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[H] The most important of these problems – similar historical time trends in the model's dependent variable and the measures used to explain its historical variation – can lead to "spurious regressions," or the appearance of behavioral relationships that are simply artifacts of the similarity (or correlation) in historical trends among the model's variables.

freight uses of HDVs, which somewhat limits its usefulness in the analysis of this proposed rulemaking.

De Borger and Mulalic (2012) examined the determinants of fuel use in the Denmark HDV freight transport sector for the years 1980 – 2007. The authors developed a system of equations that capture linkages among the demand for HDV freight transport, HDV fleet characteristics, and HDV fuel consumption.[19] As De Borger and Mulalic state, “we precisely define and estimate a rebound effect of improvements in fuel efficiency in the trucking industry: behavioral adjustments in the industry imply that an exogenous improvement in fuel efficiency reduces fuel use less than proportionately. Our best estimate of this effect is approximately 10 percent in the short run and 17 percent in the long run, so that a 1 percent improvement in fuel efficiency reduces fuel use by 0.90 percent (short-run) to 0.83 percent (long-run).”

While De Borger and Mulalic capture a number of important responses that contribute to the rebound effect, some caution is appropriate when using their results to estimate the VMT rebound effect for this proposal. Like the Matos and Silva study, this study examined HDV activity in another country, Denmark, which has a less-developed highway system, lower levels of freight railroad service than the U.S., and is also likely to have a different composition of freight shipping activity. Although the effect of some of these differences is unclear, greater competition from rail shipping in the U.S. and the resulting potential for lower trucking costs to divert some rail freight to truck could cause the VMT rebound effect to be larger in the U.S. than De Borger and Mulalic’s estimate for Denmark.

On the other hand, if freight networks are denser and commodity types are more homogenous in Denmark than the U.S., then shippers may have wider freight trucking options. If this is the case, shippers in Denmark might be more sensitive to changes in freight costs, which could cause the rebound effect in Denmark to be larger than the U.S. Like the Matos and Silva study, this analysis also focuses on freight trucking and does not consider non-freight HDVs (e.g. vocational vehicles). We have been unable to identify adequate data to employ De Borger and Mulalic’s model for the U.S. (mainly because time-series data on freight carriage by trucks, driver wages, and vehicle prices in the U.S. are limited).

The Volpe National Transportation Systems Center previously has developed a series of travel forecasting models for the Federal Highway Administration (FHWA).[20] Work conducted by the Volpe Center during 2009-2011 to develop the original version of FHWA’s forecasting model was presented in the Regulatory Impact Analysis for the HD GHG Phase 1 rule (see Table 9-2 in that document: “Range of Rebound Effect Estimates from NHTSA Econometric Analysis”).[21] In the analysis for the Phase 1 rule, Volpe estimated both state-level and national aggregate models to forecast HDV single unit and combination truck VMT that included fuel cost per mile as an explanatory variable. This analysis used data from 1970 – 2008 for its national aggregate model, and data for the 50 individual states from 1994 – 2008 for its state-level model.[I, J]

Volpe analysts tested a large number of different specifications for its national and state level models that incorporated the effects of factors such as aggregate economic activity and its composition, the volume of U.S. exports and imports, and factors affecting the cost of producing trucking services (e.g., driver wage rates, truck purchase prices, and fuel costs), and the extent and capacity of the U.S. and states' highway networks. Table 8-1 summarizes Volpe's Phase 1 estimates of the elasticity of truck VMT with respect to fuel cost per mile.[K] As it indicates, these estimates vary widely, and the estimates based on state-level and national data differ substantially.

Table 8-1 Summary of Volpe Center Estimates of Elasticity of Truck VMT with Respect to Fuel Cost per Mile

Truck Type	National Data		State Data	
	Short Run	Long Run	Short Run	Long Run
Single Unit	13-22%	28-45%	3-8%	12-21%
Combination	N/A	12-14%	N/A	4-5%

Volpe staff conducted additional analysis of the models that yielded the estimates of the elasticity of truck VMT with respect to fuel cost per mile reported in Table 8-1, using updated information on fuel costs and other variables appearing in these models, together with revised historical data on truck VMT provided by DOT's Federal Highway Administration. The newly-available data, statistical procedures employed in conducting this additional analysis, and its results are summarized in materials that can be found in the docket for this rulemaking. This new Volpe analysis was not available at the time the agencies selected the values of the rebound effect for this proposal, but the agencies will consider this work and any other new work that becomes available in the final rule.

Finally, EPA has contracted with Energy and Environmental Research Associates (EERA), LLC to analyze the HDV rebound effect for regulatory assessment purposes. Excerpts

[I] Combination trucks are defined as "all [Class 7/8] trucks designed to be used in combination with one or more trailers with a gross vehicle weight rating over 26,000 lbs." (AFDC, 2014; ORNL, 2013c). Single-unit trucks are defined as "single frame trucks that have 2–axles and at least 6 tires or a gross vehicle weight rating exceeding 10,000 lbs." (FHWA, 2013).

[J] The national-level and functional class VMT forecasting models utilize aggregate time-series data for the nation as a whole, so that only a single measure of each variable is available during each time period (i.e., year). In contrast, the state-level VMT models have an additional data dimension, since both their dependent variable (VMT) and most explanatory variables have 51 separate observations available for each time period (one for each of the 50 states as well as Washington, DC). In this context, the states represent a "cross-section," and a continuous annual sequence of these cross-sections is available.

[K] One drawback of the fuel cost measure employed in Volpe's models is that it is based on estimates of fuel economy derived from truck VMT and fuel consumption, which introduces the potential for mutual causality (or "simultaneity") between VMT and the fuel cost measure and makes the effect of the latter difficult to isolate. This may cause their estimates of the sensitivity of truck VMT to fuel costs to be inaccurate, although the direction of any resulting bias is difficult to anticipate.

of EERA's initial report to EPA are included in the docket and contain detailed qualitative discussions of the rebound effect as well as data sources that could be used in quantitative analysis.[22] EERA also conducted follow-on quantitative analyses focused on estimating the impact of fuel prices on VMT and fuel consumption. We have included a working paper in the docket on this work.[23] Note that EERA's working paper was not available at the time the agencies conducted the analysis of the rebound effect for this proposal, but the agencies will consider this work and any other work in the final rule.

There are reasons to be cautious about interpreting the elasticities from the studies reviewed in this section as a measure of VMT rebound resulting from our proposed standards. For example, vehicle capacity and loaded weight can vary dynamically in the HDV sector – possibly in response to changes in fuel price and fuel efficiency – and data on these measures are limited. This makes it difficult to confidently infer a direct relationship between trucking output (e.g., ton-miles carried) and VMT assuming a constant average payload.

In addition, fuel cost per mile – calculated by multiplying fuel price per gallon by fuel efficiency in gallons per mile – and fuel price may be imprecise proxies for an improvement in fuel efficiency, because the response of VMT to these variables may differ. For example, if truck operators are more attentive to variation in fuel prices than to changes in fuel efficiency, then fuel price or fuel cost elasticities may overstate the true magnitude of the rebound effect.

Similarly, there is some evidence in the literature that demand for crude petroleum and refined fuels is more responsive to increases than to decreases in their prices, although this research is not specific to the HDV sector.[24] Since improved fuel efficiency typically causes fuel costs for HDVs to fall (and assuming fuel costs are not fully offset by increases in vehicle purchase prices), fuel price or cost elasticities derived from historical periods when fuel prices were increasing or fuel efficiency was declining may also overstate the magnitude of the rebound effect. An additional unknown is that HDV operators may factor fuel prices and fuel costs into their decision-making about rates to charge for their service differently from the way they incorporate initial vehicle purchase costs.

Despite these limitations, elasticities with respect to fuel price and fuel cost can provide some insight into the magnitude of the HDV VMT rebound effect.

8.3.2.2 Freight Price Elasticities

Freight price elasticities measure the percent change in demand for freight in response to a percent change in freight prices, controlling for other variables that may influence freight demand such as GDP, the extent that goods are traded internationally, and road supply and capacity. This type of elasticity is only applicable to the HDV subcategory of freight trucks (i.e., combination tractors and vocational vehicles that transport freight). One desirable attribute of such measures for purposes of this analysis is that they show the response of freight trucking activity to changes to trucking rates, including changes that result from fuel cost savings as well as increases in HDV technology costs.[L]

Freight price elasticities, however, are imperfect proxies for the rebound effect in freight trucks for a number of reasons.[25] For example, in order to apply these elasticities we must assume that our proposed rule's impact on fuel and vehicle costs is fully reflected in freight rates. This may not be the case if truck operators adjust their profit margins or other operational practices (e.g., loading practices, truck driver's wages) instead of freight rates. It is not well understood how trucking firms respond to different types of cost changes (e.g., changes to fuel costs versus labor costs).

Freight price elasticity estimates in the literature typically measure freight activity in tons or ton-miles, rather than VMT. As discussed in the previous section, average truck capacity and payload in the HDV sector varies dynamically – possibly in response to changes in fuel price and fuel efficiency – and data on these measures are limited. This makes it difficult to confidently infer a direct relationship between ton-miles and VMT by assuming a constant average payload. Inferring a direct relationship between tons and VMT is even less straightforward. Additionally, there are significant limitations on national freight rate and freight truck ton-mile data in the U.S., making it difficult to confidently measure the impact of a change in freight rates on ton-miles.[26]

[L] Note however that a percent change in freight activity in response to a percent change in freight rates should theoretically be larger than a percent change in freight activity in response to a percent change in fuel efficiency because fuel efficiency only impacts a portion of freight operating costs (e.g., fuel and vehicle costs, but not likely driver wages or highway tolls).

Table 8-2 An Illustration of the Impact of Various Factors on the Elasticity of Demand for HDV Freight Services With Respect to the Price of Those Services

FACTOR OF VARIABILITY (1)	SOURCE(2)	LEAST ELASTIC (3)	FACTORS OF VARIABILITY FOR LEAST ELASTIC VALUE (4)	MOST ELASTIC (5)	FACTORS OF VARIABILITY FOR MOST ELASTIC VALUE (6)	REGION (7)	DEMAND MEASURE (8)	COMMODITY (9)
Commodity shipped	Abdelwahab (1998)	-0.75	Construction	-1.40	Textile products	US A	Mode choice	Varies
	Friedlaender & Spady (1980)	-1.00	Food Products	-3.55	Electrical machinery	USA	Ton-miles	Varies
	Oum et al (1990)	-0.41	Metallic products	-1.07	Fuel oil	Canada	Ton-miles	Varies
	Winston (1981)	-0.14	Lumber, wood and Furniture	-2.96	Transport Equipment	USA	Tons	Varies
	Friedlaender & Spady (1980)	-0.15	Wood/wood products	-5.06	Electrical machinery	Southern USA	Ton-miles	Varies
	Friedlaender and Spady (1981)	-0.59	Petroleum products	-1.72	Wood	USA	tonne-km	Various
	Campisi and Gastaldi (1996)	-0.27	Petroleum products	-1.37	Minerals	Italy	tonnes	Varies
	Li et al. (2011)	-1.09	Other	-1.30	Nature resource	USA, Italy & India	tonne-km	Varies
	Bonilla (2008)	-0.43	Oil and Coal	-1.75	Building materials	Denmark	tonne-km	Varies
Distance shipped	Beuthe et al. (2001)	-1.06	<300 km	-1.31	>300 km	Belgium	tonne-km	Aggregate
	Winston (1981)	-0.34	<900 miles (average)	-1.56	>900 miles (average)	USA	tons	Varies
	Christidis and Leduc (2009)	-0.21	< 800 km	-1.15	> 1500 km	EU	Tons	All
Competing mode	Rich et al (2011)	-0.08	All O-D pairs	-0.11	O-D Pairs w/alternatives	Scandinavia	tonne-km	Agricultural products
Demand Measure	Beuthe et al. (2001)	-0.58	Tonnes	-1.06	tonne-km	Belgium	--	Aggregate
	Li et al. (2011)	-1.02	Tonnes	-1.30	tonne-km	USA, Italy & India	--	Natural Resources
Region	Abdelwahab (1998)	-0.80	USA	-2.18	Southwestern USA	Various U.S.	Mode Choice	Metal products
	Friedlaender & Spady (1980)	-1.66	Mountain-Pacific USA	-5.06	Southern USA	Various U.S.	Ton-miles	Electrical Machinery
	Li et al. (2011)	-0.86	Canada	-1.96	Australia	Various	tonne-km	Natural Resources
Model Form	Oum et al. (1992)	-0.69	Translog	1.34	Log-linear	Various	All	Aggregate

Source: J.J. Winebrake et al./Energy Policy 48 (2012) 252-259

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Finally, freight price elasticity estimates in the literature vary significantly based on commodity type, length of haul, region, availability of alternative modes (discussed further in Section 8.3.2.3 below), and functional form of the model (i.e., log-linear, linear, translog) making it difficult to confidently apply any single estimate reported in the literature to nationwide freight activity (Table 8-2). For example, elasticity estimates for longer trips tend to be larger in magnitude than those for shorter trips, while demand to ship bulk commodities tends to be less elastic than for non-bulk commodities.

Although these factors explain some of the differences among reported estimates, much of the observed variation cannot be explained quantitatively. For example, one study that controlled for mode, commodity class, demand elasticity measure (i.e., tons or ton-miles), model estimation form, country, and temporal nature of data only accounted for about half of the observed variation.[27]

8.3.2.3 Mode Shift Case Study

Although the total demand for freight transport is generally determined by economic activity, there is often the choice of shipping freight on modes other than HDVs. This is because the United States has extensive rail, waterway, pipeline, and air transport networks in addition to an extensive highway network; these networks often closely parallel each other and are often viable choices for freight transport for many long-distance shipping routes within the continental U.S. If rates for one mode decline, demand for that mode is likely to increase, and some of this new demand could represent shifts from other modes.[M] The "cross-price elasticity of demand," which measures the percentage change in demand for shipping by another mode (*e.g.*, rail) given a percentage change in the price of HDV freight transport services, provides a measure of the importance of such mode shifting. Aggregate estimates of cross-price elasticities vary widely[28], and there is no general consensus on the most appropriate value to use for analytical purposes.

When considering intermodal shift, one of the most relevant kinds of shipments are those that are competitive between rail and HDV modes. These trips generally include long-haul shipments greater than 500 miles, which weigh between 50,000 and 80,000 pounds (the legal road limit in many states). Special kinds of cargo like coal and short-haul deliveries are of less interest because they are generally not economically transferable between HDV and rail modes, so they would not be expected to shift modes except under an extreme price change. However, to the best of our knowledge, the total amount of freight that could potentially be subject to mode shifting has not been studied extensively.

In order to explore the potential for HDV fuel efficiency standards to produce economic conditions that favor a mode shift from rail to HDVs, EPA commissioned GIFT Solutions, LLC to perform case studies on the HD GHG Phase 1 rule using a number of data sources, including the Commodity Flow Survey, interviews with trucking firms, and the Geospatial Intermodal

[M] Rail lines in parts of the U.S. are thought to be currently oversubscribed. If that is the case, and new freight demand is already being satisfied by trucks, then this would limit the potential for intermodal freight shifts between trucks and rail as the result of this proposed rule.

Freight Transportation (GIFT) model developed by Winebrake and Corbett, which includes information on infrastructure and other route characteristics in the U.S.[29,30]

A central assumption in the case studies was that economic conditions would favor a shift from rail to HDVs if either the price per ton-mile to ship a commodity by HDV, or the price to ship a given quantity of a commodity by HDV, became lower relative to rail transport options post-regulation. The results of the case studies indicate that the HD Phase 1 rule would not seem to create obvious economic conditions that lead to a mode shift from rail to truck, but there are a number of limitations and caveats to this analysis, which are discussed in the final report to EPA by GIFT.[31,32] For example, even if trucking did not become less expensive than rail post-regulation, a relative decrease in the truck versus rail rates might be enough to produce a shift, given that other factors could influence shippers' decisions on modal choice. The study did not, however, consider these other factors such as time-of-delivery and modal capacity. As another example, the analysis assumes all fuel cost savings and incremental vehicle costs from the HD Phase 1 rule would be passed on to shippers via changes in freight rates, even though the analysis found some evidence that this might not occur (in two cases, the charges for shipping a truckload over a given route and distance were the same despite differences in payloads that should have been reflected in their fuel costs). Given these limitations, more work is needed in this area to explore the potential for mode shift in response to HD fuel efficiency standards.

8.3.2.4 Case Study Using Freight Price Elasticities

Cambridge Systematics, Inc. (CSI) employed a case study approach using freight price elasticity estimates in the literature to show several examples of the magnitude of the HDV rebound effect.[33] In their unpublished paper commissioned by the National Research Council of the National Academies in support of its 2010 HDV report, CSI estimated the effect on HDV VMT from a net decrease in operating costs associated with fuel efficiency improvements, using two different technology cost and fuel savings scenarios for Class 8 combination tractors. Scenario 1 increased average fuel efficiency of the tractor from 5.59 miles per gallon to 6.8 miles per gallon, with an additional cost of $22,930 for purchasing the improved tractor. Scenario 2 increased the average fuel efficiency to 9.1 miles per gallon, at an incremental cost of $71,630 per tractor. Both of these scenarios were based on the technologies and targets from a report authored by the Northeast States Center for a Clean Air Future (NESCCAF) and International Council on Clean Transportation (ICCT).[34]

The CSI estimates were based on a range of direct (or "own-price") freight elasticities (-0.5 to -1.5)[35] and cross-price freight elasticities (0.35 to 0.59)[36] obtained from the literature.[37] In their calculations, CSI assumed 142,706 million miles of tractor VMT and 1,852 billion ton-miles were affected. The tractor VMT was based on the Bureau of Transportation Statistics' (BTS) estimate of highway miles for combination tractors in 2006, and the rail ton-miles were based on the BTS estimate of total railroad miles during 2006. This assumption is likely to overstate the rebound effect, since not all freight shipments occur on routes where tractors and rail service shipments compete directly. Nevertheless, this assumption appears to be reasonable in the absence of more detailed information on the percentage of total miles and ton-miles that are subject to potential mode shifting.

For CSI's calculations, all costs except fuel costs and vehicle costs were taken from a 2008 ATRI study.[38] It is not clear from the report how the new vehicle costs were incorporated into CSI's calculations of per-mile tractor operating costs. For example, neither the ATRI report nor the CSI report discusses assumptions about depreciation, useful lifetimes of tractors, and the opportunity cost of capital.

Based on these two scenarios, CSI estimated the change in tractor VMT in response to a net decrease in operating costs (i.e., accounting for fuel cost and changes in tractor purchase costs) associated with fuel efficiency improvement of 11-31 percent for Scenario 1 and 5-16 percent for Scenario 2, without accounting for any fuel savings from reduced rail service. When the fuel savings from reduced rail usage were included in the calculations, they estimated the change in tractor VMT in response to a net decrease in operating costs associated with fuel efficiency improvement would be 9-30 percent for Scenario 1, and 3-15 percent for Scenario 2.

Note that these estimates reflect changes to tractor VMT with respect to total operating costs, so they should theoretically be larger than a percent change in tractor VMT with respect to a percent change in fuel efficiency because fuel efficiency only impacts a portion of truck operating costs (e.g., fuel and vehicle costs, but not likely driver wages or highway tolls).

CSI included caveats associated with these calculations. For example, their report states that freight price elasticity estimates derived from the literature are "heavily reliant on factors including the type of demand measures analyzed (vehicle-miles of travel, ton-miles, or tons), geography, trip lengths, markets served, and commodities transported." These factors can increase variability in the results. Also, estimates in CSI's study have the limitation of using freight price elasticities to estimate the HDV rebound effect discussed previously in Section IV.D.2.b.

8.3.2.5 Simulation Model Study Using Freight Price Elasticities

Guerrero (2014) constructs a freight simulation model of the California trucking sector to measure the impact of fuel saving investments and fleet management on GHG emissions.[39] Rather than estimating these impacts using econometric analysis of raw data, the study uses values from the existing literature. Guerrero determines that "…improving the performance of trucking also increases the number of trips demanded because the market price also decreases. This 'rebound' effect offsets around 40-50 percent of these vehicle efficiency emission reductions, with 9-14 percent of the effect coming from increased pavement deterioration and 31-36 percent coming from increased fuel combustion." Note that to the extent that trip lengths also vary in response to improvements in HDV fuel efficiency, changes in the number of HDV trips may not exactly reflect changes in the total number of miles the vehicles are operated.

However, these findings are based on freight price elasticities, which – as we discuss in Section IV.D.2.b and in the context of the CSI study above – have significant limitations. The study also simulates only one state's freight network (California), which may not be a good representation of national activity.

8.3.3 **How the Agencies Estimated the HDV Rebound Effect for this Proposal**

8.3.3.1 Values Used in the Phase 1 Analysis

At the time the agencies conducted their analysis of the Phase 1 fuel efficiency and GHG emissions standards, the only evidence on the HDV rebound effect were the previously described studies from CSI and the Volpe Center.[N] On the basis of this evidence, the agencies chose rebound effects of 15 percent for vocational vehicles and 5 percent for combination tractors, both of which were toward the lower end of the range of values from these studies. The agencies found no evidence on the rebound effect for HD pickup trucks and vans, but concluded it would be inappropriate to use the values selected for vocational vehicles or combination tractors for those vehicles. Because the usage patterns of HD pickup trucks and vans can more closely resemble those of large light-duty vehicles, the agencies used the 10 percent rebound effect we had employed in our most recent light-duty rulemaking to analyze the Phase 1 standards for 2b/3 vehicles.

8.3.3.2 How the Agencies Analyzed VMT Rebound in this Proposal

After considering the new evidence that has become available since the HD Phase 1 final rule, the agencies elected to continue using the rebound effect estimates we used previously in the HD Phase 1 rule in our analysis of Phase 2 proposed standards. In arriving at this decision, the agencies considered the shortcomings and limitations of the newly-available studies described previously, particularly the limited applicability of the two published studies using data from European nations to the U.S. context. After weighing these attributes of the more recent studies, the agencies concluded that we had insufficient evidence to justify revising the rebound effect values that were used in the Phase 1 analysis.

In our assessment, we do not differentiate between short-run and long-run rebound effects, although these effects may differ. The vocational and combination truck estimates are based on the Volpe Center analysis presented in the HD Phase 1 rule and the case study from CSI. As with the HD Phase 1 rule, we did not find any literature specifically examining the HD pickup and truck sector. Since these vehicles are used for very different purposes than combination tractors and vocational vehicles, and they are more similar in use to large light-duty vehicles, we have chosen the light-duty rebound effect of 10 percent used in the final rule establishing fuel economy and GHG standards for MYs 2017-2025 light-duty vehicles in our analysis of HD pickup trucks and vans.

While for this proposal, the agencies have selected to use these rebound effect values, we acknowledge the literature shows a wide range of rebound effect estimates. Therefore, we will review and consider revising these estimates in the final rule, taking into consideration all available data and analysis, including submissions from public commenters and new research on the rebound effect.

[N] The Gately study was also available, however, the agencies were not aware of the work at the time.

It should be noted that the rebound estimates we have selected for our analysis represent the VMT impact from our proposed standards with respect to changes in the fuel cost per mile driven. As described previously, the HDV rebound effect should ideally be a measure of the change in fuel consumed with respect to the change in *overall* operating costs due to a change in HDV fuel efficiency. Such a measure would incorporate all impacts from our proposal, including those from incremental increases in vehicle prices that reflect costs for improving their fuel efficiency. Therefore, VMT rebound estimates with respect to fuel costs per mile must be "scaled" to apply to total operating costs, by dividing them by the fraction of total operating costs accounted for by fuel.

The agencies scaled the VMT rebound calculations to total operating costs using the most recent information from the American Transportation Research Institute (ATRI).[40] ATRI estimates that the average motor carrier cost per mile is $1.633 for 2012. Other elements of the total costs are listed below in Table 8-3.

Table 8-3 Elements of the Operating Costs per Mile

OPERATING COST PER MILE	ATRI
Fuel Cost	$0.641
New Vehicle Cost	$0.174
Maintenance & Repair Cost	$0.138
All Other (labor, insurance, etc.)	$0.680
Total Motor Carrier Costs	$1.633

The agencies made simplifying assumptions in the VMT rebound analysis for this proposal, similar to the approach taken during the development of the HD GHG Phase 1 final rule. However, for the HD Phase 2 final rulemaking, we plan to use a more comprehensive approach. Due to timing constraints during the development of this proposal, the agencies did not have the technology package costs for each of the alternatives prior to the need to conduct the inventory analysis, except for the pickup truck and van category in analysis Method A. Therefore, the same "overall" VMT rebound values were used for Alternatives 2 through 5 (as discussed in Chapter 8.3.3 of this Draft RIA and analyzed in Chapter 6 of the Draft RIA), despite the fact that each alternative results in a different change in incremental technology and fuel costs. For the final rulemaking, we plan to determine VMT rebound separately for each HDV category and for each alternative. Tables 64 through 66 in Chapter 7 of the Draft RIA present VMT rebound for each HDV sector that we estimated for the preferred alternative. These VMT impacts are reflected in the estimates of total fuel savings and reductions in emissions of GHG and other air pollutants presented in Section VI and VII of this preamble for all categories.

For the purposes of this proposal, we made several additional simplifying assumptions when applying the overall rebound effect to each class of truck. For example, we assumed that per mile vehicle costs were based on the new vehicle cost (*e.g.*, $125,000 for the reference case Class 8 combination tractor, $40,000 for the reference case HD pickups, and $70,000 for the vocational vehicles)[41] divided by the total lifetime number of expected vehicle miles (*e.g.*, 1.53 million miles for a Class 8 combination tractor, 265,869 miles for 2b/3 trucks, and 306,457 miles for vocational vehicles).[42] We recognize that this calculation implicitly assumes that truck depreciation is strictly a function of usage, and that it does not take into account the opportunity cost of alternative uses of capital. As a result, the new vehicle cost per mile assumptions used in these calculations represent a smaller percentage of total operating costs compared to the ATRI and CSI examples.

The proposal assumes an "average" incremental technology cost for the alternatives, as shown in Table 8-4. The technology cost of the combination tractor category is based on the HD GHG Phase 1 technology package cost, plus $2,368 for the trailer technology cost.[43] The technology cost for HD pickup and vans is also based on the HD GHG Phase 1 technology package cost.[44] The agencies developed a unique vocational vehicle technology cost estimate because the HD GHG Phase 1 only represents the impact of tire and engine technologies.

Table 8-4 Technology Costs Used to Determine the Rebound Effect of Each Alternative

VEHICLE CATEGORY	TECHNOLOGY COST
Combination Tractors	$8,372
HD Pickup & Vans	$985
Vocational Vehicles	$1,000

The fuel costs per mile in the analysis were calculated using EIA's Annual Energy Outlook 2014's projections for diesel fuel price.[45] The average fuel economy for each category was determined using MOVES2014. The combination tractor-trailer fuel economy used was 6.03 mpg, the vocational vehicle category was 9.84 mpg, and the HD pickup category was 13 mpg. The technology effectiveness of the alternatives in the proposal was assumed to be 20 percent for combination tractors and 15 percent for HD pickups and vocational vehicles.

The operating costs calculated based on all of these inputs are shown below in Table 8-5.

Table 8-5 Operating Costs for the Reference and Alternatives

OPERATING COST PER MILE	REFERENCE CASE	ALTERNATIVES
Fuel Cost	$0.620	$0.517
New Vehicle Cost	$0.082	$0.087
Maintenance & Repair Cost	$0.138	$0.138
All Other (labor, insurance, etc.)	$0.680	$0.680
Total Motor Carrier Costs	$1.520	$1.422

Other simplifying assumptions include the use of an average cost rather than a marginal cost. Some trucking firms may use a marginal cost to determine whether to increase their fuel usage, however we do not have any data on when firms might use a marginal cost calculation rather than an average cost calculation. Although using a marginal cost might be more appropriate for calculating the rebound effect, we do not have a methodology for calculating the marginal cost.[46]

In the costs and benefits summarized in preamble Section IX.K, we have not explicitly taken into account any potential fuel savings or GHG emission reductions from the rail, air or water-borne shipping sectors due to mode shifting because estimates of this effect seem too speculative at this time. Likewise we have not taken into account any fuel savings or GHG emissions reductions from the potential shift in VMT from older HDVs to newer, more efficient HDVs. As discussed in the preamble at Section IX.E, we have found limited evidence of the impact of HDV fuel efficiency standards on mode shifting and no evidence on shifting activity away from older HDVs to newer HDVs.

In addition, we have not attempted to capture the extent of how current market failures might impact the rebound effect. The direction and magnitude of the rebound effect in the HD truck market are expected to vary depending on the existence and types of market failures affecting the fuel efficiency of the trucking fleet. If firms are already accurately accounting for the costs and benefits of these technologies and fuel savings, then these regulations would increase their net costs, because trucks would already include all cost-effective fuel saving technologies. As a result, the rebound effect would actually be negative and truck VMT would decrease as a result of these regulations.

However, if firms are not optimizing their behavior today due to factors such as lack of reliable information (see preamble Section IX.A or RIA Chapter 8.2 for further discussion), it is more likely that truck VMT would increase. If firms recognize their lower net costs as a result of these regulations and pass those costs along to their customers, then the rebound effect would increase truck VMT. This response assumes that trucking rates include both truck purchase costs and fuel costs, and that the truck purchase costs included in the rates spread those costs over the full expected lifetime of the trucks. If those costs are spread over a shorter period, as the expected short payback period implies, then those purchase costs will inhibit reduction of freight rates, and to the extent that they do so the rebound effect will be proportionally smaller.

As discussed in more detail in preamble Section IX.A and RIA Chapter 8.2, if there are market failures such as split incentives, estimating the rebound effect may depend on the nature of the failures. For example, if the original purchaser cannot fully recoup the higher upfront costs through fuel savings before selling the vehicle nor pass those costs onto the resale buyer, the firm would be expected to raise shipping rates. A firm purchasing the truck second-hand might lower shipping rates if the firm recognizes the cost savings after operating the vehicle, leading to an increase in VMT. Similarly, if there are split incentives and the vehicle buyer is not the same entity that purchases the fuel, than there would theoretically be a positive rebound effect. In this scenario, fuel savings would lower the net costs to the fuel purchaser, which would result in a larger increase in truck VMT.

Note that while we focus on the VMT rebound effect in our analysis of this proposed rule, there are at least two other types of rebound effects discussed in the economics literature. In addition to VMT rebound effects, there are “indirect” rebound effects, which refers to the purchase of other goods or services (that consume energy) with the costs savings from energy efficiency improvements; and “economy-wide” rebound effects, which refers to the increased demand for energy throughout the economy in response to the reduced market price of energy that happens as a result of energy efficiency improvements.

Research on indirect and economy-wide rebound effects is nascent, and we have not identified any that attempts to quantify indirect or economy-wide rebound effects for HDVs. In particular, the agencies are not aware of any data to indicate that the magnitude of indirect or economy-wide rebound effects, if any, would be significant for this proposed rule.[O] Therefore, we rely the same analysis of vehicle miles traveled to estimate the rebound effect in this proposal that we did for the HD Phase 1 rule, where we attempted to quantify only rebound effects from our rule that impact HDV VMT. We will review any comments received as well as any new work in this area that helps to assess and quantify different rebound effects that could result from improvements in HDV efficiency, including different types of more intensive truck usage that affect fuel consumption but not VMT such as loaded weight, truck routing, and scheduling.

In order to test the effect of alternative assumptions about the rebound effect, NHTSA examined the sensitivity of its estimates of benefits and costs of the Phase 2 Preferred Alternative for HD pickups and vans to alternative assumptions about the rebound effect. While the main analysis for pickups and vans assumes a 10 percent rebound effect, the sensitivity analysis estimates the benefits and costs of the proposed standards under the assumptions of 5, 15, and 20 percent rebound effects.

Alternative values of the rebound effect change the estimates of benefits and costs from the proposed standards in three ways. First, higher values of the rebound effect increase the amount of additional VMT that results from improved fuel efficiency; this increases costs associated with additional congestion, accidents, and noise, thus increasing total costs associated with the proposed standards. Conversely, smaller values of the rebound effect reduce costs from additional congestion, accidents, and noise, so they reduce total costs of the proposed standards. Second, larger increases in VMT associated with higher values of the rebound effect reduce the value of fuel savings and related benefits (such as reductions in GHG emissions) by progressively larger amounts, while smaller values of the rebound effect cause smaller reductions in these benefits. At the same time, however, a higher rebound effect generates larger benefits from increased vehicle use, while a smaller rebound effect reduces these benefits compared to the base case. Thus the impact of alternative values of the rebound effect on total benefits from the proposed standards depends on the exact magnitudes of these latter two effects. On balance, these three effects can cause net benefits to increase or decrease for alternative values of the rebound effect.

[O] One entity sought reconsideration of the Phase 1 rule on the grounds that indirect rebound effects had not been considered by the agencies and could negate all of the benefits of the standards. This assertion rested on an unsupported affidavit lacking any peer review or other indicia of objectivity. This affidavit cited only one published study. The study cited did not deal with vehicle efficiency, has methodological limitations (many of them acknowledged), and otherwise was not pertinent. EPA and NHTSA thus declined to reconsider the Phase 1 rule based on these speculative assertions. See generally 77 FR 51703-04 (Aug. 27, 2012) and 77 FR 51502-03 (Aug. 24, 2012).

Table 8-6 Sensitivity of Preferred Alternative Impacts under Different Assumptions about Rebound Effect for Pickups and Vans, using 3% Discount Rate

HD PICKUPS AND VANS	REBOUND EFFECT			
	Main Analysis	Sensitivity Cases Using Alternative Rebound Assumptions		
	10 %	5 %	15 %	20 %
Fuel Reductions (Billion Gallons)	7.8	8.2	7.5	7.1
GHG Reductions (MMT CO_2 eq)	94.1	95.7	87.2	83.0
Total Costs ($ billion)	5.5	5.0	6.5	7.2
Total Benefits ($ billion)	23.5	23.0	22.9	22.8
Net Benefits ($ billion)	18.0	18.0	16.4	15.5

Table 8-6 summarizes the impact of these alternative assumptions on fuel and GHG emissions savings, total costs, total benefits, and net benefits. As it indicates, using a 5 percent value for the rebound effect reduces benefits and costs of the proposed standards by identical amounts, leaving net benefits unaffected. Values of the rebound effect above 10 percent increase costs and reduce benefits from their values in the main analysis, thus reducing net benefits of the proposed standards. Nevertheless, the preferred alternative has significant net benefits under each alternative assumption about the magnitude of the rebound effect for HD pickups and vans. Thus, these alternative values of the rebound effect would not have affected the agencies' selection of the preferred alternative, as that selection is based on NHTSA's assessment of the maximum feasible fuel efficiency standards and EPA's selection of appropriate GHG standards.

8.4 Impact on Class Shifting, Fleet Turnover, and Sales

The agencies considered two additional potential indirect effects which may lead to unintended consequences of the program to improve the fuel efficiency and reduce GHG emissions from HD trucks. The next sections cover the agencies' qualitative discussions on potential class shifting and fleet turnover effects.

8.4.1 Class Shifting

Heavy-duty vehicles are typically configured and purchased to perform a function. For example, a concrete mixer truck is purchased to transport concrete, a combination tractor is purchased to move freight with the use of a trailer, and a Class 3 pickup truck could be purchased by a landscape company to pull a trailer carrying lawnmowers. The purchaser makes decisions based on many attributes of the vehicle, including the gross vehicle weight rating of the vehicle, which in part determines the amount of freight or equipment that can be carried. If the proposed Phase 2 standards impact either the performance of the vehicle or the marginal cost of the vehicle relative to the other vehicle classes, then consumers may choose to purchase a different vehicle, resulting in the unintended consequence of increased fuel consumption and GHG emissions in-use.

The agencies, along with the NAS panel, found that there is little or no literature which evaluates class shifting between trucks.[47] NHTSA and EPA qualitatively evaluated the proposed rules in light of potential class shifting. The agencies looked at four potential cases of shifting: -from light-duty pickup trucks to heavy-duty pickup trucks; from sleeper cabs to day cabs; from combination tractors to vocational vehicles; and within vocational vehicles.

Light-duty pickup trucks, those with a GVWR of less than 8,500 pounds, are currently regulated under the existing GHG/CAFE Phase 1 program and will meet GHG/CAFE Phase 2 emission standards beginning in 2017. The increased stringency of the light-duty 2017-2025 MY vehicle rule has led some to speculate that vehicle consumers may choose to purchase heavy-duty pickup trucks that are currently regulated under the HD Phase 1 program if the cost of the light-duty regulation is high relative to the cost to buy the larger heavy-duty pickup trucks. Since fuel consumption and GHG emissions rise significantly with vehicle mass, a shift from light-duty trucks to heavy-duty trucks would likely lead to higher fuel consumption and GHG emissions, an untended consequence of the regulations. Given the significant price premium of a heavy-duty truck (often five to ten thousand dollars more than a light-duty pickup), we believe that such a class shift would be unlikely even absent this program. These proposed rules would continue to diminish any incentive for such a class shift because they would narrow the GHG and fuel efficiency performance gap between light-duty and heavy-duty pickup trucks. The proposed regulations for the HD pickup trucks, and similarly for vans, are based on similar technologies and therefore reflect a similar expected increase in cost when compared to the light-duty GHG regulation. Hence, the combination of the two regulations provides little incentive for a shift from light-duty trucks to HD trucks. To the extent that our proposed regulation of heavy-duty pickups and vans could conceivably encourage a class shift towards lighter pickups, this unintended consequence would in fact be expected to lead to lower fuel consumption and GHG emissions as the smaller light-duty pickups have significantly better fuel economy ratings than heavy-duty pickup trucks.

The projected cost increases for this proposed action differ between Class 8 day cabs and Class 8 sleeper cabs, reflecting our expectation that compliance with the proposed standards would lead truck consumers to specify sleeper cabs equipped with APUs while day cab consumers would not. Since Class 8 day cab and sleeper cab trucks perform essentially the same function when hauling a trailer, this raises the possibility that the higher cost for an APU equipped sleeper cab could lead to a shift from sleeper cab to day cab trucks. We do not believe that such an intended consequence would occur for the following reasons. The addition of a sleeper berth to a tractor cab is not a consumer-selectable attribute in quite the same way as other vehicle features. The sleeper cab provides a utility that long-distance trucking fleets need to conduct their operations -- an on-board sleeping berth that lets a driver comply with federally-mandated rest periods, as required by the Department of Transportation Federal Motor Carrier Safety Administration's hours-of-service regulations. The cost of sleeper trucks is already higher than the cost of day cabs, yet the fleets that need this utility purchase them.[48] A day cab simply cannot provide this utility with a single driver. The need for this utility would not be changed even if the additional costs to reduce greenhouse gas emissions from sleeper cabs exceed those reducing greenhouse gas emissions from day cabs.[P]

A trucking fleet could instead decide to put its drivers in hotels in lieu of using sleeper berths, and switch to day cabs. However, this is unlikely to occur in any great number, since the added cost for the hotel stays would far overwhelm differences in the marginal cost between day and sleeper cabs. Even if some fleets do opt to buy hotel rooms and switch to day cabs, they would be highly unlikely to purchase a day cab that was aerodynamically worse than the sleeper cab they replaced, since the need for features optimized for long-distance hauling would not have changed. So in practice, there would likely be little difference to the environment for any switching that might occur. Further, while our projected costs assume the purchase of an APU for compliance, in fact our regulatory structure would allow compliance using a near zero cost software utility that eliminates tractor idling after five minutes. Using this compliance approach, the cost difference between a Class 8 sleeper cab and day cab due to our proposed regulations is small. We are proposing this alternative compliance approach reflecting that some sleeper cabs are used in team driving situations where one driver sleeps while the other drives. In that situation, an APU is unnecessary since the tractor is continually being driven when occupied. When it is parked, it would automatically eliminate any additional idling through the shutdown software. If trucking businesses choose this option, then costs based on purchase of APUs may overestimate the costs of this program to this sector.

Class shifting from combination tractors to vocational vehicles may occur if a customer deems the additional marginal cost of tractors due to the regulation to be greater than the utility provided by the tractor. The agencies initially considered this issue when deciding whether to include Class 7 tractors with the Class 8 tractors or regulate them as vocational vehicles. The agencies' evaluation of the combined vehicle weight rating of the Class 7 shows that if these vehicles were treated significantly differently from the Class 8 tractors, then they could be easily substituted for Class 8 tractors. Therefore, the agencies are proposing to continue to include both classes in the tractor category. The agencies believe that a shift from tractors to vocational vehicles would be limited because of the ability of tractors to pick up and drop off trailers at locations which cannot be done by vocational vehicles.

The agencies do not envision that the proposed regulatory program would cause class shifting within the vocational vehicle class. The marginal cost difference due to the regulation of vocational vehicles is minimal. The cost of LRR tires on a per tire basis is the same for all vocational vehicles so the only difference in marginal cost of the vehicles is due to the number of axles. The agencies believe that the utility gained from the additional load carrying capability of the additional axle would outweigh the additional cost for heavier vehicles.[Q]

In conclusion, NHTSA and EPA believe that the proposed regulatory structure for HD trucks would not significantly change the current competitive and market factors that determine purchaser preferences among truck types. Furthermore, even if a small amount of shifting would

[P] The average marginal cost difference between sleeper cabs and day cabs in the proposal is roughly $2,500.
[Q] The proposed rule projects the difference in costs between the HHD and MHD vocational vehicle technologies is approximately $30.

occur, any resulting GHG impacts would likely to be negligible because any vehicle class that sees an uptick in sales is also being regulated for fuel efficiency. Therefore, the agencies did not include an impact of class shifting on the vehicle populations used to assess the benefits of the proposed program.

8.4.2 Fleet Turnover and Sales Effects

A regulation that affects the cost to purchase and/or operate trucks could affect whether a consumer decides to purchase a new truck and the timing of that purchase. The term pre-buy refers to the idea that truck purchases may occur earlier than otherwise planned to avoid the additional costs associated with a new regulatory requirement. Slower fleet turnover, or low-buys, may occur when owners opt to keep their existing truck rather than purchase a new truck due to the incremental cost of the regulation.

The 2010 NAS HD Report discussed the topics associated with HD truck fleet turnover. NAS noted that there is some empirical evidence of pre-buy behavior in response to the 2004 and 2007 heavy-duty engine emission standards, with larger impacts occurring in response to higher costs.[49] However, those regulations increased upfront costs to firms without any offsetting future cost savings from reduced fuel purchases. In summary, NAS stated that

> …during periods of stable or growing demand in the freight sector, pre-buy behavior may have significant impact on purchase patterns, especially for larger fleets with better access to capital and financing. Under these same conditions, smaller operators may simply elect to keep their current equipment on the road longer, all the more likely given continued improvements in diesel engine durability over time. On the other hand, to the extent that fuel economy improvements can offset incremental purchase costs, these impacts will be lessened. Nevertheless, when it comes to efficiency investments, most heavy-duty fleet operators require relatively quick payback periods, on the order of two to three years.[50]

The proposed regulations are projected to return fuel savings to the truck owners that offset the cost of the regulation within a few years. The effects of the regulation on purchasing behavior and sales will depend on the nature of the market failures and the extent to which firms consider the projected future fuel savings in their purchasing decisions.

If trucking firms account for the rapid payback, they are unlikely to strategically accelerate or delay their purchase plans at additional cost in capital to avoid a regulation that will lower their overall operating costs. As discussed in Chapter 8.2, this scenario may occur if this proposed program reduces uncertainty about fuel-saving technologies. More reliable information about ways to reduce fuel consumption allows truck purchasers to evaluate better the benefits and costs of additional fuel savings, primarily in the original vehicle market, but possibly in the resale market as well. In addition, the proposed standards are expected to lead manufacturers to install more fuel-saving technologies and promote their purchase; the increased availability and promotion may encourage sales.

Other market failures may leave open the possibility of some pre-buy or delayed purchasing behavior. Firms may not consider the full value of the future fuel savings for several reasons. For instance, truck purchasers may not want to invest in fuel efficiency because of uncertainty about fuel prices. Another explanation is that the resale market may not fully recognize the value of fuel savings, due to lack of trust of new technologies or changes in the uses of the vehicles. Lack of coordination (also called split incentives—see Chapter 8.2) between truck purchasers (who may emphasize the up-front costs of the trucks) and truck operators, who would like the fuel savings, can also lead to pre-buy or delayed purchasing behavior. If these market failures prevent firms from fully internalizing fuel savings when deciding on vehicle purchases, then pre-buy and delayed purchase could occur and could result in a slight decrease in the GHG benefits of the regulation.

Thus, whether pre-buy or delayed purchase is likely to play a significant role in the truck market depends on the specific behaviors of purchasers in that market. Without additional information about which scenario is more likely to be prevalent, the agencies are not projecting a change in fleet turnover characteristics due to this regulation.

Whether vehicle sales appear to be affected by the HD Phase 1 standards could provide some insight into the impacts of the proposed standards. At the time of this NPRM, sales data are not yet available for 2014 model year, the first year of the Phase 1 standards. In addition, any trends in sales are likely to be affected by macroeconomic conditions, which have been recovering since 2009-2010. As a result, it is unlikely to be possible, even when vehicle sales data are available, to separate the effects of the existing standards from other confounding factors.

8.5 Monetized GHG Impacts

8.5.1 Monetized CO_2 Impacts - Social Cost of Carbon

We estimate the global social benefits of CO_2 emission reductions expected from the Proposed HD Phase 2 program using the social cost of carbon (SC-CO_2) estimates presented in the 2013 *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (2013 SCC TSD). We refer to these estimates, which were developed by the U.S., as "SC-CO_2 estimates." The SC-CO_2 is a metric that estimates the monetary value of impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. It is used in regulatory impact analyses to quantify the benefits of reducing CO_2 emissions, or the disbenefit from increasing emissions.

The SC-CO_2 estimates used in this analysis were developed over many years, based on the best science available, and with input from the public. EPA and other federal agencies have considered the extensive public comments on ways to improve SC-CO_2 estimation received via the notice and comment period that was part of numerous rulemakings since 2006. In addition, OMB's Office of Information and Regulatory Affairs sought public comment on the approach used to develop the SC-CO_2 estimates. The comment period ended on February 26, 2014, and OMB is reviewing the comments received. An interagency process that included EPA and other executive branch entities used three integrated assessment models (IAMs) to develop SC-CO_2

estimates and selected four global values for use in regulatory analyses. The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM.

The SC-CO_2 estimates represent global measures because of the distinctive nature of the climate change problem. The climate change problem is highly unusual in at least two respects. First, emissions of most GHGs contribute to damages around the world even when they are emitted in the United States. The SC-CO_2 must therefore incorporate the full (global) damages caused by GHG emissions in order to address the global nature of the problem. Second, climate change presents a problem that the United States alone cannot solve. The US now operates in a global, highly interconnected economy such that impacts on the other side of the world now affect our economy. Climate damages in other countries can affect the U.S. economy; climate-exacerbated conflict can require military expenditures by the U.S. All of this means that the true cost of climate change to U.S. is much larger than impacts that simply occur in the U.S. A global number is the economically appropriate reference point for collective actions to reduce climate change.

A key objective in the development of the SC-CO_2 estimates was to enable a consistent exploration of three IAMs (DICE, FUND, and PAGE) while respecting the different approaches to quantifying damages taken by the key modelers in the field. The selection of the three input parameters (equilibrium climate sensitivity, reference socioeconomic scenarios, discount rate) was based on an extensive review of the literature. Specifically, a probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically. The use of three models and these input parameters allowed for exploration of important uncertainties in the way climate damages are estimated, including equilibrium climate sensitivity, reference socioeconomic and emission trajectories, and discount rate. As stated in the 2010 SCC TSD, however, key uncertainties remain as the existing models are imperfect and incomplete. See the 2010 SCC TSD for a complete discussion of the methods used to develop the estimates and the key uncertainties, and the 2013 SCC TSD for the updated estimates.

Notably, the 2013 process did not revisit the 2010 interagency modeling decisions (e.g., with regard to the equilibrium climate sensitivity, reference case socioeconomic and emission scenarios, or discount rates). Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and used for analyses in peer-reviewed publications. The model updates that are relevant to the SC-CO_2 estimates include: an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model. The 2013 SCC TSD provides complete details.

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Academies of Science (NRC, 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

The 2010 SCC TSD noted a number of limitations to the SC-CO_2 analysis, including the incomplete way in which the IAMs capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. The limited amount of research linking climate impacts to economic damages makes the modeling exercise even more difficult. These individual limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates, though taken together they suggest that the SC-CO_2 estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (2007) concluded that "It is very likely that [SC-CO_2 estimates] underestimate the damage costs because they cannot include many non-quantifiable impacts."

Nonetheless, these estimates and the discussion of their limitations represent the best available information about the social benefits of CO_2 reductions to inform benefit-cost analysis. The new versions of the models used to estimate the values presented below offer some improvements in these areas, although further work is warranted. Accordingly, EPA and other agencies continue to engage in research on modeling and valuation of climate impacts with the goal to improve these estimates. The EPA and other federal agencies have considered the extensive public comments on ways to improve SC-CO_2 estimation received via the notice and comment periods that were part of numerous rulemakings. In addition, OMB's Office of Information and Regulatory Affairs sought public comment on the approach used to develop the SC-CO_2 estimates (78 FR 70586; November 26, 2013). The comment period ended on February 26, 2014, and OMB is reviewing the comments received. OMB also responded in January 2014 to concerns submitted in a Request for Correction on the SCC TSDs.[R]

The four SC-CO_2 estimates, updated in 2013, are as follows: $13, $46, $69, and $140 per metric ton of CO_2 emissions in the year 2020 (2012$).[S] Table 8-7 presents the SC-CO_2 estimates in selected years, rounded to two significant digits. The first three values are based on the average SC-CO_2 from the three IAMs, at discount rates of 5, 3, and 2.5 percent, respectively. SC-

[R] OMB's 1/24/14 response to the petition is available at https://www.whitehouse.gov/sites/default/files/omb/inforeg/ssc-rfc-under-iqa-response.pdf

[S] The SC-CO_2 values have been rounded to two significant digits. Unrounded numbers from the 2013 SCC TSD were adjusted to 2012$ and used to calculate the CO_2 benefits.

CO_2 estimates for several discount rates are included because the literature shows that the SC-CO_2 is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). The fourth value is the 95th percentile of the SC-CO_2 from all three models at a 3 percent discount rate. It is included to represent higher-than-expected impacts from temperature change further out in the tails of the SC-CO_2 distribution (representing less likely, but potentially catastrophic, outcomes). The SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as economies grow and physical and economic systems become more stressed in response to greater climate change.

Table 8-7 Social Cost of CO_2, 2012 – 2050[a] (in 2012$ per Metric Ton)

CALENDAR YEAR	DISCOUNT RATE AND STATISTIC			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$12	$37	$58	$100
2015	$12	$40	$61	$120
2020	$13	$46	$69	$140
2025	$15	$51	$74	$150
2030	$17	$56	$81	$170
2035	$20	$60	$86	$190
2040	$23	$66	$93	$210
2045	$26	$71	$99	$220
2050	$28	$77	$100	$240

Note:
[a] The SC-CO_2 values are dollar-year and emissions-year specific and have been rounded to two significant digits. Unrounded numbers from the 2013 SCC TSD were adjusted to 2012$ and used to calculate the CO_2 benefits.

Applying the global SC-CO_2 estimates, shown in Table 8-7, to the estimated reductions in domestic CO_2 emissions for the proposed program, we estimate the dollar value of the climate related benefits for each analysis year. In order to calculate the dollar value for emission reductions, the SC-CO_2 estimate for each emissions year would be applied to changes in CO_2 emissions for that year, and then discounted back to the analysis year using the same discount rate used to estimate the SC-CO_2. For internal consistency, the annual benefits are discounted back to net present value terms using the same discount rate as each SC-CO_2 estimate (i.e. 5 percent, 3 percent, and 2.5 percent) rather than the discount rates of 3 percent and 7 percent used to derive the net present value of other streams of costs and benefits of the proposed rule.[T] The SC-CO_2 estimates are presented in and the associated CO_2 benefit estimates for each calendar year are shown in Table 8-8.

[T] See more discussion on the appropriate discounting of climate benefits using SC-CO_2 in the 2010 SCC TSD. Other benefits and costs of proposed regulations unrelated to CO_2 emissions are discounted at the 3% and 7% rates specified in OMB guidance for regulatory analysis.

Table 8-8 Annual Upstream and Downstream CO_2 Benefits and Net Present Values for the Given SC-CO_2 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B,[a,b] (Millions of 2012$)

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $37 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95^{TH} PERCENTILE = $105 IN 2012)
2018	$13	$43	$65	$130
2019	$26	$91	$130	$270
2020	$40	$140	$210	$420
2021	$92	$330	$500	$1,000
2022	$170	$590	$880	$1,800
2023	$250	$860	$1,300	$2,600
2024	$400	$1,300	$1,900	$4,000
2025	$540	$1,800	$2,600	$5,500
2026	$720	$2,300	$3,400	$7,000
2027	$890	$2,900	$4,200	$8,900
2028	$1,100	$3,500	$5,100	$11,000
2029	$1,300	$4,200	$5,900	$13,000
2030	$1,500	$4,800	$6,900	$15,000
2035	$2,500	$7,400	$11,000	$23,000
2040	$3,300	$9,700	$14,000	$30,000
2050	$5,000	$14,000	$19,000	$42,000
NPV[b]	$22,000	$100,000	$160,000	$320,000

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SCC TSD for more detail.

We also conducted a separate analysis of the CO_2 benefits over the model year lifetimes of vehicles sold in the regulatory timeframe. In contrast to the calendar year analysis, the model year lifetime analysis shows the impacts of the program on each of these MY fleets over the course of their lifetimes. Full details of the inputs to this analysis can be found in RIA chapter 5. The CO_2 benefits in the context of this MY lifetime analysis are shown in Table 8-9 for each of the four different social cost of carbon values. The CO_2 benefits shown for each model year represent the net present value of the benefits in each year in the model year life discounted back to the first year of the model year. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate the net present value of SCC for internal consistency.

Table 8-9 Discounted Model Year Lifetime Upstream & Downstream CO_2 Benefits for the Given SC-CO_2 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$)[a,b]

MODEL YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $37 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95TH PERCENTILE = $105 IN 2012)
2018	$93	$380	$580	$1,100
2019	$90	$370	$570	$1,100
2020	$87	$360	$560	$1,100
2021	$520	$2,200	$3,400	$6,600
2022	$540	$2,300	$3,500	$6,900
2023	$550	$2,300	$3,600	$7,200
2024	$870	$3,700	$5,800	$11,000
2025	$900	$3,900	$6,100	$12,000
2026	$920	$4,000	$6,300	$12,000
2027	$1,100	$4,800	$7,600	$15,000
2028	$1,100	$4,800	$7,600	$15,000
2029	$1,100	$4,900	$7,700	$15,000
Sum	$7,800	$34,000	$53,000	$100,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SCC TSD for more detail.

8.5.2 Sensitivity Analysis - Monetized Non-CO_2 Impacts

One limitation of the primary benefits analysis is that it does not include the valuation of non-CO_2 GHG impacts (CH_4, N_2O, HFC-134a). Specifically, the IWG did not estimate the social costs of non-CO_2 GHG emissions using an approach analogous to the one used to estimate the SC-CO_2. However, EPA recognizes that non-CO_2 GHG impacts associated with this rulemaking (e.g., net reductions in CH_4, N_2O, HFC-134a) would provide benefits to society. To understand the potential implication of omitting these benefits, EPA has conducted sensitivity analysis using two approaches: 1) an approximation approach based on global warming potential (GWP) gas comparison metrics that has been used in previous rulemakings, and 2) a set of recently published SC-CH_4 and SC-N_2O estimates that are consistent with the modeling assumptions underlying the SC-CO_2 estimates (Marten et al. 2014). This section describes both approaches and presents estimates of the non-CO_2 benefits of the proposed rulemaking. Other unquantified non-CO_2 benefits are discussed in this section as well.

8.5.2.1 Non-CO_2 GHG Benefits Based on the GWP Approximation Approach

In the absence of directly modeled estimates, one potential method for approximating the value of marginal non-CO_2 GHG emission reductions is to convert non-CO_2 emissions reductions to CO_2-equivalents that may then be valued using the SC-CO_2. Conversion to CO_2-equivalents is typically based on the global warming potentials (GWPs) for the non-CO_2 gases.

This approach, henceforth referred to as the "GWP approach," has been used in sensitivity analyses to estimate the non-CO_2 benefits in previous EPA rulemakings (see US EPA 2012, 2013).[51] EPA has not presented these estimates in a main benefit-cost analysis due to the limitations associated with using the GWP approach to value changes in non-CO_2 GHG emissions, and considered the GWP approach as an interim method of analysis until social cost estimates for non-CO_2 GHGs, consistent with the SC-CO_2 estimates, were developed.

The GWP is a simple, transparent, and well-established metric for assessing the relative impacts of non-CO_2 emissions compared to CO_2 on a purely physical basis. However, as discussed both in the 2010 SCC TSD and previous rulemakings (e.g., US EPA 2012, 2013), the GWP approximation approach to measuring non-CO_2 GHG benefits has several well-documented limitations (e.g., Reilly and Richards 1993[52]; Schmalensee 1993[53]; Fankhauser 1994[54]; Marten and Newbold 2012[55]). Gas comparison metrics, such as the GWP, are designed to measure the impact of non-CO_2 GHG emissions relative to CO_2 at a specific point along the pathway from emissions to monetized damages (depicted in Figure 8-2), and this point may differ across measures. The GWP measures the cumulative radiative forcing from a perturbation of a non-CO_2 GHG relative to a perturbation of CO_2 over a fixed time horizon. The GWP and other gas comparison metrics are not ideally suited for use in benefit-cost analyses to approximate the social cost of non-CO_2 GHGs because they ignore important nonlinear relationships beyond radiative forcing in the chain between emissions and damages. These can become relevant because gases have different lifetimes and the SC-CO_2 takes into account the fact that marginal damages from an increase in temperature are a function of existing temperature levels. Another limitation of gas comparison metrics for this purpose is that some environmental and socioeconomic impacts are not linked to all of the gases under consideration and will therefore be incorrectly allocated. For example, the economic impacts associated with increased agricultural productivity due to higher atmospheric CO_2 concentrations included in the SC-CO_2 would be incorrectly allocated to CH_4 emissions with the GWP-based valuation approach.

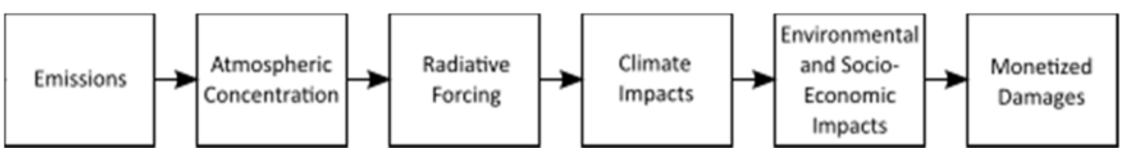

Figure 8-2 Path from GHG Emissions to Monetized Damages (Source: Marten et al., 2014)

Furthermore, the assumptions made in estimating the GWP are not consistent with the assumptions underlying SC-CO_2 estimates in general, and the SC-CO_2 estimates more specifically. For example the 100 year time horizon usually used in estimating the GWP is less than the 300 year horizon used in developing the SC-CO_2 estimates. The GWP approach also treats all impacts within the time horizon equally, independent of the time at which they occur. This is inconsistent with the role of discounting in economic analysis, which accounts for a basic preference for earlier over later gains in utility, the small but positive probability of a large global catastrophe (e.g., large asteroid collision, super volcanic eruption, pandemic), and expectations regarding future levels of economic growth. In the case of CH_4, which has a relatively short lifetime compared to CO_2, the temporal independence of the GWP could lead the

GWP approach to underestimate the SC-CH_4 with a larger downward bias under higher discount rates (Marten and Newbold 2012).[U]

Similar to the approach used in the RIA of the Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards (US EPA, 2013), EPA applies the GWP approach to estimate the benefits associated with reductions of CH_4, N_2O and HFCs in each calendar year. Under the GWP Approach, EPA converted CH_4, N_2O, and HFC-134a to CO_2 equivalents using the AR4 100-year GWP for each gas: CH_4 (25), N_2O (298), and HFC-134a (1,430).[56] These CO_2-equivalent emission reductions are multiplied by the SC-CO_2 estimate corresponding to each year of emission reductions. As with the calculation of annual benefits of CO_2 emission reductions, the annual benefits of non-CO_2 emission reductions based on the GWP approach are discounted back to net present value terms using the same discount rate as each SC-CO_2 estimate. The estimated non-CO_2 GHG benefits using the GWP approach are presented in Table 8-10 through Table 8-11. The total net present value of the GHG benefits for this proposed rulemaking would increase by about $760 million to $11 billion (2012$), depending on discount rate, or roughly 3 percent if these non-CO_2 estimates were included.

[U] We note that the truncation of the time period in the GWP calculation could lead to an overestimate of SC-CH_4 for near term perturbation years in cases where the SC-CO_2 is based on a sufficiently low or steeply declining discount rate.

Table 8-10 Annual Upstream and Downstream CH_4 GHG Benefits and Net Present Values for the Given SC-CO_2 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B, using the GWP Approach (Millions of 2012$) [a,b]

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $37 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95^{TH} PERCENTILE = $105 IN 2012)
2018	$0.3	$1.1	$1.6	$3.2
2019	$0.6	$2.2	$3.3	$6.6
2020	$1.0	$3.5	$5.2	$10
2021	$3.1	$11	$17	$33
2022	$6.0	$20	$30	$62
2023	$8.8	$30	$45	$93
2024	$14	$46	$68	$140
2025	$19	$62	$91	$190
2026	$25	$79	$120	$240
2027	$30	$99	$140	$300
2028	$36	$120	$170	$360
2029	$43	$140	$200	$420
2030	$49	$160	$230	$480
2035	$82	$240	$350	$760
2040	$110	$320	$440	$990
2050	$160	$440	$600	$1,400
NPV[b]	$730	$3,400	$5,400	$11,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SCC TSD for more detail.

Table 8-11 Annual Upstream and Downstream N_2O GHG Benefits and Net Present Values for the Given SC-CO_2 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B, using the GWP Approach (Millions of 2012$) [a,b]

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $37 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95TH PERCENTILE = $105 IN 2012)
2018	$0.0	$0.0	$0.1	$0.2
2019	$0.0	$0.1	$0.2	$0.3
2020	$0.0	$0.2	$0.2	$0.5
2021	$0.1	$0.4	$0.5	$1.1
2022	$0.2	$0.6	$1.0	$1.9
2023	$0.3	$0.9	$1.4	$2.8
2024	$0.4	$1.4	$2.1	$4.4
2025	$0.6	$2.0	$2.9	$6.0
2026	$0.8	$2.6	$3.7	$7.8
2027	$1.0	$3.2	$4.7	$10
2028	$1.2	$3.9	$5.7	$12
2029	$1.5	$4.6	$6.6	$14
2030	$1.6	$5.3	$7.7	$16
2035	$2.8	$8.3	$12	$26
2040	$3.8	$11	$15	$34
2050	$5.6	$15	$21	$47
NPV[b]	$25	$120	$180	$360

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SCC TSD for more detail.

Table 8-12 Annual Upstream and Downstream HFC-134a GHG Benefits and Net Present Values for the Given SC-CO_2 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B, using the GWP Approach (Millions of 2012$) [a,b]

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $37 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95TH PERCENTILE = $105 IN 2012)
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.2	$0.8	$1.3	$2.6
2022	$0.5	$1.7	$2.6	$5.3
2023	$0.8	$2.7	$4.0	$8.1
2024	$1.1	$3.7	$5.4	$11
2025	$1.4	$4.7	$6.9	$14
2026	$1.8	$5.9	$8.6	$18
2027	$2.2	$7.1	$10	$22
2028	$2.5	$8.3	$12	$25
2029	$3.0	$10	$14	$29
2030	$3.4	$11	$16	$34
2035	$5.2	$15	$22	$48
2040	$6.1	$18	$25	$56
2050	$8.4	$23	$31	$71
NPV[b]	$44	$200	$320	$630

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SCC TSD for more detail.

8.5.2.2 Non-CO_2 GHG Benefits Based on Directly Modeled Estimates

Several researchers have directly estimated the social cost of non-CO_2 emissions using integrated assessment models (IAMs), though the number of such estimates is small compared to the large number of SC-CO_2 estimates available in the literature. As discussed in previous RIAs (e.g., EPA 2012), there is considerable variation among these published estimates in the models and input assumptions they employ. These studies differ in the emission perturbation year, employ a wide range of constant and variable discount rate specifications, and consider a range of baseline socioeconomic and emissions scenarios that have been developed over the last 20 years. However, none of the other published estimates of the social cost of non-CO_2 GHG are consistent with the SC-CO_2 estimates, and most are likely underestimates due to changes in the underlying science since their publication.

Recently, a paper by Marten et al. (2014) provided the first set of published SC-CH_4 and SC-N_2O estimates that are consistent with the modeling assumptions underlying the SC-CO_2.[57] Specifically, the estimation approach of Marten et al. (2014) used the same set of three IAMs, five socioeconomic-emissions scenarios, equilibrium climate sensitivity distribution, and three constant discount rates used to develop the SC-CO_2 estimates. Marten et al. also used the same aggregation method as the SC-CO_2 to distill the 45 distribution of the SC-CH_4 and SC-N_2O produced for each emissions year into four estimates: the mean across all models and scenarios using a 2.5 percent, 3 percent, and 5 percent discount rate, and the 95th percentile of the pooled estimates from all models and scenarios using a 3 percent discount rate. Marten et al. used lifetimes and radiative efficiencies for CH_4 and N_2O based on the IPCC AR4 values. The authors also adjusted the CH_4 radiative efficiency for CH_4 to account for additional radiative effects due to increases in tropospheric ozone and stratospheric water vapor resulting from methane emissions, using the same adjustment used by in IPCC AR4 for calculating GWP values. Using this approach, Marten et al. (2014) finds that the GWP approach provides conservative estimates for the benefits of marginal reductions in CH_4 and N_2O emissions.

The resulting SC-CH_4 and SC-N_2O estimates are presented in Table 8-13. More detailed results and a comparison to other published estimates can be found in Marten et al. (2014). The tables do not include HFC-134a because EPA is unaware of analogous estimates.

Table 8-13 Social Cost of CH_4 and N_2O, 2012 – 2050[a] [2012$ per metric ton]
(Source: Marten et al. (2014))

YEAR	SC-CH_4				SC-N_2O			
	5% Average	3% Average	2.5% Average	3% 95th percentile	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$440	$1000	$1400	$2800	$4000	$14000	$20000	$37000
2015	500	1200	1500	3100	4400	15000	22000	39000
2020	590	1300	1700	3500	5200	16000	24000	44000
2025	710	1500	19000	4100	6000	18000	27000	50000
2030	840	1700	2300	4600	7000	20000	29000	55000
2035	990	2000	2500	5400	8100	23000	32000	61000
2040	1200	2300	2800	6000	9300	25000	35000	67000
2045	1300	2500	3100	6800	11000	27000	38000	73000
2050	1500	2700	3300	7400	12000	29000	41000	80000

Note:
[a] The values are emissions-year specific and have been rounded to two significant digits, as shown in Marten et al. (2014). These rounded numbers were used to calculate the GHG benefits.

The application of directly modeled estimates from Marten et al. (2014) to benefit-cost analysis of a regulatory action is analogous to the use of the SC-CO_2 estimates. Specifically, the SC-CH_4 and SC-N_2O estimates in Table 8-13 are used to monetize the benefits of changes in CH_4 and N_2O emissions expected as a result of the proposed rulemaking. Forecast changes in CH_4 and N_2O emissions in a given year resulting from the regulatory action are multiplied by the SC-CH_4 and SC-N_2O estimate for that year, respectively. To obtain a present value estimate, the monetized stream of future non-CO_2 benefits are discounted back to the analysis year using the same discount rate used to estimate the social cost of the non-CO_2 GHG emission changes.

The CH_4 and N_2O benefits based on Marten et al. (2014) are presented for each calendar year in Table 8-14. Including these benefits would increase the total net present value of the GHG benefits for this proposed rulemaking by about $1.5 billion to $12 billion (2012$), or roughly 4 percent to 7 percent, depending on discount rate.

Table 8-14 Annual Upstream and Downstream CH_4 GHG Benefits and Net Present Values for the Given SC-CH_4 Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B, using the Directly Modeled Approach, Calendar Year Analysis (Millions of 2012$) [a,b]

CALENDAR YEAR	5% (AVERAGE SC-CH_4 = $440 IN 2012)	3% (AVERAGE SC-CH_4 = $1000 IN 2012)	2.5% (AVERAGE SC-CH_4 = $1400 IN 2012)	3% (95TH PERCENTILE = $2800 IN 2012)
2018	$0.6	$1.3	$1.6	$3.3
2019	$1.1	$2.6	$3.4	$6.8
2020	$1.8	$3.9	$5.2	$10
2021	$5.8	$13	$17	$35
2022	$11	$24	$31	$65
2023	$17	$35	$49	$97
2024	$26	$56	$72	$150
2025	$35	$74	$95	$200
2026	$46	$99	$130	$260
2027	$57	$120	$150	$320
2028	$69	$140	$190	$390
2029	$82	$170	$220	$460
2030	$95	$190	$260	$520
2035	$160	$330	$400	$870
2040	$230	$430	$540	$1,200
2050	$350	$620	$770	$1,700
NPV[b]	$1,500	$4,600	$6,400	$12,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CH_4 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CH_4 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CH_4 for internal consistency.

Table 8-15 Annual Upstream and Downstream N_2O GHG Benefits and Net Present Values for the Given SC-N_2O Value for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B, using the Directly Modeled Approach, Calendar Year Analysis (Millions of 2012$) [a,b]

CALENDAR YEAR	5% (AVERAGE SC-N_2O = $4000 IN 2012)	3% (AVERAGE SC-N_2O = $14000 IN 2012)	2.5% (AVERAGE SC-N_2O = $20000 IN 2012)	3% (95TH PERCENTILE = $37000 IN 2012)
2018	$0.0	$0.1	$0.1	$0.2
2019	$0.0	$0.1	$0.2	$0.3
2020	$0.1	$0.2	$0.3	$0.5
2021	$0.1	$0.4	$0.6	$1.2
2022	$0.3	$0.8	$1.1	$2.1
2023	$0.4	$1.1	$1.7	$3.1
2024	$0.6	$1.8	$2.5	$4.7
2025	$0.8	$2.4	$3.5	$6.5
2026	$1.0	$3.0	$4.5	$8.4
2027	$1.3	$4.0	$5.8	$11
2028	$1.6	$4.8	$6.9	$13
2029	$1.9	$5.8	$8.2	$15
2030	$2.2	$6.5	$9.3	$18
2035	$3.7	$10	$15	$28
2040	$5.2	$14	$19	$37
2050	$7.9	$20	$27	$53
NPV[b]	$34	$150	$230	$400

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-N_2O values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (N_2O at 5, 3, and 2.5 percent) is used to calculate discounted values of N_2O for internal consistency.

As illustrated above, compared to the use of directly modeled estimates the GWP-based approximation approach underestimates the climate benefits of the CH_4 emission reductions by 12 percent to 52 percent, and the climate benefits of N_2O reductions by 10 percent to 26 percent, depending on the discount rate assumption.

8.5.2.3 Additional non-CO_2 GHGs Co-Benefits

In determining the relative social costs of the different gases, the Marten et al. (2014) analysis accounts for differences in lifetime and radiative efficiency between the non-CO_2 GHGs and CO_2. The analysis also accounts for radiative forcing resulting from methane's effects on tropospheric ozone and stratospheric water vapor, and for at least some of the fertilization effects of elevated carbon dioxide concentrations. However, there exist several other differences between these gases that have not yet been captured in this analysis, namely the non-radiative effects of methane-driven elevated tropospheric ozone levels on human health, agriculture, and ecosystems, and the effects of carbon dioxide on ocean acidification. Inclusion of these additional non-radiative effects would potentially change both the absolute and relative value of the various gases.

Of these effects, the human health effect of elevated tropospheric ozone levels resulting from methane emissions is the closest to being monetized in a way that would be comparable to the SCC. Premature ozone-related cardiopulmonary deaths resulting from global increases in tropospheric ozone concentrations produced by the methane oxidation process have been the focus of a number of studies over the past decade (e.g., West et al. 2006[58]). Recent studies have produced an estimate of a monetized benefit of methane emissions reductions, with results on the order of $1000 per metric ton of CH_4 emissions reduced (Anenberg et al. 2012[59]; Shindell et al. 2012[60]), an estimate similar in magnitude to the climate benefits of CH_4 reductions estimated by the Marten et al. or GWP methods. However, though EPA is continuing to monitor this area of research as it evolves, EPA is not applying them for benefit estimates at this time.

8.6 Quantified and Monetized Non-GHG Health and Environmental Impacts

This section analyzes the economic benefits from reductions in health and environmental impacts resulting from non-GHG emission reductions that can be expected to occur as a result of the proposed Phase 2 standards. CO_2 emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutant emissions. The vehicles that are subject to the proposed standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The proposed standards would affect exhaust emissions of these pollutants from vehicles and would also affect emissions from upstream sources that occur during the refining and distribution of fuel. Changes in ambient concentrations of ozone, $PM_{2.5}$, and air toxics that would result from the proposed standards are expected to affect human health by reducing premature deaths and other serious human health effects, as well as other important improvements in public health and welfare.

It is important to quantify the health and environmental impacts associated with the proposed standards because a failure to adequately consider these ancillary impacts could lead to an incorrect assessment of their costs and benefits. Moreover, the health and other impacts of exposure to criteria air pollutants and airborne toxics tend to occur in the near term, while most effects from reduced climate change are likely to occur only over a time frame of several decades or longer.

EPA typically quantifies and monetizes the health and environmental impacts related to both PM and ozone in its regulatory impact analyses (RIAs) when possible. However, EPA was unable to do so in time for this proposal. EPA attempts to make emissions and air quality modeling decisions early in the analytical process so that we can complete the photochemical air quality modeling and use that data to inform the health and environmental impacts analysis. Time constraints precluded the agency from completing this work in time for the proposal. Instead, EPA has applied PM-related benefits per-ton values to its estimated emission reductions as an interim approach to estimating the PM-related benefits of the proposal.[61,V] EPA also

[V] See also: http://www.epa.gov/airquality/benmap/sabpt.html. The current values available on the webpage have been updated since the publication of the Fann et al., 2012 paper. For more information regarding the updated values, see: http://www.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf (accessed September 9, 2014).

characterizes the health and environmental impacts that will be quantified and monetized for the final rulemaking.

This section is split into two sub-sections: the first presents the benefits-per-ton values used to monetize the benefits from reducing population exposure to PM associated with the proposed standards; the second explains what PM- and ozone-related health and environmental impacts EPA will quantify and monetize in the analysis for the final rule. EPA bases its analyses on peer-reviewed studies of air quality and health and welfare effects and peer-reviewed studies of the monetary values of public health and welfare improvements, and is generally consistent with benefits analyses performed for the analysis of the final Tier 3 Vehicle Rule,[62] the final 2012 PM NAAQS Revision,[63] and the final 2017-2025 Light Duty Vehicle GHG Rule.[64]

Though EPA is characterizing the changes in emissions associated with toxic pollutants, we are not able to quantify or monetize the human health effects associated with air toxic pollutants for either the proposal or the final rule analyses (see Chapter 8.6.2.3 for more information). Please refer to Chapter 5 for more information about the air toxics emissions impacts associated with the proposed standards.

8.6.1 Economic Value of Reductions in Criteria Pollutants

As described in Chapter 5, the proposed standards would reduce emissions of several criteria and toxic pollutants and their precursors. In this analysis, EPA estimates the economic value of the human health benefits associated with the resulting reductions in $PM_{2.5}$ exposure. Due to analytical limitations with the benefit per-ton method, this analysis does not estimate benefits resulting from reductions in population exposure to other criteria pollutants such as ozone.[W] Furthermore, the benefits per-ton method, like all air quality impact analyses, does not monetize all of the potential health and welfare effects associated with reduced concentrations of $PM_{2.5}$.

This analysis uses estimates of the benefits from reducing the incidence of the specific $PM_{2.5}$-related health impacts described below. These estimates, which are expressed per ton of $PM_{2.5}$-related emissions eliminated by the proposed rule, represent the total monetized value of human health benefits (including reduction in both premature mortality and premature morbidity) from reducing each ton of directly emitted $PM_{2.5}$, or its precursors (SO_2 and NOx), from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ as determined by full-scale air quality modeling. However, the length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this proposal. We will conduct this modeling for the final rule.

The dollar-per-ton estimates used in this analysis are provided in Table 8-16. As the table indicates, these values differ among pollutants, and also depend on their original source,

[W] The air quality modeling that underlies the PM-related benefit per ton values also produced estimates of ozone levels attributable to each sector. However, the complex non-linear chemistry governing ozone formation prevented EPA from developing a complementary array of ozone benefit per ton values. This limitation notwithstanding, we anticipate that the ozone-related benefits associated with reducing emissions of NO_X and VOC could be substantial.

because emissions from different sources can result in different degrees of population exposure and resulting health impacts. In the summary of costs and benefits, Chapter 8.10, EPA presents the monetized value of PM-related improvements associated with the proposal.

Table 8-16 Benefits-per-ton Values (thousands, 2012$) [a]

YEAR[C]	ON-ROAD MOBILE SOURCES			UPSTREAM SOURCES[D]		
	Direct $PM_{2.5}$	SO_2	NO_X	Direct $PM_{2.5}$	SO_2	NO_X
Estimated Using a 3 Percent Discount Rate[b]						
2016	$380-$850	$20-$45	$7.7-$18	$330-$750	$69-$160	$6.8-$16
2020	$400-$910	$22-$49	$8.1-$18	$350-$790	$75-$170	$7.4-$17
2025	$440-$1,000	$24-$55	$8.8-$20	$390-$870	$83-$190	$8.1-$18
2030	$480-$1,100	$27-$61	$9.6-$22	$420-$950	$91-$200	$8.7-$20
Estimated Using a 7 Percent Discount Rate[b]						
2016	$340-$770	$18-$41	$6.9-$16	$290-$670	$63-$140	$6.2-$14
2020	$370-$820	$20-$44	$7.4-$17	$320-$720	$67-$150	$6.6-$15
2025	$400-$910	$22-$49	$8.0-$18	$350-$790	$75-$170	$7.3-$17
2030	$430-$980	$24-$55	$8.6-$20	$380-$850	$81-$180	$7.9-$18

Notes:

[a] The benefit-per-ton estimates presented in this table are based on a range of premature mortality estimates derived from the ACS study (Krewski et al., 2009) and the Six-Cities study (Lepeule et al., 2012).

[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.

[c] Benefit-per-ton values were estimated for the years 2016, 2020, 2025 and 2030. We hold values constant for intervening years (e.g., the 2016 values are assumed to apply to years 2017-2019; 2020 values for years 2021-2024; 2030 values for years 2031 and beyond).

[d] We assume for the purpose of this analysis that "upstream emissions" are most closely associated with refinery sector benefit per-ton values. The majority of upstream emission reductions associated with the NPRM are related to domestic onsite refinery emissions and domestic crude production. While upstream emissions also include storage and transport sources, as well as upstream refinery sources, we have chosen to simply apply the refinery values. Full-scale air quality modeling, and the associated benefits analysis, will include upstream emissions from all sources in the FRM.

The benefit per-ton technique has been used in previous analyses, including EPA's 2017-2025 Light-Duty Vehicle Greenhouse Gas Rule,[65] the Reciprocating Internal Combustion Engine rules,[66,67] and the Residential Wood Heaters NSPS.[68] Table 8-17 shows the quantified $PM_{2.5}$-related co-benefits captured in those benefit per-ton estimates, as well as unquantified effects the benefits per-ton estimates are unable to capture.

Table 8-17 Human Health and Welfare Effects of $PM_{2.5}$

POLLUTANT	QUANTIFIED AND MONETIZED IN PRIMARY ESTIMATES	UNQUANTIFIED EFFECTS CHANGES IN:
$PM_{2.5}$	Adult premature mortality Acute bronchitis Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Chronic and subchronic bronchitis cases Strokes and cerebrovascular disease Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

Consistent with the cost-benefit analysis that accompanied the 2012 PM NAAQS revision, the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. [X,69] To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates.

Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult EPA's "Technical Support Document: Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors."[Y] Readers can also refer to Fann et al. (2012)[70] for a detailed description of the benefit-per-ton methodology.

As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (e.g., NO_2 emitted from on-road mobile sources; direct PM emitted from electricity generating units). Our estimate of $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and PM-related precursor emissions controlled by sector and multiplied by each per-ton value.

As Table 8-17indicates, EPA projects that the per-ton values for reducing emissions of non-GHG pollutants from both vehicle use and upstream sources such as fuel refineries.[Z] These projected increases reflect rising income levels, which increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution.[AA] They also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially among older age groups with the highest mortality risk.[BB]

[X] Although we summarize the main issues in this chapter, we encourage interested readers to see the benefits chapter of the RIA that accompanied the PM NAAQS for a more detailed description of recent changes to the quantification and monetization of PM benefits. Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the PM NAAQS.

[Y] For more information regarding the updated values, see: http://www.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf (accessed September 9, 2014).

[Z] As we discuss in the emissions chapter (Chapter 5), the rule would yield emission reductions from upstream refining and fuel distribution due to decreased petroleum consumption.

[AA] The issue is discussed in more detail in the 2012 PM NAAQS RIA, Section 5.6.8. See U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, EPA-452-R-12-005, December 2012. Available on the internet: http://www.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf

[BB] For more information about EPA's population projections, please refer to the following: http://www.epa.gov/air/benmap/models/BenMAPManualAppendicesAugust2010.pdf (See Appendix K)

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties:

- The benefit-per-ton estimates used here reflect specific geographic patterns of emissions reductions and specific air quality and benefits modeling assumptions associated with the derivation of those estimates (see the TSD describing the calculation of the national benefit-per-ton estimates).[71,CC] Consequently, these estimates may not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors associated with the current analysis. Therefore, use of these benefit-per-ton values to estimate non-GHG benefits may lead to higher or lower benefit estimates than if these benefits were calculated based on direct air quality modeling. EPA will conduct full-scale air quality modeling for the final rulemaking in an effort to capture this variability.
- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources. The PM ISA, which was twice reviewed by SAB-CASAC, concluded that "many constituents of $PM_{2.5}$ can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific outcomes".[72] PM composition and the size distribution of those particles vary within and between areas due to source characteristics. Any specific location could have higher or lower contributions of certain PM species and other pollutants than the national average, meaning potential regional differences in health impact of given control strategies. Depending on the toxicity of each PM species reduced by the proposed standards, assuming equal toxicity could over or underestimate benefits.
- This analysis assumes that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including regions that are in attainment with the fine particle standard. The direction of bias that assuming linear-no threshold model or alternative model introduces depends upon the "true" functional from of the relationship and the specific assumptions and data in a particular analysis. For example, if the true function identifies a threshold below which health effects do not occur, benefits may be overestimated if a substantial portion of those benefits were estimated to occur below that threshold. Alternately, if a substantial portion of the benefits occurred above that threshold, the benefits may be underestimated because an assumed linear no-threshold function may not reflect the steeper slope

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[CC] See also: http://www.epa.gov/airquality/benmap/sabpt.html. The current values available on the webpage have been updated since the publication of the Fann et al., 2012 paper. For more information regarding the updated values, see: http://www.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf (accessed September 9, 2014).

above that threshold to account for all health effects occurring above that threshold.

- There are several health benefit categories that EPA was unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because the NO_X and VOC emission reductions associated with this proposal are also precursors to ozone, reductions in NO_X and VOC would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, ozone-related benefits-per-ton estimates do not exist due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits. Please refer to Chapter 8.6.2for a description of the agency's plan to quantify and monetize the PM- and ozone-related health impacts for the FRM and a description of the unquantified co-pollutant benefits associated with this rulemaking.
- There are many uncertainties associated with the health impact functions that underlie the benefits-per-ton estimates. These include: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the concentration-response function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.
- EPA has investigated methods to characterize uncertainty in the relationship between $PM_{2.5}$ exposure and premature mortality. EPA's final $PM_{2.5}$ NAAQS analysis provides a more complete picture about the overall uncertainty in $PM_{2.5}$ benefits estimates. For more information, please consult the $PM_{2.5}$ NAAQS RIA.[73]
- The benefit-per-ton unit values used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines, incomes, and technology. These projections introduce some uncertainties to the benefit per ton estimates.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as there may be localized impacts associated with the proposed rulemaking. Additionally, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. As discussed above, timing constraints precluded EPA from conducting a full-scale photochemical air quality modeling analysis in time for the

NPRM. For the final rule, however, a national-scale air quality modeling analysis will be performed to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics. The benefits analysis plan for the final rulemaking is discussed in the next section.

8.6.2 Human Health and Environmental Benefits for the Final Rule

8.6.2.1 Human Health and Environmental Impacts

As noted above, to model the ozone and PM air quality benefits of the final standards, EPA plans to use the Community Multiscale Air Quality (CMAQ) model (see Chapter 6 for a description of the CMAQ model). The modeled ambient air quality data will serve as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[DD] BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIAs (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

Table 8-18 lists the PM- and ozone-related benefits categories we will use to quantify the non-GHG incidence impacts associated with the final standards. Table 8-18 also lists non-GHG-related endpoints we are currently unable to quantify and/or monetize.

Table 8-18 Estimated Quantified and Unquantified Health Effects

BENEFITS CATEGORY	*SPECIFIC EFFECT*	*EFFECT HAS BEEN QUANTIFIED*	*EFFECT HAS BEEN MONETIZED*	*MORE INFORMATION*
Improved Human Health				
Reduced incidence of premature mortality and morbidity from exposure to $PM_{2.5}$	Adult premature mortality based on cohort study estimates and expert elicitation estimates (age >25 or age >30)	✓	✓	PM NAAQS RIA, Section 5.6
	Infant mortality (age <1)	✓	✓	PM NAAQS RIA, Section 5.6
	Non-fatal heart attacks (age > 18)	✓	✓	PM NAAQS RIA, Section 5.6
	Hospital admissions—respiratory (all ages)	✓	✓	PM NAAQS RIA, Section 5.6
	Hospital admissions—cardiovascular (age >20)	✓	✓	PM NAAQS RIA, Section 5.6
	Emergency department visits for asthma (all ages)	✓	✓	PM NAAQS RIA, Section 5.6
	Acute bronchitis (age 8–12)	✓	✓	PM NAAQS RIA, Section 5.6
	Lower respiratory symptoms (age 7–14)	✓	✓	PM NAAQS RIA, Section 5.6

[DD] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/benmodels.html.

BENEFITS CATEGORY	*SPECIFIC EFFECT*	*EFFECT HAS BEEN QUANTIFIED*	*EFFECT HAS BEEN MONETIZED*	*MORE INFORMATION*
	Upper respiratory symptoms (asthmatics age 9–11)	✓	✓	PM NAAQS RIA, Section 5.6
	Asthma exacerbation (asthmatics age 6–18)	✓	✓	PM NAAQS RIA, Section 5.6
	Lost work days (age 18–65)	✓	✓	PM NAAQS RIA, Section 5.6
	Minor restricted-activity days (age 18–65)	✓	✓	PM NAAQS RIA, Section 5.6
	Chronic Bronchitis (age >26)	—	—	PM NAAQS RIA, Section 5.6[c]
	Emergency department visits for cardiovascular effects (all ages)	—	—	PM NAAQS RIA, Section 5.6[c]
	Strokes and cerebrovascular disease (age 50–79)	—	—	PM NAAQS RIA, Section 5.6[c]
	Other cardiovascular effects (e.g., other ages)	—	—	PM ISA[a]
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	PM ISA[a]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	PM ISA[a,b]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[a,b]
Reduced incidence of premature mortality and morbidity from exposure to ozone	Premature mortality based on short-term study estimates (all ages)	✓	✓	Ozone ISA
	Premature mortality based on long-term study estimates (age 30–99)	—	—	Ozone ISA[c]
	Hospital admissions—respiratory causes (age > 65)	✓	✓	Ozone ISA
	Hospital admissions—respiratory causes (age <2)	✓	✓	Ozone ISA
	Emergency department visits for asthma (all ages)	✓	✓	Ozone ISA
	Minor restricted-activity days (age 18–65)	✓	✓	Ozone ISA
	School absence days (age 5–17)	✓	✓	Ozone ISA
	Decreased outdoor worker productivity (age 18–65)	✓	✓	Ozone ISA
	Other respiratory effects (e.g., premature aging of lungs)	—	—	Ozone ISA[a]
	Cardiovascular and nervous system effects	—	—	Ozone ISA[b]
	Reproductive and developmental effects	—	—	Ozone ISA[b]
Reduced incidence of morbidity from exposure to air toxics	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene)	—	—	IRIS[a,b]

BENEFITS CATEGORY	SPECIFIC EFFECT	EFFECT HAS BEEN QUANTIFIED	EFFECT HAS BEEN MONETIZED	MORE INFORMATION
	Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein)			

Notes:

[a] We assess these benefits qualitatively because we do not have sufficient confidence in available data or methods.

[b] We assess these benefits qualitatively because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

[c] We assess these benefits qualitatively due to time and resource limitations for this analysis.

Table 8-19 lists the specific PM- and ozone-related health effect exposure-response functions we will use to quantify the non-GHG incidence impacts associated with the final standards.

Table 8-19 Health Impact Functions Used in BenMAP to Estimate Impacts of $PM_{2.5}$ and Ozone Reductions

ENDPOINT	POLLUTANT	STUDY	STUDY POPULATION
Premature Mortality			
Premature mortality – daily time series	O_3	Multi-city Bell et al (2004) (NMMAPS study)[74] – Non-accidental Huang et al (2005)[75] - Cardiopulmonary Schwartz (2005)[76] – Non-accidental Meta-analyses: Bell et al (2005)[77] – All cause Ito et al (2005)[78] – Non-accidental Levy et al (2005)[79] – All cause	All ages
Premature mortality — cohort study, all-cause	$PM_{2.5}$	Krewski et al. (2009)[80] Lepeule et al. (2012)[81]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[82]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[83]	Infant (<1 year)

ENDPOINT	*POLLUTANT*	*STUDY*	*STUDY POPULATION*
Chronic Illness			
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[84] Pooled estimate: Pope et al. (2006)[85] Sullivan et al. (2005)[86] Zanobetti et al. (2009)[87] Zanobetti and Schwartz (2006)[88]	Adults (>18 years)
Hospital Admissions			
Respiratory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[89] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[90,91] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[92] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[93]	<2 years
	$PM_{2.5}$	Pooled estimate: Zanobetti et al. (2009)—ICD 460-519 (All respiratory) Kloog et al. (2012)—ICD 460-519 (All Respiratory)[94]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490–496 (Chronic lung disease)[95]	18–64 years
	$PM_{2.5}$	Pooled estimate: Babin et al. (2007)—ICD 493 (asthma)[96] Sheppard (2003)—ICD 493 (asthma)[97]	<18 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Zanobetti et al. (2009)—ICD 390-459 (all cardiovascular) Peng et al. (2009)—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)[98] Peng et al. (2008)—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)[99] Bell et al. (2008)—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)[100]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	O_3	Pooled estimate: Peel et al (2005)[101] Wilson et al (2005)[102]	 All ages All ages
Asthma-related ER visits (cont'd)	$PM_{2.5}$	Pooled estimate: Mar et al. (2010)[103] Slaughter et al. (2005)[104] Glad et al. (2012)[105]	All ages
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[106]	8–12 years

ENDPOINT	*POLLUTANT*	*STUDY*	*STUDY POPULATION*
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[107]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[108]	7–14 years
Asthma exacerbations	$PM_{2.5}$	<u>Pooled estimate:</u> Ostro et al. (2001)[109] (cough, wheeze and shortness of breath) Mar et al. (2004) (cough, shortness of breath)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[110]	18–65 years
School absence days	O_3	<u>Pooled estimate:</u> Gilliland et al. (2001)[111] Chen et al. (2000)[112]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[113]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

Notes:
[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 7 to 12 for the Mar et al. (2004) study. Based on advice from the SAB-HES, we extended the applied population to 6-18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. EPA-SAB (2004) and NRC (2002).
[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on advice from the National Research Council and EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

8.6.2.2 Monetized Estimates of Impacts of Reductions in Co-Pollutants

Table 8-20 presents the monetary values we will apply to changes in the incidence of health and welfare effects associated with reductions in non-GHG pollutants that will occur when these GHG control strategies are finalized.

Table 8-20 Valuation Metrics Used in BenMAP to Estimate Monetary Co-Benefits

ENDPOINT	VALUATION METHOD	VALUATION (2011$)
Premature mortality	Assumed Mean VSL	$8,300,000
Myocardial Infarctions, Nonfatal	Medical Costs Over 5 Years. Varies by age and discount rate. Russell (1998)[114]	---
	Medical Costs Over 5 Years. Varies by age and discount rate. Wittels (1990)[115]	---
Hospital Admissions		
Respiratory, Age 65+	COI: Medical Costs + Wage Lost	$37,000
Respiratory, Ages 0-2	COI: Medical Costs	$13,000
Chronic Obstructive Pulmonary Disease (COPD)	COI: Medical Costs + Wage Lost	$22,000
Asthma	COI: Medical Costs + Wage Lost	$17,000
Cardiovascular	COI: Medical Costs + Wage Lost (18-64)	$43,000
	COI: Medical Costs + Wage Lost (65-99)	$42,000
ER Visits, Asthma	COI: Average of Smith et al. (1997)[116]	$440
	and Standford et al. (1999)[117]	
Other Health Endpoints		
Acute Bronchitis	WTP: 6 Day Illness, CV Studies	$470
Upper Respiratory Symptoms	WTP: 1 Day, CV Studies	$32
Lower Respiratory Symptoms	WTP: 1 Day, CV Studies	$21
Asthma Exacerbation	WTP: Bad Asthma Day, Rowe and Chestnut (1986) [118]	$57
Work Loss Days	Median Daily Wage, County-Specific (median = $150)	---
Minor Restricted Activity Days	WTP: 1 Day, CV Studies	$66
School Absence Days	Median Daily Wage, Women 25+	$98
Source: Dollar amounts for each valuation method were extracted from BenMAP and adjusted to year 2011 dollars (from year 2000 dollars) using the Consumer Price Urban Index (CPI-U). For endpoints valued using measures of VSL, WTP, or are wage-based, we use the CPI-U for "all items": 224.939 (2011) and 172.2 (2000). For endpoints valued using a Cost-of-Illness measure, we use the CPI-U for "medical care": 375.613 (2009) and 260.8 (2000).		

8.6.2.3 Other Unquantified Health and Environmental Impacts

In addition to the co-pollutant health and environmental impacts we plan to quantify for the analysis of the HD GHG standards, there are a number of other health and human welfare endpoints that we will not be able to quantify because of current limitations in the methods or available data. These impacts are associated with emissions of air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and ethanol), ambient ozone, and ambient $PM_{2.5}$ exposures. For example, we have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). In addition, we are currently unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.

Although there will be impacts associated with air toxic pollutant emission changes that result from this action, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). EPA's Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[119] While EPA has since improved these tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics.

As part of the second prospective analysis of the benefits and costs of the Clean Air Act,[120] EPA conducted a case study analysis of the health effects associated with reducing exposure to benzene in Houston from implementation of the Clean Air Act. While reviewing the draft report, EPA's Advisory Council on Clean Air Compliance Analysis concluded that "the challenges for assessing progress in health improvement as a result of reductions in emissions of hazardous air pollutants (HAPs) are daunting...due to a lack of exposure-response functions, uncertainties in emissions inventories and background levels, the difficulty of extrapolating risk estimates to low doses and the challenges of tracking health progress for diseases, such as cancer, that have long latency periods."[121] EPA continues to work to address these limitations; however, we will not have the methods and tools available for national-scale application in time for the analysis of the final action.[EE]

8.7 Additional Impacts

8.7.1 Cost of Noise, Congestion, and Accidents

Section 8.3 discusses the likely sign of the rebound effect. If net operating costs of the vehicle decline, then we expect a positive rebound effect. Increased vehicle use associated with a positive rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed throughout the day and on where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled during peak periods. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses. Because drivers do not take these added costs into account in deciding when and where to travel, they must be accounted for separately as a cost of the added driving associated with the rebound effect.

EPA and NHTSA rely on estimates of congestion, accident, and noise costs caused by pickup trucks and vans, single unit trucks, buses, and combination tractors developed by the

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[EE] In April, 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit http://epa.gov/air/toxicair/2009workshop.html for more information about the workshop and its associated materials.

Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[122] The FHWA estimates are intended to measure the increases in costs from added congestion, property damages and injuries in traffic accidents, and noise levels caused by various classes of trucks that are borne by persons other than their drivers (or "marginal" external costs). EPA and NHTSA employed estimates from this source previously in the analysis accompanying the light-duty 2012-2016 vehicle rulemaking. The agencies continue to find them appropriate for this analysis after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values.

FHWA's congestion cost estimates for trucks, which are weighted averages based on the estimated fractions of peak and off-peak freeway travel for each class of trucks, already account for the fact that trucks make up a smaller fraction of peak period traffic on congested roads because they try to avoid peak periods when possible. FHWA's congestion cost estimates focus on freeways because non-freeway effects are less serious due to lower traffic volumes and opportunities to re-route around the congestion. The agencies, however, applied the congestion cost to the overall VMT increase, though the fraction of VMT on each road type used in MOVES range from 27 to 29 percent of the vehicle miles on freeways for vocational vehicles and 53 percent for combination tractors. The results of this analysis potentially overestimate the congestions costs associated with increased truck use, and thus lead to a conservative estimate of benefits.

EPA and NHTSA estimated the costs of additional vocational vehicle travel using a weighted average of 15 percent of the FHWA estimate for bus costs and 85 percent of the FHWA estimate for single unit truck costs to reflect the make-up of this segment. The low, mid, and high cost estimates from FHWA updated to 2012 dollars are included in Table 8-21.

Table 8-21 Low-Mid-High Cost Estimates (2012$/mile)

NOISE			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.002	$0.001	$0.000
Vocational Vehicle	$0.024	$0.009	$0.003
Combination Tractor	$0.054	$0.021	$0.006
Accidents			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.086	$0.028	$0.015
Vocational Vehicle	$0.050	$0.017	$0.008
Combination Tractor	$0.073	$0.023	$0.011
Congestion			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.151	$0.051	$0.014
Vocational Vehicle	$0.344	$0.117	$0.031
Combination Tractor	$0.331	$0.113	$0.030

The agencies are using FHWA's "Middle" estimates for marginal congestion, accident, and noise costs caused by increased travel from trucks.[123] This approach is consistent with the methodology used in the HD GHG Phase 1 rule and both LD GHG rules. These costs are multiplied by the annual increases in vehicle miles travelled from the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year. The results are shown in Table 8-22 through Table 8-24.

Table 8-22 Annual Costs & Net Present Values Associated with Increased Noise, Accidents and Congestion for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$9	$26	$82	$117
2022	$18	$51	$103	$172
2023	$27	$76	$123	$226
2024	$35	$102	$141	$279
2025	$44	$127	$159	$330
2026	$52	$151	$177	$379
2027	$59	$173	$192	$425
2028	$66	$194	$207	$467
2029	$72	$213	$221	$506
2030	$78	$230	$234	$542
2035	$100	$294	$282	$676
2040	$111	$330	$317	$758
2050	$126	$375	$370	$871
NPV, 3%	$1,335	$3,934	$4,066	$9,334
NPV, 7%	$593	$1,743	$1,867	$4,202

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-23 Discounted Model Year Lifetime Costs Associated with Increased Noise, Accidents and Congestion for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (3% discount rate, Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$132	$132
2019	$0	$0	$146	$146
2020	$0	$0	$162	$162
2021	$71	$203	$176	$450
2022	$69	$197	$173	$438
2023	$66	$191	$169	$427
2024	$65	$190	$168	$424
2025	$64	$189	$169	$422
2026	$64	$188	$168	$420
2027	$63	$185	$167	$415
2028	$61	$182	$166	$409
2029	$60	$178	$164	$402
Sum	$583	$1,704	$1,959	$4,247

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-24 Discounted Model Year Lifetime Costs Associated with Increased Noise, Accidents and Congestion for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (7% discount rate, Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$85	$85
2019	$0	$0	$94	$94
2020	$0	$0	$103	$103
2021	$45	$129	$110	$284
2022	$42	$120	$104	$266
2023	$39	$112	$98	$250
2024	$37	$108	$94	$239
2025	$35	$103	$91	$229
2026	$33	$98	$88	$219
2027	$32	$93	$84	$209
2028	$30	$88	$80	$198
2029	$28	$83	$76	$187
Sum	$320	$935	$1,106	$2,362

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

8.7.2 Benefits of Reduced Refueling Time

Reducing the fuel consumption of heavy-duty trucks will either increase their driving range before they require refueling, or lead truck manufacturers to offer, and truck purchasers to buy, smaller fuel tanks. Keeping the fuel tank the same size will allow truck operators to reduce the frequency with which drivers typically refuel their vehicles, by extending the upper limit on the distance they can travel before requiring refueling. Alternatively, if truck purchasers and manufacturers respond to improved fuel economy by reducing the size of fuel tanks, the smaller tank will require less time to fill during each refueling stop.

Because refueling time represents a time cost of truck operation, these time savings should be incorporated into truck purchasers' decisions about how much fuel-saving technology they purchase as part of their choices of new vehicles. The savings calculated here thus raise the same questions discussed in preamble Section IX VIII.A and RIA Chapter 8.2: does the apparent existence of these savings reflect failures in the market for fuel economy, or does it reflect costs that are not addressed in this analysis? The response to these questions could vary across truck segment.

No direct estimates of the value of extended vehicle range or reduced fuel tank size are readily available. Instead, this analysis calculates the reduction in the annual amount of time a driver of each type of truck would spend filling its fuel tank; this reduced time could result either from fewer refueling events, if new trucks' fuel tanks stay the same size, or from less time spent filling the tank during each refueling stop, if new trucks' fuels tank are made proportionately smaller. As discussed in Section 8.3 in this RIA, the average number of miles each type of vehicle is driven annually would likely increase under the regulation, as truck operators respond to lower fuel expenditures (the "rebound effect"). The estimates of refueling time with the proposal in effect allow for this increase in truck use. However, the estimate of the rebound effect does not account for any reduction in net operating costs from lower refueling time. Because the rebound effect should measure the change in VMT with respect to the net change in overall operating costs, refueling time costs would ideally factor into this calculation. The effect of this omission is expected to be minor because refueling time savings are generally small relative to the value of reduced fuel expenditures.

The savings in refueling time are calculated as the total amount of time the driver of a typical truck in each class would save each year as a consequence of pumping less fuel into the vehicle's tank. The calculation also includes a fixed time per refill event of 3.5 minutes which would not occur as frequently due to the fewer number of refills.

The calculation uses the reduced number of gallons consumed by truck type and divides that value by the tank volume and refill amount to get the number of refills, then multiplies that by the time per refill to determine the number of hours saved in a given year. The calculation then applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value. The input metrics used in the analysis are included in Table 8-25. The equation for the calculation is shown below:

$$Refueling\ Benefit = \left(\frac{Gal_{reference} - Gal_{policy}}{Gal\ per\ refill}\right) \times \left(\frac{Gal\ per\ refill}{Fuel\ dispense\ rate} + time\ per\ refill\right) \times \left(\frac{\$}{hr}\right)_{labor}$$

The annual impacts associated with reduced refueling time are shown in Table 8-26 and the MY lifetime impacts are shown in Table 8-27 [a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-27and Table 8-28.

Table 8-25 Inputs to Calculate Refueling Time Savings

	HD PICKUP AND VAN	VOCATIONAL VEHICLE	TRACTOR
Fuel Dispensing Rate (gallon/minute)[124]	10	10	20
Refueling fixed time (minutes/refill)[125]	3.5	3.5	3.5
Tank volume (gallons)[a]	30	40	200
Refill amount (%volume/refill) [a]	60%	75%	75%
Resultant time/refill (minutes/refill)	5.3	6.5	11.0
Wage rate (2012$/hr)[126,b]	$27.22	31.01	28.56

Notes:
[a] HD pickup and van values based on a NHTSA survey, other are estimated.
[b] A wage growth rate of 1.2% has been assumed for future years.

Table 8-26 Annual Refueling Benefits and Net Present Values for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Dollar Values in Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUP AND VANS		VOCATIONAL		TRACTOR/TRAILER		SUM OF BENEFITS
	Hours saved (thousands)	Benefits	Hours saved (thousands)	Benefits	Hours saved (thousands)	Benefits	
2018	0	$0	0	$0	90	$3	$3
2019	0	$0	0	$0	183	$6	$6
2020	0	$0	0	$0	278	$9	$9
2021	51	$2	122	$4	598	$19	$25
2022	192	$6	244	$9	999	$32	$47
2023	419	$13	365	$13	1,401	$46	$72
2024	732	$23	620	$22	2,046	$67	$113
2025	1,130	$36	874	$32	2,691	$90	$157
2026	1,611	$52	1,124	$41	3,327	$112	$205
2027	2,164	$70	1,558	$58	4,043	$138	$266
2028	2,699	$89	1,979	$74	4,731	$164	$327
2029	3,211	$107	2,387	$91	5,387	$188	$386
2030	3,694	$125	2,778	$107	6,011	$213	$444
2035	5,595	$200	4,343	$177	8,526	$320	$698
2040	6,695	$254	5,286	$229	10,205	$407	$890
2050	7,788	$334	6,260	$305	12,365	$556	$1,195
NPV, 3%		$2,627		$2,347		$4,436	$9,410
NPV, 7%		$1,067		$950		$1,851	$3,868

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-27 Discounted Model Year Lifetime Refueling Benefits at 3% for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$23	$23
2019	$0	$0	$22	$22
2020	$0	$0	$21	$21
2021	$13	$36	$114	$163
2022	$35	$36	$113	$184
2023	$56	$35	$112	$203
2024	$77	$72	$176	$325
2025	$97	$73	$179	$349
2026	$118	$73	$181	$372
2027	$136	$123	$207	$466
2028	$135	$122	$207	$465
2029	$134	$121	$208	$463
Sum	$801	$691	$1,563	$3,055

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-28 Discounted Model Year Lifetime Refueling Benefits at 7% for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$16	$16
2019	$0	$0	$15	$15
2020	$0	$0	$14	$14
2021	$8	$23	$71	$101
2022	$21	$21	$67	$110
2023	$33	$20	$64	$117
2024	$43	$40	$97	$181
2025	$52	$39	$95	$187
2026	$61	$38	$93	$191
2027	$68	$61	$102	$231
2028	$65	$59	$98	$222
2029	$62	$56	$95	$213
Sum	$413	$357	$827	$1,597

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

8.7.3 Benefits of Increased Travel Associated with Rebound Driving

The increase in travel associated with the rebound effect produces additional benefits to vehicle owners and operators, which reflect the value of the added (or more desirable) social and economic opportunities that become accessible with additional travel. The analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel expenditures incurred plus the vehicle owner/operator surplus from the additional accessibility it provides. As evidenced by the fact that vehicles make more frequent or longer trips when the cost of driving declines, the benefits from this added travel exceed added expenditures for the fuel consumed. Note that the amount by which the benefits from this increased driving *exceed* its increased fuel costs measures the net benefits from the additional travel, usually referred to as increased consumer surplus or, in this case, increased owner/operator surplus. The equation for the calculation of the *total* travel benefit is shown below:

$$Travel\ Benefit = (VMT_{rebound})\left(\frac{\$}{mi}\right)_{policy} + \left(\frac{1}{2}\right)(VMT_{rebound})\left[\left(\frac{\$}{mile}\right)_{reference} - \left(\frac{\$}{mile}\right)_{policy}\right]$$

The agencies' analysis estimates the economic value of the increased owner/operator surplus provided by added driving using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel economy, the value of benefits from increased vehicle use changes by model year and varies among alternative standards. Under even those alternatives that would impose the highest standards, however, the magnitude of the surplus from additional vehicle use represents a small fraction of this benefit. The benefits are shown in Table 8-29 through Table 8-31.

Table 8-29 Annual Value of Increased Travel and Net Present Values at 3% and 7% Discount Rates for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$32	$68	$345	$445
2022	$64	$138	$434	$636
2023	$96	$208	$517	$821
2024	$127	$279	$595	$1,001
2025	$157	$349	$672	$1,179
2026	$186	$416	$744	$1,346
2027	$213	$481	$813	$1,506
2028	$237	$538	$872	$1,647
2029	$261	$593	$929	$1,783
2030	$282	$644	$983	$1,909
2035	$372	$855	$1,217	$2,445
2040	$437	$1,008	$1,428	$2,873
2050	$489	$1,141	$1,656	$3,286
NPV, 3%	$5,021	$11,518	$17,700	$34,240
NPV, 7%	$2,209	$5,045	$8,062	$15,316

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-30 Discounted Model Year Lifetime Value of Increased Travel for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (3% discount rate, Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$554	$554
2019	$0	$0	$618	$618
2020	$0	$0	$686	$686
2021	$252	$548	$711	$1,510
2022	$244	$539	$706	$1,488
2023	$236	$529	$698	$1,463
2024	$232	$522	$680	$1,434
2025	$229	$524	$689	$1,442
2026	$227	$525	$695	$1,447
2027	$223	$511	$688	$1,421
2028	$220	$507	$688	$1,415
2029	$218	$502	$686	$1,406
Sum	$2,080	$4,706	$8,098	$14,884

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-31 Discounted Model Year Lifetime Value of Increased Travel for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (7% discount rate, Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$353	$353
2019	$0	$0	$390	$390
2020	$0	$0	$429	$429
2021	$158	$343	$441	$942
2022	$148	$325	$422	$894
2023	$138	$307	$402	$847
2024	$130	$292	$377	$799
2025	$124	$282	$368	$774
2026	$118	$272	$358	$748
2027	$111	$255	$341	$708
2028	$106	$244	$328	$678
2029	$101	$232	$315	$649
Sum	$1,134	$2,553	$4,524	$8,211

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

8.8 The Effect of Safety Standards and Voluntary Safety Improvements on Vehicle Weight

Safety standards developed by NHTSA in previous rulemakings may make compliance with the fuel efficiency and CO_2 emissions standards more difficult or may reduce the projected benefits of the program. The primary way that safety regulations can impact fuel efficiency and

CO_2 emissions is through increased vehicle weight, which reduces the fuel efficiency (and thus increases the CO_2 emissions) of the vehicle. Using MY 2010 as a baseline, this section discusses the effects of other government regulations on MYs 2014-2016 medium and heavy-duty vehicle fuel efficiency and CO_2 emissions. At this time, no known safety standards will affect new models in MY 2017 or 2018. NHTSA's estimates are based on cost and weight tear-down studies of a few vehicles and cannot possibly cover all the variations in the manufacturers' fleets. NHTSA also requested, and various manufacturers provided, confidential estimates of increases in weight resulting from safety improvements. Those increases are shown in subsequent tables.

We have broken down our analysis of the impact of safety standards that might affect the MYs 2014-2016 fleets into three parts: 1) those NHTSA final rules with known effective dates, 2) proposed rules or soon-to-be proposed rules by NHTSA with or without final effective dates, and 3) currently voluntary safety improvements planned by the manufacturers.

8.8.1 Weight Impacts of Required Safety Standards

NHTSA has undertaken several rulemakings in which several standards would become effective for medium- and heavy-duty (MD/HD) vehicles between MY 2014 and MY 2016. We will examine the potential impact on MD/HD vehicle weights for MYs 2014-2016 using MY 2010 as a baseline.

1. FMVSS 119, Heavy Truck Tires Endurance and High Speed Tests
2. FMVSS 121, Air Brake Systems Stopping Distance
3. FMVSS 214, Motor Coach Lap/Shoulder Belts
4. MD/HD Vehicle Electronic Stability Control Systems

8.8.1.1 FMVSS 119, Heavy Truck Tires Endurance and High Speed Tests

NHTSA tentatively determined that the FMVSS No. 119 performance tests developed in 1973 should be updated to reflect the increased operational speeds and duration of truck tires in commercial service. A Notice of Proposed Rulemaking (NPRM) was issued December 7, 2010 (75 FR 60036). It proposed to increase significantly the stringency of the endurance test and to add a new high speed test. The data in the large truck crash causation study (LTCCS) that preceded that NPRM found that J and L load range tires were having proportionately more problems than the other sizes and the agency's test results indicate that H, J, and L load range tires are more likely to fail the proposed requirements among the targeted F, G, H, J and L load range tires.[127] To address these problems, the H and J load range tires could potentially use improved rubber compounds, which would add no weight to the tires, to reduce heat retention and improve the durability of the tires. The L load range tires, in contrast, appear to need to use high tensile strength steel chords in the tire bead, carcass and belt areas, which would enable a weight reduction with no strength penalties. Thus, if the update to FMVSS No. 119 was finalized, we anticipate no change in weight for H and J load range tires and a small reduction in weight for L load range tires. This proposal could become a final rule with an effective date of MY 2016.

8.8.1.2 FMVSS No. 121, Airbrake Systems Stopping Distance

FMVSS No. 121 contains performance and equipment requirements for braking systems on vehicles with air brake systems. The most recent major final rule affecting FMVSS No. 121 was published on July 27, 2009, and became effective on November 24, 2009 (MY 2009). The final rule requires the vast majority of new heavy truck tractors (approximately 99 percent of the fleet) to achieve a 30 percent reduction in stopping distance compared to currently required levels. Three-axle tractors with a gross vehicle weight rating (GVWR) of 59,600 pounds or less must meet the reduced stopping distance requirements by August 1, 2011 (MY 2011), while two-axle tractors and tractors with a GVWR above 59,600 pounds must meet the reduced stopping distance requirements by the later date of August 1, 2013 (MY 2013). NHTSA determined that there are several brake systems that can meet the requirements established in the final rule, including installation of larger S-cam drum brakes or disc brake systems at all positions, or hybrid disc and larger rear S-cam drum brake systems.

According to data provided by a manufacturer (Bendix) in response to the NPRM, the heaviest drum brakes weigh more than the lightest disc brakes, while the heaviest disc brakes weigh more than the lightest drum brakes. For a three-axle tractor equipped with all disc brakes, then, the total weight could increase by 212 pounds or could decrease by 134 pounds compared to an all-drum-braked tractor, depending on which disc or drum brakes are used for comparison. The improved brakes may add a small amount of weight to the affected vehicles for MYs 2014-2016, resulting in a slight increase in fuel consumption.

8.8.1.3 FMVSS No. 208, Motor coach Lap/Shoulder Belts

NHTSA is proposing lap/shoulder belts for all motorcoach seats. About 2,000 motorcoaches are sold per year in the United States. Based on preliminary results from the agency's cost/weight teardown studies of motor coach seats,[128] NHTSA estimates that the weight added by 3-point lap/shoulder belts ranges from 5.96 to 9.95 pounds per 2-person seat. This is the weight only of the seat belt assembly itself, and does not include changing the design of the seat, reinforcing the floor, walls or other areas of the motor coach. Few current production motor coaches have been installed with lap/shoulder belts on their seats, and the number of vehicles with these belts already installed could be negligible. Assuming a 54 passenger motor coach, the added weight for the 3-point lap/shoulder belt assembly would be in the range of 161 to 269 pounds (27 * (5.96 to 9.95)) per vehicle. This proposal could become a final rule with an effective date of MY 2016.

8.8.2 Electronic Stability Control Systems (ESC) for Medium- and Heavy-Duty (MD/HD) Vehicles

The purpose of an ESC system for MD/HD vehicles is to reduce crashes caused by rollover or by directional loss-of-control. ESC monitors a vehicle's rollover threshold and lateral stability using vehicle speed, wheel speed, steering wheel angle, lateral acceleration, side slip and yaw rate data and upon sensing an impending rollover or loss of directional control situation automatically reduces engine throttle and applies braking forces to individual wheels or sets of wheel to slow the vehicle down and regain directional control. ESC is not currently required in MD/HD vehicles, but could be proposed to be required in these vehicles by NHTSA. FMVSS

No. 105, Hydraulic and electric brake systems, requires multipurpose passenger vehicles, trucks and buses with a GVWR greater than 4,536 kg (10,000 pounds) to be equipped with an antilock brake system (ABS). All MD/HD vehicles having a GVWR of more than 10,000 pounds, are required to have ABS installed by that standard.

In addition to the existing ABS functionality, ESC requires sensors including a yaw rate sensor, lateral acceleration sensor, steering angle sensor and brake pressure sensor along with a brake solenoid valve. According to data provided by Meritor WABCO, the weight of an ESC system for the model 4S4M tractor is estimated to be around 55.5 pounds, and the weight of the ABS only is estimated to be 45.5 pounds. Thus, we estimate the added weight for the ESC for the vehicle to be 10 (55.5 – 45.5) pounds.

8.8.3 Summary – Overview of Anticipated Weight Increases

Table 8-32 summarizes estimates made by NHTSA regarding the weight added by the above discussed standards or likely rulemakings. NHTSA estimates that weight additions required by final rules and likely NHTSA regulations effective in MY 2016 compared to the MY 2010 fleet will increase motor coach vehicle weight by 171-279 pounds and will increase other heavy-duty truck weights by 10 pounds.

Table 8-32 Weight Additions Due to Final Rules or Likely NHTSA Regulations: Comparing MY 2016 to the MY 2010 Baseline Fleet

STANDARD NUMBER	ADDED WEIGHT IN POUNDS MD/HD VEHICLE	ADDED WEIGHT IN KILOGRAMS MD/HD VEHICLE
119	0	0
121	0[a]	0[a]
208 Motor coaches only	161-269	73-122
MD/HD Vehicle Electronic Stability Control Systems	10	4.5
Total Motor coaches	171- 279	77.5-126.5
Total All other MD/HD vehicles	10	4.5

Note:
NHTSA's final rule on Air Brakes, docket NHTSA-2009-0083, dated July 27, 2009, concluded that a small amount of weight would be added to the brake systems but a weight value was not provided.

8.8.4 Effects of Vehicle Mass Reduction on Safety

NHTSA and EPA have been considering the effect of vehicle weight on vehicle safety for the past several years in the context of our joint rulemaking for light-duty vehicle CAFE and GHG standards, consistent with NHTSA's long-standing consideration of safety effects in setting CAFE standards. Combining all modes of impact, the latest analysis by NHTSA for the MYs 2012-2016 final rule[129] found that reducing the weight of the heavier light trucks (LT > 3,870) had a positive overall effect on safety, reducing societal fatalities.

In the context of the current rulemaking for HD fuel consumption and GHG standards, one would expect that reducing the weight of medium-duty trucks similarly would, if anything, have a positive impact on safety. However, given the large difference in weight between light-duty vehicles and medium-duty trucks, and even larger difference between light-duty vehicles and heavy-duty vehicles with loads, the agencies believe that the impact of weight reductions of medium- and heavy-duty trucks would not have a noticeable impact on safety for any of these classes of vehicles.

However, the agencies recognize that it is important to conduct further study and research into the interaction of mass, size and safety to assist future rulemakings, and we expect that the collaborative interagency work currently on-going to address this issue for the light-duty vehicle context may also be able to inform our evaluation of safety effects for the final HD vehicle rule. We intend to continue monitoring this issue going forward, and may take steps in a future rulemaking if it appears that the MD/HD fuel efficiency and GHG standards have unforeseen safety consequences. The American Chemistry Council stated in comments to the agencies that plastics and plastic composite materials provide a new way to lighten vehicles while maintaining passenger safety. They added that properties of plastics including strength to weight ratio, energy absorption, and flexible design make these materials well suited for the manufacture of medium- and heavy-duty vehicles. They submitted supporting analyses with their comments. The National School Transportation Association stated that added structural integrity requirements increase weight of school buses, and thus decrease fuel economy. They asked that if there are safety and fuel economy trade-offs manufacturers should be able to receive a waiver from the regulation requirements. Since no weight reduction is required for school buses – or any other vocational vehicle – the agencies do not believe this is an issue with the current regulation.

8.9 Petroleum, Energy and National Security impact

8.9.1 Energy Security Impacts

The Phase 2 standards are designed to require improvements in the fuel efficiency of medium- and heavy-duty vehicles and, thereby, reduce fuel consumption and GHG emissions. In turn, the Phase 2 standards help to reduce U.S. petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. This reduction in risk increases U.S. energy security. This section summarizes the agency’s estimates of U.S. oil import reductions and energy security benefits of the proposed Phase 2 standards. Additional discussion of this issue can be found in Section IX.H of the preamble.

The U.S., as a large oil importer and oil consumer, is economically vulnerable to outcomes in a volatile global oil market that relies on oil supplies from potentially unstable sources. Much of the world’s oil and gas supplies are located in countries facing social, economic, and demographic challenges, thus making them vulnerable to potential local instability. In 2010, just over 40 percent of world oil supply came from OPEC (e.g., Organization of Petroleum Exporting Countries) nations and the Annual Energy Outlook 2014

(Early Release) projects that this share will rise steadily. In the AEO 2014 (Early Release) projections, OPEC nations supply over 44 percent by 2040.[FF]

Approximately 31 percent of global supply is from Middle East and North African countries alone, a share that is expected to grow.[GG] Measured in terms of the share of world oil resources or the share of global oil export supply, rather than oil production, the concentration of global petroleum resources in OPEC nations is even larger. As another measure of concentration, of the 137 countries/principalities that export either crude or product, the top 12 have recently accounted for over 55 percent of exports.[130] Eight of these countries are members of OPEC, and a ninth is Russia.[HH] In a market where even a 1-2 percent supply loss raises prices noticeably, and where a 10 percent supply loss could lead to an unprecedented price shock, this regional concentration is of concern.[II] Historically, the countries of the Middle East have been the source of eight of the ten major world oil disruptions, with the ninth originating in Venezuela, an OPEC country, and the tenth being Hurricanes Katrina and Rita.[JJ]

One impact of the Proposed Phase 2 HD National Program is that it promotes more efficient use of transportation fuels in the U.S. The result is that it reduces U.S. oil consumption and imports, which reduces both financial and strategic risks associated with a potential disruption in supply or a spike in the cost of a particular energy source. This reduction in risks increases U.S. energy security. For this rule, an "oil premium" approach is utilized that identifies those energy security related economic costs which are not reflected in the market price of oil, and which are expected to change in response to an incremental change in the level of U.S. oil imports.

8.9.2 Impact on U.S. Petroleum Imports

U.S. energy security is broadly defined as the continued availability of energy sources at an acceptable price. Most discussion of U.S. energy security revolves around the topic of the

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[FF] The agencies used the AEO 2014 (Early Release) since this version of AEO was available at the time that fuel savings from the rule were being estimated. The AEO 2014 (Early Release) and the AEO 2014 have very similar energy market and economic projections. For example, world oil prices are the same between the two forecasts.

[GG] Middle East and North African oil supply share reaches 36 percent in 2040 in the AEO (Early Release) Reference Case.

[HH] The other three are Norway, Canada, and the EU, an exporter of product.

[II] For example, the 2005 Hurricanes Katrina/Rita and the 2011 Libyan conflict both led to a 1.8 percent reduction in global crude supply. While the price impact of the latter is not easily distinguished given the rapidly rising post-recession prices, the former event was associated with a 10-15 percent world oil price increase. There are a range of smaller events with smaller but noticeable impacts. Somewhat larger events, such as the 2002/3 Venezuelan Strike and the War in Iraq, corresponded to about a 2.9 percent sustained loss of supply, and was associated with a 28 percent world oil price increase. (Compiled from EIA oil price data, IEA2012 [IEA Response System for Oil Supply Emergencies] (http://www.iea.org/publications/freepublications/publication/EPPD_Brochure_English_2012_02.pdf) See table on P. 11. and Hamilton 2011 "Historical Oil Shocks,"(http://econweb.ucsd.edu/~jhamilto/oil_history.pdf) in *Routledge Handbook of Major Events in Economic History*, pp. 239-265, edited by Randall E. Parker and Robert Whaples, New York: Routledge Taylor and Francis Group, 2013).

[JJ] The events IEA categorized as oil supply disruptions all had a gross peak oil supply loss of at least 1.5 million barrels a day as a result of wars, revolutions, embargoes or strikes involving major oil exporting nations or from major storm events or disasters (like the double Hurricane Katrina/Rita) affecting oil producing/processing regions. IEA 2011 "IEA Response System for Oil Supply Emergencies."

economic costs of U.S. dependence on oil imports. However, it is not imports alone, but both imports and consumption of petroleum from all sources, and their role in economic activity, that expose the U.S. to risk from price shocks in the world oil price. The relative significance of petroleum consumption and import levels for the macroeconomic disturbances that follow from oil price shocks is not fully understood. Recognizing that changing petroleum consumption will change U.S. imports, this assessment of oil costs focuses on those incremental social costs that follow from the resulting changes in imports, employing the usual oil import premium measure. The agencies will review any comments we receive on how to incorporate the impacts of changes in oil consumption, rather than imports exclusively, into our energy security analysis.

The U.S.'s energy security problem is that the U.S. relies on imported oil from potentially unstable sources. In addition, oil exporters have the ability to raise the price of oil by exerting monopoly power through the formation of a cartel, the Organization of Petroleum Exporting Countries (OPEC). These factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes. In 2012, U.S. net expenditures for imports of crude oil and petroleum products were $290 billion, and total consumption expenditure was $634 billion (in 2012$) (see Figure 8-3).[131] Import costs have declined since 2011 but total oil expenditures (domestic and imported) remain near historical highs, at roughly triple the real oil costs experienced by the U.S. from 1986 to 2002.

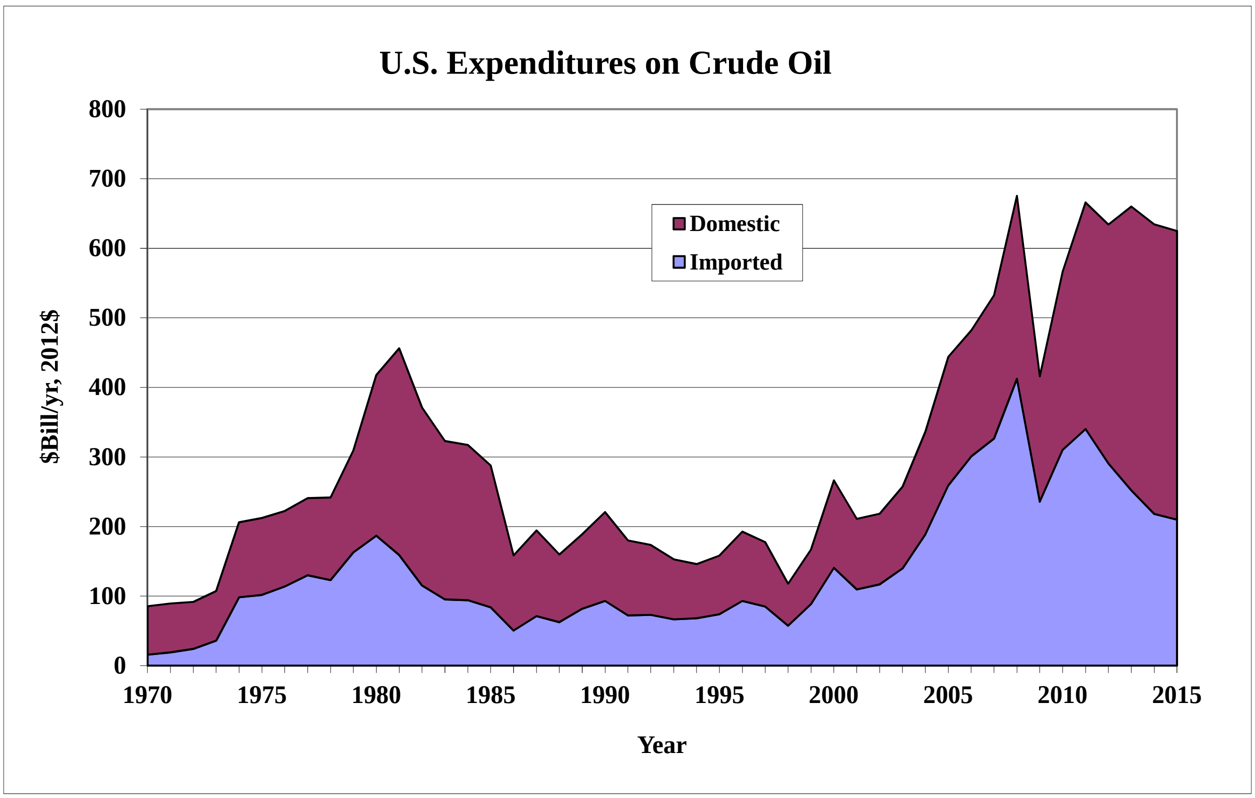

Figure 8-3 U.S. Expenditures on Crude Oil from 1970 through 2015[132]

The agencies used EPA's MOVES model to estimate the reductions in U.S. fuel consumption due to this proposed rule for vocational vehicles and tractors. For HD pickups and vans, the agencies used both DOT's CAFE model and EPA's MOVES model to estimate the fuel consumption impacts. (Detailed explanations of the MOVES and CAFE models can be found in Chapters 5 and 10 of the draft RIA. See IX.C of the preamble for estimates of reduced fuel consumption from the proposed rule). Based on a detailed analysis of differences in U.S. fuel consumption, petroleum imports, and imports of petroleum products, the agencies estimate that approximately 90 percent of the reduction in fuel consumption resulting from adopting improved GHG emissions standards and fuel efficiency standards is likely to be reflected in reduced U.S. imports of crude oil and net imported petroleum products.[KK] Thus, on balance, each gallon of fuel saved as a consequence of the HD GHG and fuel efficiency standards is anticipated to reduce total U.S. imports of petroleum by 0.90 gallons.[LL] Based upon the fuel savings estimated by the MOVES/CAFE models and the 90 percent oil import factor, the reduction in U.S. oil imports from this rule are estimated for the years 2020, 2025, 2030, 2040, and 2050 (in millions of barrels per day (MMBD)) in Table 8-27 below. For comparison purposes, Table 8-27 also shows U.S. imports of crude oil in 2020, 2025, 2030 and 2040 as projected by DOE in the Annual Energy Outlook 2014 (Early Release) Reference Case. U.S. Gross Domestic Product (GDP) is projected to grow by roughly 59 percent between 2020 – 2040 in the AEO 2014 (Early Release) projections.

[KK] We looked at changes in crude oil imports and net petroleum products in the Reference Case in comparison to two cases from the AEO 2014. The two cases are the Low Demand and Low VMT cases. See the spreadsheet "Impacts on Fuel Demands and ImportsJan9.xlsx" comparing the AEO 2014 Reference Case to the Low Demand Case. See the spreadsheet "Impact of Fuel Demand and Impacts January20VMT.xlsl" for a comparison of AEO 2014 Reference Case and the Low VMT Case. We also considered a paper entitled "Effect of a U.S. Demand Reduction on Imports and Domestic Supply Levels" by Paul Leiby, 4/16/2013. This paper suggests that "Given a particular reduction in oil demand stemming from a policy or significant technology change, the fraction of oil use savings that shows up as reduced U.S. imports, rather than reduced U.S. supply, is actually quite close to 90 percent, and probably close to 95 percent".

[LL] The NHTSA analysis uses a slightly different value that was estimated using unique runs of the National Energy Modeling System (NEMS) that forms the foundation of the Annual Energy Outlook. NHTSA ran a version of NEMS from 2012 (which would have been used in the 2013 AEO) and computed the change in imports of petroleum products with and without the Phase 1 MDHD program to estimate the relationship between changes in fuel consumption and oil imports. The analysis found that reducing gasoline consumption by 1 gallon reduces imports of refined gasoline by 0.06 gallons and domestic refining from imported crude by 0.94 gallons. Similarly, one gallon of diesel saved by the Phase 1 rule was estimated to reduce imports of refined diesel by 0.26 gallons and domestic refining of imported crude by 0.74 gallons. The agencies will update this analysis for the Final Rule using the model associated with AEO2014, modeling the Phase 2 Preferred Alternative explicitly.

Table 8-33 Projected U.S. Imports of Crude Oil and U.S. Oil Import Reductions in 2020, 2025, 2030, 2040 and 2050 for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of barrels per day (MMBD)) [a]

YEAR	U.S. OIL IMPORTS	REDUCTIONS FROM PROPOSED HD RULE
2020	4.94	0.01
2025	5.07	0.16
2030	5.38	0.37
2040	6.0	0.65
2050	X	0.78

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
X – The AEO 2014 (Early Release) only projects energy market and economic trends through 2040.

8.9.3 Methodology Used to Estimate U.S. Energy Security Benefits

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled, "*The Energy Security Benefits of Reduced Oil Use, 2006-2015*," completed in March 2008. This ORNL study is an updated version of the approach used for estimating the energy security benefits of U.S. oil import reductions developed in a 1997 ORNL Report.[133] For EPA and NHTSA rulemakings, the ORNL methodology is updated periodically to account for forecasts of future energy market and economic trends reported in the U.S. Energy Information Administration's Annual Energy Outlook.

As part of the process for developing the ORNL energy security estimates, EPA sponsored an independent, expert peer review of the 2008 ORNL study.[134] In addition, EPA worked with ORNL to address comments raised in the peer review and to develop estimates of the energy security benefits associated with a reduction in U.S. oil imports. In response to peer reviewer comments, ORNL modified its model by changing several key parameters involving OPEC supply behavior, the responsiveness of oil demand and supply to a change in the world oil price, and the responsiveness of U.S. economic output to a change in the world oil price.

When conducting this analysis, ORNL considered the full cost of importing petroleum into the U.S. The full economic cost is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs for oil imports resulting from the effect of U.S. demand on the world oil price (i.e., the "demand" or "monopsony" costs); and (2) the risk of reductions in U.S. economic output and disruption to the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (i.e., macroeconomic disruption/adjustment costs).

The literature on the energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global value for the Social Cost of Carbon (SCC) the question arises: how should the energy security premium be used when some benefits from the rule, such as the benefits of reducing greenhouse gas emissions, are calculated from a global perspective? Monopsony benefits represent avoided payments by U.S. consumers to oil producers that result from a decrease in the world oil price as the U.S. decreases its demand for oil. Although there is clearly an overall benefit to the U.S. when considered from a domestic perspective, the decrease in price due to decreased demand in the U.S. also represents a loss to oil producing countries, one of which is the United States. Given the redistributive nature of this monopsony effect from a global perspective, and the fact that an increasing fraction of it represents a transfer from U.S. consumers and producers, it is excluded in the energy security benefits calculations for this proposed rule.

In contrast, the other portion of the energy security premium, the avoided U.S. macroeconomic disruption and adjustment cost that arises from reductions in U.S. petroleum imports, does not have offsetting impacts outside of the U.S., and, thus, is included in the energy security benefits estimated for this proposed rule. To summarize, the agencies have included only the avoided macroeconomic disruption portion of the energy security benefits to estimate the monetary value of the total energy security benefits of this proposed rule.

For this rulemaking, ORNL updated the energy security premiums by incorporating the most recent oil price forecast and energy market trends, particularly regional oil supplies and demands, from the AEO 2014 (Early Release) into its model.[135] Table 8-28 provides estimates for energy security premiums for the years 2020, 2025, 2030 and 2040,[MM] as well as a breakdown of the components of the energy security premiums for each year. The components of the energy security premiums and their values are discussed below.

Table 8-34 Energy Security Premiums in 2020, 2025, 2030 and 2040 (20012$/Barrel)*

YEAR (RANGE)	MONOPSONY (RANGE)	AVOIDED MACROECONOMIC DISRUPTION/ADJUSTMENT COSTS (RANGE)	TOTAL MID-POINT (RANGE)
2020	$4.91 (1.63 – 9.15)	$6.35 (3.07 – 10.15)	$11.25 (6.67 – 16.53)
2025	$5.46 (1.81 – 10.47)	$7.29 (3.57 – 11.67)	$12.75 (7.58 – 18.65)
2030	$6.04 (2.00 – 11.67)	$8.39 (4.12 – 13.41)	$14.43 (8.54 – 21.13)
2040	$7.17 (2.32 – 14.03)	$10.74 (5.36 – 17.22)	$17.91 (10.52 – 26.14)

Note:
*Top values in each cell are the midpoints, the values in parentheses are the 90 percent confidence intervals.

[MM] AEO 2014 (Early Release) forecasts energy market trends and values only to 2040. The post-2040 energy security premium values are assumed to be equal to the 2040 estimate.

8.9.3.1 Effect of Oil Use on the Long-Run Oil Price

The first component of the full economic costs of importing petroleum into the U.S. follows from the effect of U.S. import demand on the world oil price over the long-run. Because the U.S. is a sufficiently large purchaser of global oil supplies, its purchases can affect the world oil price. This monopsony power means that increases in U.S. petroleum demand can cause the world price of crude oil to rise, and conversely, that reduced U.S. petroleum demand can reduce the world price of crude oil. Thus, one benefit of decreasing U.S. oil purchases, due to improvements in the fuel efficiency of medium- and heavy-duty vehicles is the potential decrease in the crude oil price paid for all crude oil purchased.

The demand or monopsony effect can be readily illustrated with an example. If the U.S. imports 10 million barrels per day at a world oil price of $100 per barrel, its total daily bill for oil imports is one billion dollars. If a 10 percent decrease in U.S. imports to 9 million barrels per day causes the world oil price to drop to $99 per barrel, the daily U.S. oil import bill drops to $891 million (9 million barrels times $99 per barrel). While the world oil price only declines $1, the resulting decrease in oil purchase payments of $109 million per day (one billion dollars minus $891 million) is equivalent to an incremental benefit of $109 per barrel of oil imports reduced, or $10 more than the newly-decreased world price of $99 per barrel. This additional $10 per barrel "import cost premium" represents the incremental external benefits to the U.S. for avoided import costs beyond the price paid for oil purchases. This additional benefit from import reduction arises only to the extent that a reduction in U.S. oil imports affects the world oil price. ORNL estimates this component of the energy security benefit in 2020 to be $4.91/barrel, with a range of $1.63/barrel to $9.15/barrel of imported oil reduced.

A variety of oil market and economic factors have contributed to lowering the estimated monopsony premium compared to monopsony premiums cited in recent EPA/NHTSA rulemakings. Three principal factors contribute to lowering the monopsony premium: lower world oil prices, lower U.S. oil imports and less responsiveness of world oil prices to changes in U.S. oil demand. For example, between 2012 (using the AEO 2012 (Early Release)) and 2014 (using the AEO 2014 (Early Release)), there has been a general downward revision in world oil price projections in the near term (e.g. 19 percent in 2020) and a sharp reduction in projected U.S. oil imports in the near term, due to increased U.S. supply (i.e., a 41 percent reduction in U.S. oil imports by 2017 and a 36 percent reduction in 2020). Over the longer term, oil's share of total U.S. imports is projected to gradually increase after 2020 but still remain 27 percent below the AEO 2012 (Early Release) projected level in 2035.

Another factor influencing the monopsony premium is that U.S. demand on the global oil market is projected to decline, suggesting diminished overall influence and some reduction in the influence of U.S. oil demand on the world price of oil. Outside of the U.S., projected OPEC supply remains roughly steady as a share of world oil supply compared to the AEO 2012 (Early Release). OPEC's share of world oil supply *outside* of the U.S. actually increases slightly. Since OPEC supply is estimated to be more price sensitive than non-OPEC supply, this means that under AEO 2014 (Early Release) world oil supply is slightly more responsive to changes in U.S. oil demand. Together, these factors suggest that changes in U.S. oil import reductions have a somewhat smaller effect on the long-run world oil price than changes based the 2012 estimates.

These changes in oil price and import levels lower the monopsony portion of energy security premium since this portion of the security premium is related to the change in total U.S. oil import costs that is achieved by a marginal reduction in U.S oil imports. Since both the price and the quantity of oil imports are lower, the monopsony premium component is 46 – 57 percent lower over the years 2017–2025 than the estimates based upon the AEO 2012 (Early Release) projections.

There is disagreement in the literature about the magnitude of the monopsony component, and its relevance for policy analysis. Brown and Huntington (2013)[136], for example, argue that the United States' refusal to exercise its market power to reduce the world oil price does not represent a proper externality, and that the monopsony component should not be considered in calculations of the energy security externality. However, they also note in their earlier discussion paper (Brown and Huntington 2010)[137] that this is a departure from the traditional energy security literature, which includes sustained wealth transfers associated with stable but higher-price oil markets. On the other hand, Greene (2010)[138] and others in prior literature (e.g., Toman 1993)[139] have emphasized that the monopsony cost component is policy-relevant because the world oil market is non-competitive and strongly influenced by cartelized and government-controlled supply decisions. Thus, while sometimes couched as an externality, Greene notes that the monopsony component is best viewed as stemming from a completely different market failure than an externality (Ledyard 2008)[140], yet still implying marginal social costs to importers.

There is also a question about the ability of gradual, long-term reductions, such as those resulting from this proposed rule, to reduce the world oil price in the presence of OPEC's monopoly power. OPEC is currently the world's marginal petroleum supplier, and could conceivably respond to gradual reductions in U.S. demand with gradual reductions in supply over the course of several years as the fuel savings resulting from this rule grow. However, if OPEC opts for a long-term strategy to preserve its market share, rather than maintain a particular price level (as they have done recently in response to increasing U.S. petroleum production), reduced demand would create downward pressure on the global price. The Oak Ridge analysis assumes that OPEC does respond to demand reductions over the long run, but there is still a price effect in the model. Under the mid-case behavioral assumption used in the premium calculations, OPEC responds by gradually reducing supply to maintain *market share* (consistent with the long-term self-interested strategy suggested by Gately (2004, 2007)).[141]

It is important to note that the decrease in global petroleum prices resulting from this rulemaking could spur increased consumption of petroleum in other sectors and countries, leading to a modest uptick in GHG emissions outside of the United States. This increase in global fuel consumption could offset some portion of the GHG reduction benefits associated with this proposed rule. The agency have not quantified this increase in global GHG emissions. We will review any comments we receive, as well as data sources and methodologies for how global rebound effects may be quantified.

8.9.3.2 Macroeconomic Disruption Adjustment Costs

The second component of the oil import premium, "avoided macroeconomic disruption/adjustment costs," arises from the effect of oil imports on the expected cost of supply disruptions and accompanying price increases. A sudden increase in oil prices triggered by a disruption in world oil supplies has two main effects: (1) it increases the costs of oil imports in the short-run, and (2) it can lead to macroeconomic contraction, dislocation and Gross Domestic Product (GDP) losses. For example, ORNL estimates the combine value of these two factors to be $6.34/barrel when U.S. oil imports are reduced in 2020, with a range from $3.07/barrel to $10.15/barrel of imported oil reduced.

There are two main effects of macroeconomic disruption/adjustment costs. The first is the aggregate effect of the short-run price increase from an oil shock. The oil price shock results in a combination of real resource shortages, costly short-run shifts in energy supply, behavioral and demand adjustments by energy users, and other response costs. Unlike pure transfers, the root cause of the disruption price increase is a real resource supply reduction due, for example, to disaster or war. Regions where supplies are disrupted, such as the U.S., suffer high costs. Businesses' and households' emergency responses to supply disruptions and rapid price increases consume real economic resources.

When households and businesses make decisions related to their oil consumption, such as whether to invest in fuel-saving technologies or use futures markets, they are unlikely to account for the effect of their petroleum consumption on the magnitude of costs that supply interruptions and accompanying price shocks impose on others. As a consequence, the U.S. economy as a whole will not make sufficient use of these mechanisms to insulate itself from the real costs of rapid increases in energy prices and outlays that usually accompany oil supply interruptions. Therefore, the ORNL estimate of avoided macroeconomic disruption/adjustment costs that the agencies use to value energy security benefits includes the increased oil import costs stemming from oil price shocks that are unanticipated and not internalized by advance actions of U.S. consumers and businesses. This aggregate output effect will last as long as the oil price is elevated. It depends on the extent and duration of any disruption in the world supply of oil, since these factors determine the magnitude of the resulting increases in prices for petroleum products, as well as how rapidly these prices return to their pre-disruption level.

The second main effect of macroeconomic disruption/adjustment costs is the macroeconomic losses due to "allocative" losses. These are the costs of temporary dislocation and underutilization of available resources due to the oil shock, such as labor unemployment and idle plant capacity. Because supply disruptions and resulting price increases occur suddenly, empirical evidence shows they impose additional costs on businesses and households that must adjust their use of petroleum and other productive factors more rapidly than if the same price increase had occurred gradually. Dislocational effects include the unemployment of workers and other resources during the time needed for their intersectoral or interregional reallocation, and pauses in capital investment due to uncertainty. These adjustments temporarily reduce the level of economic output that can be achieved even below the "potential" output level that would ultimately be reached once the economy's adaptation to higher petroleum prices is complete. The additional costs imposed on businesses and households for making these adjustments reflect their limited ability to adjust prices, output levels, and their use of energy, labor and other inputs quickly and smoothly in response to rapid changes in prices for petroleum products.

Since future disruptions in foreign oil supplies are an uncertain prospect, each of the disruption cost components must be weighted by the probability that the supply of petroleum to the U.S. will actually be disrupted. Thus, the "expected value" of these costs – the product of the probability that a supply disruption will occur and the sum of costs from reduced economic output and the economy's abrupt adjustment to sharply higher petroleum prices – is the relevant measure of their magnitude. Further, when assessing the energy security value of a policy to reduce oil use, it is only the change in the expected costs of disruption that results from the policy that is relevant. The expected costs of disruption may change from lowering the normal (*i.e.*, pre-disruption) level of domestic petroleum use and imports, from any induced alteration in the likelihood or size of disruption, or from altering the short-run flexibility (*e.g.*, elasticity) of petroleum use.

With updated oil market and economic factors, the avoided macroeconomic disruption component of the energy security premiums is slightly lower in comparison to avoided macroeconomic disruption premiums used in previous rulemakings. There are several reasons why the avoided macroeconomic disruption premiums change only moderately. One reason is that the macroeconomic sensitivity to oil price shocks is assumed unchanged in recent years since U.S. oil consumption levels and the value share of oil in the U.S. economy remain at high levels. For example, Figure 8-4 below shows that under AEO 2014 (Early Release), projected U.S. real annual oil expenditures continue to rise after 2015 to over $800 billion (2012$) by 2030. The value share of oil use in the U.S. economy remains between three and four percent, well above the levels observed from 1985 to 2005. A second factor is that oil disruption risks are little changed. The two factors influencing disruption risks are the probability of global supply interruptions and the world oil supply share from OPEC. Both factors are not significantly different from previous forecasts of oil market trends.

Factors that contribute to moderately lowering the avoided macroeconomic disruption component are lower projected GDP, moderately lower oil prices and slightly smaller price increases during prospective shocks. For example, oil price levels are 5 – 19 percent lower over the 2020 – 2035 period, and the likely increase in oil prices in the event of an oil shock are somewhat smaller, given small increases in the responsiveness of oil supply to changes in the world price of oil. Overall, the avoided macroeconomic disruption component estimates for the oil security premiums are 2 – 19 percent lower over the period from 2020-2035 based upon different projected oil market and economic trends in the AEO 2014 (Early Release) compared to the AEO 2012 (Early Release).

The energy security costs estimated here follow the oil security premium framework, which is well established in the energy economics literature. The oil import premium gained attention as a guiding concept for energy policy around the time of the second and third major post-war oil shocks (Bohi and Montgomery 1982, EMF 1982) .[142] Plummer (1982)[143] provided valuable discussion of many of the key issues related to the oil import premium as well as the analogous oil stockpiling premium. Bohi and Montgomery (1982)[144] detailed the theoretical foundations of the oil import premium established many of the critical analytic relationships through their thoughtful analysis. Hogan (1981)[145] and Broadman and Hogan (1986, 1988)[146] revised and extended the established analytical framework to estimate optimal oil import premia with a more detailed accounting of macroeconomic effects.

Since the original work on energy security was undertaken in the 1980's, there have been several reviews on this topic. For example, Leiby, Jones, Curlee and Lee (1997)[147] provided an extended review of the literature and issues regarding the estimation of the premium. Parry and Darmstadter (2004)[148] also provided an overview of extant oil security premium estimates and estimated of some premium components.

The recent economics literature on whether oil shocks are a threat to economic stability that they once were is mixed. Some of the current literature asserts that the macroeconomic component of the energy security externality is small. For example, the National Research Council (2009) argued that the non-environmental externalities associated with dependence on foreign oil are small, and potentially trivial.[149] Analyses by Nordhaus (2007) and Blanchard and Gali (2010) question the impact of more recent oil price shocks on the economy.[150] They were motivated by attempts to explain why the economy actually expanded immediately after the last shocks, and why there was no evidence of higher energy prices being passed on through higher wage inflation. Using different methodologies, they conclude that the economy has largely gotten over its concern with dramatic swings in oil prices.

One reason, according to Nordhaus, is that monetary policy has become more accommodating to the price impacts of oil shocks. Another is that consumers have simply decided that such movements are temporary, and have noted that price impacts are not passed on as inflation in other parts of the economy. He also notes that real changes to productivity due to oil price increases are incredibly modest,[NN] and that the general direction of the economy matters a great deal regarding how the economy responds to a shock. Estimates of the impact of a price shock on aggregate demand are insignificantly different from zero.

Blanchard and Gali (2010) contend that improvements in monetary policy (as noted above), more flexible labor markets, and lessening of energy intensity in the economy, combined with an absence of concurrent shocks, all contributed to lessen the impact of oil shocks after 1980. They find "… the effects of oil price shocks have changed over time, with steadily smaller effects on prices and wages, as well as on output and employment."[151] In a comment at the chapter's end, this work is summarized as follows: "The message of this chapter is thus optimistic in that it suggests a transformation in U.S. institutions has inoculated the economy against the responses that we saw in the past."

At the same time, the implications of the "Shale Oil Revolution" are now being felt in the international markets, with current prices at four year lows. Analysts generally attribute this result in part to the significant increase in supply resulting from U.S. production, which has put liquid petroleum production on par with Saudi Arabia. The price decline is also attributed to the sustained reductions in U.S. consumption and global demand growth from fuel efficiency policies and high oil prices. The resulting decrease in foreign imports, down to about one-third of domestic consumption (from 60 percent in 2005, for example[152]), effectively permits U.S.

[NN] In fact, "… energy-price changes have no effect on multifactor productivity and very little effect on labor productivity." Page 19. He calculates the productivity effect of a doubling of oil prices as a decrease of 0.11 percent for one year and 0.04 percent a year for ten years. Page 5. (The doubling reflects the historical experience of the post-war shocks, as described in Table 7.1 in Blanchard and Gali, p. 380.)

supply to act as a buffer against artificial or other supply restrictions (the latter due to conflict or natural disaster, for example).

However, other papers suggest that oil shocks, particularly sudden supply shocks, remain a concern. Both Blanchard and Gali's and Nordhaus work were based on data and analysis through 2006, ending with a period of strong global economic growth and growing global oil demand. The Nordhaus work particularly stressed the effects of the price increase from 2002-2006 that were comparatively gradual (about half the growth rate of the 1973 event and one-third that of the 1990 event). The Nordhaus study emphasizes the robustness of the U.S. economy during a time period through 2006. This time period was just before rapid further increases in the price of oil and other commodities with oil prices more-than-doubling to over $130/barrel by mid-2008, only to drop after the onset of the largest recession since the Great Depression.

Hamilton (2012) reviewed the empirical literature on oil shocks and suggested that the results are mixed, noting that some work (e.g. Rasmussen and Roitman (2011) finds less evidence for economic effects of oil shocks, or declining effects of shocks (Blanchard and Gali 2010), while other work continues to find evidence regarding the economic importance of oil shocks. For example, Baumeister and Peersman (2011) found that an oil price increase of a given size seems to have a decreasing effect over time, but noted that the declining price-elasticity of demand meant that a given physical disruption had a bigger effect on price and turned out to have a similar effect on output as in the earlier data."[153] Hamilton observes that "a negative effect of oil prices on real output has also been reported for a number of other countries, particularly when nonlinear functional forms have been employed" (citing as recent examples Kim 2012, Engemann, Kliesen, and Owyang 2011 and Daniel, et. al. 2011). Alternatively, rather than a declining effect, Ramey and Vine (2010) found "remarkable stability in the response of aggregate real variables to oil shocks once we account for the extra costs imposed on the economy in the 1970s by price controls and a complex system of entitlements that led to some rationing and shortages."[154]

Some of the recent literature on oil price shocks has emphasized that economic impacts depend on the nature of the oil shock, with differences between price increases caused by sudden supply loss and those caused by rapidly growing demand. Most recent analyses of oil price shocks have confirmed that "demand-driven" oil price shocks have greater effects on oil prices and tend to have positive effects on the economy while "supply-driven" oil shocks still have negative economic impacts (Baumeister, Peersman and Robays, 2010). A recent paper by Kilian and Vigfusson (2014), for example, assigned a more prominent role to the effects of price increases that are unusual, in the sense of being beyond range of recent experience. Kilian and Vigfussen also conclude that the difference in response to oil shocks may well stem from the different effects of demand- and supply-based price increases: "One explanation is that oil price shocks are associated with a range of oil demand and oil supply shocks, some of which stimulate the U.S. economy in the short run and some of which slow down U.S. growth (see Kilian 2009a). How recessionary the response to an oil price shock is thus depends on the average composition of oil demand and oil supply shocks over the sample period."

The general conclusion that oil supply-driven shocks reduce economic output is also reached in a recently published paper by Cashin et al. (2014) for 38 countries from 1979-2011. "The results indicate that the economic consequences of a supply-driven oil-price shock are very different from those of an oil-demand shock driven by global economic activity, and vary for oil-importing countries compared to energy exporters," and "oil importers [including the U.S.] typically face a long-lived fall in economic activity in response to a supply-driven surge in oil prices" but almost all countries see an increase in real output for an oil-demand disturbance. Note that the energy security premium calculation in this analysis is based on price shocks from potential future supply events only.

Despite continuing uncertainty about oil market behavior and outcomes and the sensitivity of the U.S. economy to oil shocks, it is generally agreed that it is beneficial to reduce petroleum fuel consumption from an energy security standpoint. Reducing fuel consumption reduces the amount of domestic economic activity associated with a commodity whose price depends on volatile international markets. Also, reducing U.S. oil import levels reduces the likelihood and significance of supply disruptions.

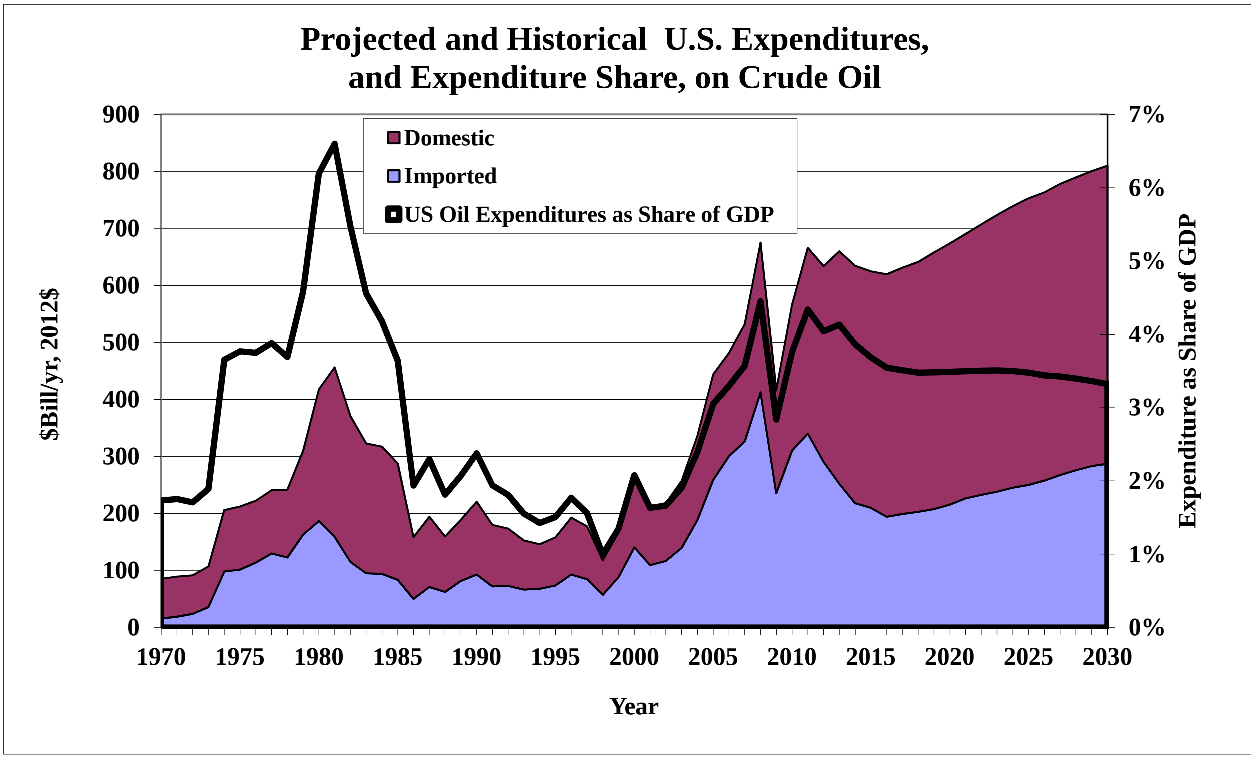

Figure 8-4 Projected and Historical U.S. Expenditures, and Expenditure Share, on Crude Oil[155]

8.9.3.3 Cost of Existing U.S. Energy Security Policies

The last often-identified component of the full economic costs of U.S. oil imports are the costs to the U.S. taxpayers of existing U.S. energy security policies. The two primary examples are maintaining the Strategic Petroleum Reserve (SPR) and maintaining a military presence to help secure a stable oil supply from potentially vulnerable regions of the world. The SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973/74 oil embargo, the SPR provides the U.S. with a response option should a disruption in commercial oil supplies threaten the U.S. economy. It also allows the U.S. to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and it provides a national defense fuel reserve. While the costs for building and maintaining the SPR are more clearly related to U.S. oil use and imports, historically these costs have not varied in response to changes in U.S. oil import levels. Thus, while the effect of the SPR in moderating price shocks is factored into the ORNL analysis, the cost of maintaining the SPR is excluded.

U.S. military costs are excluded from the analysis performed by ORNL because their attribution to particular missions or activities is difficult, and because it is not clear that these outlays would decline in response to incremental reductions in U.S. oil imports. Most military forces serve a broad range of security and foreign policy objectives. Attempts to attribute some share of U.S. military costs to oil imports are further challenged by the need to estimate how those costs might vary with incremental variations in U.S. oil imports.

8.9.4 Energy Security Benefits of this Program

Using the ORNL "oil premium" methodology, updating world oil price values and energy trends using AEO 2014 (Early Release) and using the estimated fuel savings from the proposed rule estimated from the MOVES/CAFE models, the agencies has calculated the energy security benefits of this proposed rule for different classes for medium- and heavy-duty vehicles for the various years up to 2050.[OO] Since the agencies are taking a global perspective with respect to valuing greenhouse gas benefits from the rule, only the avoided macroeconomic adjustment/disruption portion of the energy security premium is used in the energy security benefits estimates present below. These results are shown below in Table 8-35. Table 8-36 and Table 8-37 show discounted model year lifetime energy security benefits for different classes of heavy-duty vehicles using a three and seven percent discount rate.

[OO] In order to determine the energy security benefits beyond 2040, we use the 2040 energy security premium multiplied by the estimate fuel savings from the proposed rule. Since the AEO 2014 (Early Release) only goes to 2040, we only calculate energy security premiums to 2040.

Table 8-35 Annual U.S. Energy Security Benefits and Net Present Values at 3% and 7% Discount Rates for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (in Millions of 2012$) [a]

CALENDAR YEAR	HD PICKUP & VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$10	$10
2019	$0	$0	$20	$20
2020	$0	$0	$31	$31
2021	$3	$6	$69	$77
2022	$10	$12	$118	$140
2023	$23	$19	$170	$211
2024	$41	$33	$255	$328
2025	$65	$47	$344	$456
2026	$95	$63	$438	$596
2027	$131	$91	$548	$770
2028	$167	$120	$660	$947
2029	$204	$150	$772	$1,126
2030	$241	$180	$884	$1,306
2035	$413	$322	$1,421	$2,156
2040	$556	$443	$1,922	$2,920
2050	$647	$522	$2,328	$3,498
NPV, 3%	$5,356	$4,209	$19,383	$28,947
NPV, 7%	$2,163	$1,689	$8,005	$11,857

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-36 Discounted Model Year Lifetime Energy Security Benefits at a 3% Discount Rate for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$86	$86
2019	$0	$0	$85	$85
2020	$0	$0	$84	$84
2021	$24	$55	$455	$534
2022	$66	$54	$458	$579
2023	$107	$54	$460	$621
2024	$148	$116	$732	$996
2025	$190	$118	$751	$1,060
2026	$233	$120	$768	$1,121
2027	$272	$216	$887	$1,375
2028	$273	$217	$898	$1,388
2029	$272	$217	$907	$1,397
Sum	$1,587	$1,168	$6,571	$9,325

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-37 Discounted Model Year Lifetime Energy Security Benefits due to the Preferred Alternative at a 7% Discount Rates for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B using the MOVES Analysis of HD Pickups and Vans and Relative to the Less Dynamic Baseline (Millions of 2012$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$60	$60
2019	$0	$0	$56	$56
2020	$0	$0	$53	$53
2021	$15	$34	$277	$326
2022	$40	$32	$269	$341
2023	$62	$31	$260	$353
2024	$82	$64	$400	$546
2025	$102	$63	$395	$560
2026	$120	$62	$390	$571
2027	$135	$107	$434	$676
2028	$130	$104	$423	$657
2029	$125	$100	$412	$637
Sum	$810	$597	$3,430	$4,837

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

8.10 Summary of Benefits and Costs

This section presents the costs, benefits, and other economic impacts of the proposed Phase 2 standards. It is important to note that NHTSA's proposed fuel consumption standards and EPA's proposed GHG standards would both be in effect, and would jointly lead to increased fuel efficiency and reductions in GHG and non-GHG emissions. The individual categories of benefits and costs presented in the tables below include:

- the vehicle program costs (costs of complying with the vehicle CO2 and fuel consumption standards),
- changes in fuel expenditures associated with reduced fuel use by more efficient vehicles and increased fuel use associated with the "rebound" effect, both of which result from the program,
- the global economic value of reductions in GHGs,
- the economic value of reductions in non-GHG pollutants,
- costs associated with increases in noise, congestion, and accidents resulting from increased vehicle use,
- savings in drivers' time from less frequent refueling,
- benefits of increased vehicle use associated with the "rebound" effect, and
- the economic value of improvements in U.S. energy security impacts.

For a discussion of the cost of ownership and the agencies' payback analysis of vehicles covered by this proposal, please see Chapter 7 of this draft RIA.

The agencies conducted coordinated and complementary analyses using two analytical methods referred to as Method A and Method B. For an explanation of these methods, please see Section I.D for the preamble. And as discussed in preamble Section X.A.1, the agencies present estimates of benefits and costs that are measured against two different assumptions about improvements in fuel efficiency that might occur in the absence of the Phase 2 standards. The first case (Alternative 1a) uses a baseline that projects very little improvement in new vehicles in the absence of new Phase 2 standards, and the second (Alternative 1b) uses a more dynamic baseline that projects more significant improvements in vehicle fuel efficiency.

Table 8-38 shows benefits and costs for the proposed standards from the perspective of a program designed to improve the nation's energy security and conserve energy by improving fuel efficiency. From this viewpoint, technology costs occur when the vehicle is purchased. Fuel savings are counted as benefits that occur over the lifetimes of the vehicles produced during the model years subject to the Phase 2 standards as they consume less fuel. The table shows that benefits far outweigh the costs, and the preferred alternative is anticipated to result in large net benefits to the U.S economy.

Table 8-38 Lifetime Benefits & Costs of the Preferred Alternative for Model Years 2018 - 2029 Vehicles Using Analysis Method A (Billions of 2012$ discounted at 3% and 7%)

CATEGORY	BASELINE 1A		BASELINE 1B	
	3%	7%	3%	7%
Vehicle Program: Technology and Indirect Costs, Normal Profit on Additional Investments	25.4	17.1	25.0	16.8
Additional Routine Maintenance	1.1	0.6	1.0	0.6
Congestion, Accidents, and Noise from Increased Vehicle Use	4.7	2.8	4.5	2.6
Total Costs	**31.1**	**20.5**	**30.5**	**20.0**
Fuel Savings (valued at pre-tax prices)	175.1	94.2	165.1	89.2
Savings from Less Frequent Refueling	3.1	1.6	2.9	1.5
Economic Benefits from Additional Vehicle Use	15.1	8.4	14.7	8.2
Reduced Climate Damages from GHG Emissions [a]	34.9	34.9	32.9	32.9
Reduced Health Damages from Non-GHG Emissions	38.8	20.7	37.2	20.0
Increased U.S. Energy Security	8.9	4.7	8.1	4.3
Total Benefits	**276**	**165**	**261**	**156**
Net Benefits	**245**	**144**	**231**	**136**

Note:
[a] Benefits and net benefits use the 3 percent average global SCC value applied only to CO_2 emissions; GHG reductions include CO_2, CH_4, N_2O and HFC reductions, and include benefits to

other nations as well as the U.S. See Draft RIA Chapter 8.5 and Preamble Section IX.G for further discussion.

Table 8-39, Table 8-40 and Table 8-41 report benefits and cost from the perspective of reducing GHG. Table 8-39 shows the annual impacts and net benefits of the preferred alternative for selected future years, together with the net present values of cumulative annual impacts from 2018 through 2050, discounted at 3 percent and 7 percent rates. Table 8-40 and Table 8-41 show the discounted lifetime costs and benefits for each model year affected by the Phase 2 standards at 3 percent and 7 percent discount rates, respectively.

Table 8-39 Annual Benefits & Costs and Net Present Values for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Billions of 2012$)[a,b,c]

	2018	2021	2024	2030	2035	2040	2050	NPV, 3%	NPV, 7%
Vehicle program	-$0.1	-$2.4	-$3.7	-$5.4	-$5.9	-$6.3	-$7.0	-$86.8	-$41.1
Maintenance	$0.0	$0.0	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$1.8	-$0.9
Pre-tax Fuel	$0.2	$1.7	$6.9	$24.0	$37.2	$47.8	$57.5	$495.6	$206.7
Energy security	$0.0	$0.1	$0.3	$1.3	$2.2	$2.9	$3.5	$28.9	$11.9
Accidents/ Congestion/ Noise	$0.0	-$0.1	-$0.3	-$0.5	-$0.7	-$0.8	-$0.9	-$9.3	-$4.2
Refueling	$0.0	$0.0	$0.1	$0.4	$0.7	$0.9	$1.2	$9.4	$3.9
Travel value	$0.0	$0.4	$1.0	$1.9	$2.4	$2.9	$3.3	$34.2	$15.3
Non-GHG	$0.0 to $0.1	$0.4 to $0.9	$1.0 to $2.4	$3.3 to $8.3	$4.8 to $12.1	$5.7 to $14.3	$7.0 to $17.5	$69.7 to $157.0	$26.6 to $60.4
SCC									
SC-CO_2; 5% avg	$0.0	$0.1	$0.4	$1.5	$2.5	$3.3	$5.0	$22.1	$22.1
SC-CO_2; 3% avg	$0.0	$0.3	$1.3	$4.8	$7.4	$9.7	$13.6	$103.1	$103.1
SC-CO_2; 2.5% avg	$0.1	$0.5	$1.9	$6.9	$10.6	$13.7	$18.5	$164.1	$164.1
SC-CO_2; 3% 95th	$0.1	$1.0	$4.0	$14.6	$23.2	$30.3	$42.0	$320.5	$320.5
Net benefits [d]									
SC-CO_2; 5% avg	$0.2	$0.4	$6.4	$28.8	$46.8	$60.6	$74.6	$605.8	$257.1
SC-CO_2; 3% avg	$0.2	$0.7	$7.3	$32.1	$51.7	$66.9	$83.2	$686.8	$338.1
SC-CO_2; 2.5% avg	$0.2	$0.8	$7.9	$34.2	$54.9	$70.9	$88.2	$747.8	$399.1
SC-CO_2; 3% 95th	$0.3	$1.3	$10.0	$41.9	$67.5	$87.6	$111.7	$904.1	$555.5

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO_2 for internal consistency. Refer to the SCC TSD for more detail.
[c] Section 8.5 of the draft RIA notes that SC-CO_2 increases over time. Corresponding to the years in this table (2020-2050), the SC-CO_2 estimates range as follows: for Average SC-CO_2 at 5%: $7-$16; for Average SC-CO_2 at 3%: $27-$46; for Average SC-CO_2 at 2.5%: $43-$67; and for 95th percentile SC-CO_2 at 3%: $83-$140. Section VIII.F also presents these SC-CO_2 estimates.
[d] Net impacts are the summation of results within columns of the table with the exception that the net impacts at each SC-CO_2 value include only the SC-CO_2 impacts at that value.

The table shows the benefits of reduced CO_2 emissions—and consequently the annual quantified benefits (*i.e.*, total benefits)—for each of four SC-CO_2 values estimated by the interagency working group. As discussed in Section 8.5, there are some limitations to the SC-CO_2 analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

In addition, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (CH_4, N_2O, HFC) expected under this program. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs in this Section 8.10, the value of these reductions should not be interpreted as zero. The reader is referred to Section 8.5.2 of this draft RIA to see the value of those monetized benefits. Also, note that the net reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F of the preamble.

The agencies have also conducted a separate analysis of the total benefits over the model year lifetimes of 2018 through 2029 model year vehicles. In contrast to the calendar year analysis presented in Table 8-39, the model year lifetime analysis shows the impacts of the program on vehicles produced during each of the affected model years over the course of their expected lifetimes. The net societal benefits over the full lifetimes of vehicles produced during each of the model years are shown in Table 8-40 and Table 8-41 at both 3 percent and 7 percent discount rates, respectively.

Table 8-40 Discounted Model Year Lifetime Impacts for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Billions of 2012$; 3% Discount Rate) [a,b,c]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	SUM
Vehicle Program	-$0.1	-$0.1	-$0.1	-$2.0	-$1.9	-$1.9	-$2.8	-$2.7	-$2.7	-$3.7	-$3.6	-$3.5	-$25.1
Maintenance	-$0.1	$0.0	$0.0	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$1.1
Pre-tax Fuel	$1.9	$1.9	$1.8	$11.1	$11.5	$11.9	$18.9	$19.6	$20.2	$24.1	$24.1	$24.1	$171.1
Energy Security	$0.1	$0.1	$0.1	$0.5	$0.6	$0.6	$1.0	$1.1	$1.1	$1.4	$1.4	$1.4	$9.3
Accidents, Noise, Congestion	-$0.1	-$0.1	-$0.2	-$0.4	-$0.4	-$0.4	-$0.4	-$0.4	-$0.4	-$0.4	-$0.4	-$0.4	-$4.2
Refueling	$0.0	$0.0	$0.0	$0.2	$0.2	$0.2	$0.3	$0.3	$0.4	$0.5	$0.5	$0.5	$3.1
Travel value	$0.6	$0.6	$0.7	$1.5	$1.5	$1.5	$1.4	$1.4	$1.4	$1.4	$1.4	$1.4	$14.9
Non-GHG	$0.2 to $0.5	$0.2 to $0.4	$0.2 to $0.4	$2.0 to $4.5	$2.0 to $4.5	$2.0 to $4.5	$2.9 to $6.6	$3.0 to $6.8	$2.6 to $5.9	$3.1 to $6.9	$3.1 to $6.9	$3.1 to $7.0	$24.4 to $55.0
SCC													
$SC\text{-}CO_2$; 5% avg	$0.1	$0.1	$0.1	$0.5	$0.5	$0.5	$0.9	$0.9	$0.9	$1.1	$1.1	$1.1	$7.8
$SC\text{-}CO_2$; 3% avg	$0.4	$0.4	$0.4	$2.2	$2.3	$2.3	$3.7	$3.9	$4.0	$4.8	$4.8	$4.9	$34.0
$SC\text{-}CO_2$; 2.5% avg	$0.6	$0.6	$0.6	$3.4	$3.5	$3.6	$5.8	$6.1	$6.3	$7.6	$7.6	$7.7	$53.4
$SC\text{-}CO_2$; 3% 95th	$1.1	$1.1	$1.1	$6.6	$6.9	$7.2	$11.5	$12.0	$12.4	$14.9	$15.0	$15.1	$105.0
Net benefits [d]													
$SC\text{-}CO_2$; 5% avg	$2.8	$2.7	$2.7	$14.6	$15.1	$15.5	$23.9	$25.0	$25.1	$29.2	$29.4	$29.4	$215.5
$SC\text{-}CO_2$; 3% avg	$3.0	$3.0	$3.0	$16.2	$16.8	$17.3	$26.8	$28.0	$28.2	$33.0	$33.1	$33.2	$241.7
$SC\text{-}CO_2$; 2.5% avg	$3.2	$3.2	$3.2	$17.4	$18.1	$18.6	$28.9	$30.2	$30.5	$35.7	$35.9	$36.0	$261.1
$SC\text{-}CO_2$; 3% 95th	$3.8	$3.8	$3.7	$20.7	$21.5	$22.1	$34.5	$36.0	$36.6	$43.1	$43.3	$43.5	$312.7

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this program (see draft RIA Chapter 8.5). Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero.

[c] Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions ($SC\text{-}CO_2$ at 5, 3, 2.5 percent) is used to calculate net present value of $SC\text{-}CO_2$ for internal consistency. Refer to the SCC TSD for more detail.

[d] Net impacts are the summation of results within columns of the table with the exception that the net impacts at each $SC\text{-}CO_2$ value include only the $SC\text{-}CO_2$ impacts at that value.

Table 8-41 Discounted Model Year Lifetime Impacts for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Billions of 2012$; 7% Discount Rate) [a,b,c]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	SUM
Vehicle Program	-$0.1	-$0.1	-$0.1	-$1.6	-$1.4	-$1.4	-$1.9	-$1.8	-$1.7	-$2.3	-$2.1	-$2.0	-$16.6
Maintenance	$0.0	$0.0	$0.0	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	-$0.1	$0.0	-$0.6
Pre-tax Fuel	$1.4	$1.3	$1.2	$6.9	$6.9	$6.8	$10.5	$10.4	$10.4	$11.9	$11.5	$11.0	$90.1
Energy Security	$0.1	$0.1	$0.1	$0.3	$0.3	$0.4	$0.5	$0.6	$0.6	$0.7	$0.7	$0.6	$4.8
Accidents, Noise, Congestion	-$0.1	-$0.1	-$0.1	-$0.3	-$0.3	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$2.4
Refueling	$0.0	$0.0	$0.0	$0.1	$0.1	$0.1	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$1.6
Travel value	$0.4	$0.4	$0.4	$0.9	$0.9	$0.8	$0.8	$0.8	$0.7	$0.7	$0.7	$0.6	$8.2
Non-GHG	$0.1 to $0.3	$0.1 to $0.3	$0.1 to $0.3	$1.1 to $2.5	$1.1 to $2.4	$1.0 to $2.3	$1.4 to $3.3	$1.4 to $3.2	$1.2 to $2.7	$1.3 to $3.0	$1.3 to $2.9	$1.3 to $2.8	$11.5 to $26.0
SCC													
SC-CO_2; 5% avg	$0.1	$0.1	$0.1	$0.5	$0.5	$0.5	$0.9	$0.9	$0.9	$1.1	$1.1	$1.1	$7.8
SC-CO_2; 3% avg	$0.4	$0.4	$0.4	$2.2	$2.3	$2.3	$3.7	$3.9	$4.0	$4.8	$4.8	$4.9	$34.0
SC-CO_2; 2.5% avg	$0.6	$0.6	$0.6	$3.4	$3.5	$3.6	$5.8	$6.1	$6.3	$7.6	$7.6	$7.7	$53.4
SC-CO_2; 3% 95th	$1.1	$1.1	$1.1	$6.6	$6.9	$7.2	$11.5	$12.0	$12.4	$14.9	$15.0	$15.1	$105.0
Net benefits [d]													
SC-CO_2; 5% avg	$1.9	$1.8	$1.7	$8.7	$8.7	$8.7	$13.0	$13.1	$12.7	$14.3	$13.8	$13.4	$111.8
SC-CO_2; 3% avg	$2.2	$2.1	$2.0	$10.3	$10.4	$10.5	$15.8	$16.1	$15.8	$18.0	$17.6	$17.2	$138.0
SC-CO_2; 2.5% avg	$2.4	$2.3	$2.2	$11.5	$11.7	$11.8	$17.9	$18.3	$18.1	$20.7	$20.4	$20.0	$157.4
SC-CO_2; 3% 95th	$2.9	$2.8	$2.8	$14.8	$15.1	$15.3	$23.6	$24.2	$24.2	$28.1	$27.8	$27.4	$209.0

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this program (see draft RIA Chapter 8.5). Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero.

[c] Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO_2 for internal consistency. Refer to the SCC TSD for more detail.

[d] Net impacts are the summation of results within columns of the table with the exception that the net impacts at each SC-CO_2 value include only the SC-CO_2 impacts at that value.

8.11 Employment Impacts

8.11.1 Introduction

Executive Order 13563 (January 18, 2011) directs federal agencies to consider regulatory impacts on, among other criteria, job creation.[156] According to the Executive Order "Our regulatory system must protect public health, welfare, safety, <u>and our environment</u> while promoting economic growth, innovation, competitiveness, and <u>job creation</u>. It must be based on the best available science." Analysis of employment impacts of a regulation is not part of a standard benefit-cost analysis (except to the extent that labor costs contribute to costs). Employment impacts of federal rules are of general interest, however, and have been particularly so, historically, in the auto sector during periods of challenging labor market conditions. For this reason, we are describing the connections of these proposed standards to employment in the regulated sector, the motor vehicle manufacturing sector, as well as the motor vehicle body and trailer and motor vehicle parts manufacturing sectors.

The overall effect of the proposed rules on motor vehicle sector employment depends on the relative magnitude of output and substitution effects, described below. Because we do not have quantitative estimates of the output effect, and only a partial estimate of the substitution effect, we cannot reach a quantitative estimate of the overall employment effects of the proposed rules on motor vehicle sector employment or even whether the total effect will be positive or negative.

According to the U.S. Bureau of Labor Statistics, in 2014, about 850,000 people in the U.S. were employed in the Motor Vehicle and Parts Manufacturing Sector (NAICS 3361, 3362, and 3363),[157] the directly regulated sector. The employment effects of these proposed rules are expected to expand beyond the regulated sector. Though some of the parts used to achieve the proposed standards are likely to be built by motor vehicle manufacturers (including trailer manufacturers) themselves, the motor vehicle parts manufacturing sector also plays a significant role in providing those parts, and will also be affected by changes in vehicle sales. Changes in truck sales, discussed in Chapter8.4.2, could also affect employment for truck and trailer vendors. As discussed in Chapter 7.2, this proposed rule is expected to reduce the amount of fuel these vehicles use, and thus affect the petroleum refinery and supply industries as well. Finally, since the net reduction in cost associated with these proposed rules is expected to lead to lower transportation and shipping costs, in a competitive market a substantial portion of those cost savings will be passed along to consumers, who then will have additional discretionary income (how much of the cost is passed along to consumers depends on market structure and the relative price elasticities). The proposed rules are not expected to have any notable inflationary or recessionary effect.

The employment effects of environmental regulation are difficult to disentangle from other economic changes and business decisions that affect employment, over time and across regions and industries. In light of these difficulties, we lean on economic theory to provide a constructive framework for approaching these assessments and for better understanding the inherent complexities in such assessments. Neoclassical microeconomic theory describes how profit-maximizing firms adjust their use of productive inputs in response to changes in their economic conditions.[158] Berman and Bui (2001, pp. 274-75) model two components that drive changes in firm-level labor demand: output effects and substitution effects.[159,PP] Regulation can affect the profit-maximizing quantity of output by changing the marginal cost of production. If regulation causes marginal cost to increase, it will place upward pressure on output prices, leading to a decrease in the quantity demanded, and resulting in a decrease in production. The output effect describes how, holding labor intensity constant, a decrease in production causes a decrease in labor demand. As noted by Berman and Bui, although many assume that regulation increases marginal cost, it need not be the case. A regulation could induce a firm to upgrade to less polluting and more efficient equipment that lowers marginal production costs, or it may induce use of technologies that may prove popular with buyers or provide positive network externalities (see Chapter 8.2 for discussion of this effect). In such a case, output could increase.

The substitution effect describes how, holding output constant, regulation affects labor intensity of production. Although increased environmental regulation may increase use of pollution control equipment and energy to operate that equipment, the impact on labor demand is ambiguous. For example, equipment inspection requirements, specialized waste handling, or pollution technologies that alter the production process may affect the number of workers necessary to produce a unit of output. Berman and Bui (2001) model the substitution effect as the effect of regulation on pollution control equipment and expenditures required by the regulation and the corresponding change in labor intensity of production.

In summary, as output and substitution effects may be positive or negative, theory alone cannot predict the direction of the net effect of regulation on labor demand at the level of the regulated firm. Operating within the bounds of standard economic theory, empirical estimation of net employment effects on regulated firms is possible when data and methods of sufficient detail and quality are available. The literature, however, illustrates difficulties with empirical estimation. For example, studies sometimes rely on confidential plant-level employment data from the U.S. Census Bureau, possibly combined with pollution abatement expenditure data that are too dated to be reliably informative. In addition, the most commonly used empirical methods do not permit estimation of net effects.

The conceptual framework described thus far focused on regulatory effects on plant-level decisions within a regulated industry. Employment impacts at an individual plant do not necessarily represent impacts for the sector as a whole. The approach must be modified when applied at the industry level.

At the industry level, labor demand is more responsive if: (1) the price elasticity of demand for the product is high, (2) other factors of production can be easily substituted for labor, (3) the supply of other factors is highly elastic, or (4) labor costs are a large share of total production costs.[160] For example, if all firms in an industry are faced with the same regulatory compliance costs and product demand is inelastic, then industry output may not change much, and output of individual firms may change slightly.[161] In this case, the output effect may be small, while the substitution effect depends on input substitutability. Suppose, for example, that new equipment for fuel efficiency

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[PP] Berman and Bui also discuss a third component, the impact of regulation on factor prices, but conclude that this effect is unlikely to be important for large competitive factor markets, such as labor and capital. Morgenstern, Pizer and Shih (2002) use a very similar model, but they break the employment effect into three parts: 1) a demand effect; 2) a cost effect; and 3) a factor-shift effect.

improvements requires labor to install and operate. In this case, the substitution effect may be positive, and with a small output effect, the total effect may be positive. As with potential effects for an individual firm, theory cannot determine the sign or magnitude of industry-level regulatory effects on labor demand. Determining these signs and magnitudes requires additional sector-specific empirical study. For environmental rules, much of the data needed for these empirical studies is not publicly available, would require significant time and resources in order to access confidential U.S. Census data for research, and also would not be necessary for other components of a typical RIA.

In addition to changes to labor demand in the regulated industry, net employment impacts encompass changes in other related sectors. For example, the proposed standards are expected to increase demand for fuel-saving technologies. This increased demand may increase revenue and employment in the firms providing these technologies. At the same time, the regulated industry is purchasing the equipment, and these costs may impact labor demand at regulated firms. Therefore, it is important to consider the net effect of compliance actions on employment across multiple sectors or industries.

If the U.S. economy is at full employment, even a large-scale environmental regulation is unlikely to have a noticeable impact on aggregate net employment.[QQ] Instead, labor would primarily be reallocated from one productive use to another, and net national employment effects from environmental regulation would be small and transitory (e.g., as workers move from one job to another).[162]

Affected sectors may experience transitory effects as workers change jobs. Some workers may retrain or relocate in anticipation of new requirements or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers. These adjustment costs can lead to local labor disruptions. Although the net change in the national workforce is expected to be small, localized reductions in employment may adversely impact individuals and communities just as localized increases may have positive impacts.

If the economy is operating at less than full employment, economic theory does not clearly indicate the direction or magnitude of the net impact of environmental regulation on employment; it could cause either a short-run net increase or short-run net decrease.[163] An important research question is how to accommodate unemployment as a structural feature in economic models. This feature may be important in assessing large-scale regulatory impacts on employment.[164]

Environmental regulation may also affect labor supply. In particular, pollution and other environmental risks may impact labor productivity or employees' ability to work.[165] While the theoretical framework for analyzing labor supply effects is analogous to that for labor demand, it is more difficult to study empirically. There is a small emerging literature described in the next section that uses detailed labor and environmental data to assess these impacts.

To summarize, economic theory provides a framework for analyzing the impacts of environmental regulation on employment. The net employment effect incorporates expected employment changes (both positive and negative) in the regulated sector and elsewhere. Labor

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[QQ] Full employment is a conceptual target for the economy where everyone who wants to work and is available to do so at prevailing wages is actively employed. The unemployment rate at full employment is not zero.

demand impacts for regulated firms, and also for the regulated industry, can be decomposed into output and substitution effects which may be either negative or positive. Estimation of net employment effects for regulated sectors is possible when data of sufficient detail and quality are available. Finally, economic theory suggests that labor supply effects are also possible. In the next section, we discuss the empirical literature.

8.11.1.1 Current State of Knowledge Based on the Peer-Reviewed Literature

In the labor economics literature there is an extensive body of peer-reviewed empirical work analyzing various aspects of labor demand, relying on the above theoretical framework.[166] This work focuses primarily on the effects of employment policies, e.g. labor taxes, minimum wage, etc.[167] In contrast, the peer-reviewed empirical literature specifically estimating employment effects of environmental regulations is very limited. Several empirical studies, including Berman and Bui (2001),[168] Morgenstern, Pizer and Shih (2002),[169] Gray et al (2014),[170] and Ferris, Shadbegian and Wolverton (2014)[171] suggest that net employment impacts may be zero or slightly positive but small even in the regulated sector. Other research suggests that more highly regulated counties may generate fewer jobs than less regulated ones.[172] However, since these latter studies compare more regulated to less regulated counties, they overstate the net national impact of regulation to the extent that regulation causes plants to locate in one area of the country rather than another. List et al. (2003)[173] find some evidence that this type of geographic relocation may be occurring. Overall, the peer-reviewed literature does not contain evidence that environmental regulation has a large impact on net employment (either negative or positive) in the long run across the whole economy.

Analytic challenges make it very difficult to accurately produce net employment estimates for the whole economy that would appropriately capture the way in which costs, compliance spending, and environmental benefits propagate through the macro-economy. Quantitative estimates are further complicated by the fact that macroeconomic models often have very little sectoral detail and usually assume that the economy is at full employment. EPA is currently in the process of seeking input from an independent expert panel on modeling economy-wide impacts, including employment effects. For more information, see: https://federalregister.gov/a/2014-02471.

8.11.2 Employment Impacts in the Motor Vehicle and Parts Manufacturing Sector

This chapter describes changes in employment in the motor vehicle, trailer, and parts (hence, motor vehicle) manufacturing sectors due to these proposed rules. We focus on the motor vehicle manufacturing sector because it is directly regulated, and because it is likely to bear a substantial share of changes in employment due to these proposed rules. We include discussion of effects on the parts manufacturing sector, because the motor vehicle manufacturing sector can either produce parts internally or buy them from an external supplier, and we do not have estimates of the likely breakdown of effort between the two sectors.

We follow the theoretical structure of Berman and Bui [174] of the impacts of regulation in employment in the regulated sectors. In Berman and Bui's (2001, p. 274-75) theoretical model, as described above, the change in a firm's labor demand arising from a change in regulation is decomposed into two main components: output and substitution effects.[RR] As the output and substitution effects may be both positive, both negative, or some combination, standard neoclassical theory alone does not point to a definitive net effect of regulation on labor demand at regulated firms.

Following the Berman and Bui framework for the impacts of regulation on employment in the regulated sector, we consider two effects for the motor vehicle sector: the output effect and the substitution effect.

8.11.2.1 The Output Effect

If truck or trailer sales increase, then more people will be required to assemble trucks, trailers, and their components. If truck or trailer sales decrease, employment associated with these activities will decrease. The effects of this proposed rulemaking on HD vehicle sales thus depend on the perceived desirability of the new vehicles. On one hand, this proposed rulemaking will increase truck and trailer costs; by itself, this effect would reduce truck and trailer sales. In addition, while decreases in truck performance would also decrease sales, this program is not expected to have any negative effect on truck performance. On the other hand, this proposed rulemaking will reduce the fuel costs of operating the trucks; by itself, this effect would increase truck sales, especially if potential buyers have an expectation of higher fuel prices. The agencies have not made an estimate of the potential change in truck or trailer sales. However, as discussed in Chapter 8.3, the agencies have estimated an increase in vehicle miles traveled (*i.e.*, VMT rebound) due to the reduced operating costs of trucks meeting these proposed standards. Since increased VMT is most likely to be met with more drivers and more trucks, our projection of VMT rebound is suggestive of an increase in vehicle sales and truck driver employment (recognizing that these increases may be partially offset by a decrease in manufacturing and sales for equipment of other modes of transportation such as rail cars or barges).

8.11.2.2 The Substitution Effect

The output effect, above, measures the effect due to new truck and trailer sales only. The substitution effect includes the impacts due to the changes in technologies needed for vehicles to meet the proposed standards, separate from the effect on output (that is, as though holding output constant). This effect includes both changes in employment due to incorporation of abatement technologies and overall changes in the labor intensity of manufacturing. We present estimates for this effect to provide a sense of the order of magnitude of expected impacts on employment,

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[RR] The authors also discuss a third component, the impact of regulation on factor prices, but conclude that this effect is unlikely to be important for large competitive factor markets, such as labor and capital. Morgenstern, Pizer and Shih (2002) use a very similar model, but they break the employment effect into three parts: 1) the demand effect; 2) the cost effect; and 3) the factor-shift effect. See Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. "Jobs Versus the Environment: An Industry-Level Perspective." Journal of Environmental Economics and Management 43 (2002): 412-436 (Docket EPA-HQ-OAR).

which we expect to be small in the automotive sector, and to repeat that regulations may have positive as well as negative effects on employment.

One way to estimate this effect, given the cost estimates for complying with the proposed rule, is to use the ratio of workers to each $1 million of expenditures in that sector. The use of these ratios has both advantages and limitations. It is often possible to estimate these ratios for quite specific sectors of the economy: for instance, it is possible to estimate the average number of workers in the motor vehicle body and trailer manufacturing sector per $1 million spent in the sector, rather than use the ratio from another, more aggregated sector, such as motor vehicle manufacturing. As a result, it is not necessary to extrapolate employment ratios from possibly unrelated sectors. On the other hand, these estimates are averages for the sectors, covering all the activities in those sectors; they may not be representative of the labor required when expenditures are required on specific activities, or when manufacturing processes change sufficiently that labor intensity changes. For instance, the ratio for the motor vehicle manufacturing sector represents the ratio for all vehicle manufacturing, not just for emissions reductions associated with compliance activities. In addition, these estimates do not include changes in sectors that supply these sectors, such as steel or electronics producers. They thus may best be viewed as the effects on employment in the motor vehicle sector due to the changes in expenditures in that sector, rather than as an assessment of all employment changes due to these changes in expenditures. In addition, this approach estimates the effects of increased expenditures while holding constant the labor intensity of manufacturing; it does not take into account changes in labor intensity due to changes in the nature of production. This latter effect could either increase or decrease the employment impacts estimated here.[SS]

Some of the costs of these proposed rules will be spent directly in the motor vehicle manufacturing sector, but it is also likely that some of the costs will be spent in the motor vehicle body and trailer and motor vehicle parts manufacturing sectors. The analysis here draws on estimates of workers per $1 million of expenditures for each of these sectors.

There are several public sources for estimates of employment per $1 million expenditures. The U.S. Bureau of Labor Statistics (BLS) provides its Employment Requirements Matrix (ERM),[175] which provides direct estimates of the employment per $1 million in sales of goods in 202 sectors. The values considered here are for Motor Vehicle Manufacturing (NAICS 3361), Motor Vehicle Body and Trailer Manufacturing (NAICS 3362), and Motor Vehicle Parts Manufacturing (NAICS 3363) for 2012.

The Census Bureau provides the Annual Survey of Manufacturers[176] (ASM), a subset of the Economic Census, based on a sample of establishments; though the Census itself is more complete, it is conducted only every 5 years, while the ASM is annual. Both include more sectoral detail than the BLS ERM: for instance, while the ERM includes the Motor Vehicle Manufacturing sector, the ASM and Economic Census have detail at the 6-digit NAICS code level (e.g., light truck and utility vehicle manufacturing). While the ERM provides direct

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[SS] As noted above, Morgenstern et al. (2002) separate the effect of holding output constant into two effects: the cost effect, which holds labor intensity constant, and the factor shift effect, which estimates those changes in labor intensity.

estimates of employees/$1 million in expenditures, the ASM and Economic Census separately provide number of employees and value of shipments; the direct employment estimates here are the ratio of those values. At this time, the Economic Census values for 2012 (the most recent year) are not fully available; we therefore do not report them, and instead provide the 2011 ASM results (the most recent available). The values reported are for Motor Vehicle Manufacturing (NAICS 3361), Light Truck and Utility Vehicle Manufacturing (NAICS 336112), Heavy Duty Truck Manufacturing (33612), Motor Vehicle Body and Trailer Manufacturing (3362), and Motor Vehicle Parts Manufacturing (NAICS 3363). The values used here are adjusted to remove the employment effects of imports through use of a ratio of domestic production to domestic sales of 0.78.[TT]

Table 8-42 provides the values, either given (BLS) or calculated (ASM) for employment per $1 million of expenditures, all adjusted to 2012 dollars using the Bureau of Economic Analysis's Implicit GDP Price Deflators. Although the ASM appears to provide slightly higher values than the ERM, the different data sources provide similar patterns for the estimates for the sectors. Body and trailer manufacturing and parts manufacturing appear to be more labor-intensive than vehicle manufacturing; light truck and utility vehicle manufacturing appears to be less, and heavy duty truck manufacturing appears to be more, labor-intensive than motor vehicle manufacturing as a whole.

Table 8-42 Employment per $1 Million Expenditures (2012$) in the Motor Vehicle Manufacturing Sector[a]

SOURCE	SECTOR	RATIO OF WORKERS PER $1 MILLION EXPENDITURES	RATIO OF WORKERS PER $1 MILLION EXPENDITURES, ADJUSTED FOR DOMESTIC VS. FOREIGN PRODUCTION
BLS ERM	Motor vehicle mfg (3361)	0.460	0.355
BLS ERM	Motor vehicle body & trailer mfg (3362)	1.450	1.153
BLS ERM	Motor vehicle parts mfg (3363)	1.950	1.590
ASM	Motor vehicle mfg (3361)	0.538	0.414
ASM	Light truck & utility vehicle mfg (336112)	0.443	0.341
ASM	Heavy duty truck mfg (33612)	0.832	0.641
ASM	Motor vehicle body & trailer mfg (3362)	2.797	2.156
ASM	Motor Vehicle Parts Mfg (3363)	1.635	1.260

Note:
[a] BLS ERM refers to the U.S. Bureau of Labor Statistics' Employment Requirement Matrix, 2012 values. ASM refers to the U.S. Census Bureau's Annual Survey of Manufactures, 2011 values.

Over time, the amount of labor needed in the motor vehicle industry has changed: automation and improved methods have led to significant productivity increases. The BLS

[TT] To estimate the proportion of domestic production affected by the change in sales, we use data from Ward's Automotive Group for total truck production in the U.S. compared to total truck sales in the U.S. For the period 2004-2013, the proportion is 78 percent (Docket EPA-HQ-OAR-), ranging from 68 percent (2009) to 83 percent (2012) over that time.

ERM, for instance, provided estimates that, in 1993, 1.52 workers in the Motor Vehicle Manufacturing sector were needed per $1 million, but only 0.53 workers by 2012 (in 2005$).[177] Because the ERM is available annually for 1993-2012, we used these data to estimate productivity improvements over time. We regressed logged ERM values on a year trend for the Motor Vehicle Manufacturing, Motor Vehicle Body and Trailer Manufacturing, and Motor Vehicle Parts Manufacturing sectors. We used this approach because the coefficient describing the relationship between time and productivity is a direct measure of the average percent change in productivity per year. The results suggest a 5.1 percent per year productivity improvement in the Motor Vehicle Manufacturing Sector, and a 4.7 percent per year improvement in the Motor Vehicle Parts Manufacturing Sector. The Motor Vehicle Body and Trailer Manufacturing Sector results were more complex: the workers/$1 million values before 2009 are substantially higher (averaging 5.90 in 2005$) than those in 2009 and after (averaging 2.45 in 2005$); we used dummy variables to account for this shift, and estimate productivity gains of 0.4 percent per year before 2009, and 22 percent after. This dramatic difference may suggest taking care when relying on the data for this sector. As discussed further below, we only report maximum and minimum employment impacts, and the Motor Vehicle Body and Trailer Manufacturing estimates provide the minimum values; they may therefore create greater uncertainty about the lower bound of the substitution-effect employment.

We then used the regression results to project the number of workers per $1 million through 2027. We calculated separate sets of projections (adjusted to 2012$) for both the BLS ERM data as well as the ASM for all three sectors discussed above. The BLS ERM projections were calculated directly from the fitted regression equations since the regressions themselves used ERM data. For the ASM projections, we used the ERM's ratio of the projected value in each future year to the projected value in 2011 (the base year for the ASM) to determine how many workers will be needed per $1 million of 2012$. In other words, we apply the projected productivity growth estimated using the ERM data to the ASM numbers.

Finally, to simplify the presentation and give a range of estimates, we compared the projected employment among the 3 sectors for the ERM and ASM, and we provide only the maximum and minimum employment effects estimated for the ERM and the ASM. We provide the range rather than a point estimate because of the inherent difficulties in estimating employment impacts; the range gives an estimate of the expected magnitude. The details of the calculations may be found in the docket. The ERM estimate in the Motor Vehicle Parts Manufacturing Sector are consistently the maximum values. The ERM estimate in the Motor Vehicle Body and Trailer Manufacturing Sector are the minimum values for all years but 2018-2019, where the ASM value for the Light Truck and Utility Vehicle Manufacturing Sector (336112) provide the minimum values.

Chapter 7 of the draft RIA discusses the vehicle cost estimates developed for these proposed rules. The final step in estimating employment impacts is to multiply costs (in $ millions) by workers per $1 million in costs, to estimate employment impacts in the regulated and parts manufacturing sectors. Increased costs of vehicles and parts would, by itself, and holding labor intensity constant, be expected to increase employment between 2018 and 2027 from none to a few thousand jobs each year.

While we estimate employment impacts, measured in job-years, beginning with program implementation, some of these employment gains may occur earlier as motor vehicle manufacturers and parts suppliers hire staff in anticipation of compliance with the standards. A job-year is a way to calculate the amount of work needed to complete a specific task. For example, a job-year is one year of work for one person.

Table 8-43 Employment Effects due to Increased Costs of Vehicles and Parts (Substitution Effect), in Job-years

YEAR	COSTS (MILLIONS OF 2012$)	MINIMUM EMPLOYMENT DUE TO SUBSTITUTION EFFECT (ERM ESTIMATES, EXPENDITURES IN THE PARTS SECTOR[a])	MAXIMUM EMPLOYMENT DUE TO SUBSTITUTION EFFECT (ERM ESTIMATES, EXPENDITURES IN THE BODY AND TRAILER MFG SECTOR)
2018	$ 116	0	100
2019	$ 113	0	100
2020	$ 112	0	100
2021	$ 2,173	300	2,300
2022	$ 2,161	300	2,200
2023	$ 2,224	200	2,100
2024	$ 3,455	300	3,200
2025	$ 3,647	200	3,200
2026	$ 3,736	200	3,100
2027	$ 5,309	200	4,200

Note:
a For 2018 and 2019, the minimum employment effects are associated with the ASM's Light Truck and Utility Vehicle Manufacturing sector.

8.11.2.3 Summary of Employment Effects in the Motor Vehicle Sector

The overall effect of these proposed rules on motor vehicle sector employment depends on the relative magnitude of the output effect and the substitution effect. Because we do not have quantitative estimates of the output effect, and only a partial estimate of the substitution effect, we cannot reach a quantitative estimate of the overall employment effects of these proposed rules on motor vehicle sector employment or even whether the total effect will be positive or negative.

The proposed standards are not expected to provide incentives for manufacturers to shift employment between domestic and foreign production. This is because the proposed standards will apply to vehicles sold in the U.S. regardless of where they are produced. If foreign manufacturers already have increased expertise in satisfying the requirements of the standards, there may be some initial incentive for foreign production, but the opportunity for domestic manufacturers to sell in other markets might increase. To the extent that the requirements of these proposed rules might lead to installation and use of technologies that other countries may seek now or in the future, developing this capacity for domestic production now may provide some additional ability to serve those markets.

Some vehicle parts are made in-house and would be included directly in the regulated sector. Others are made by independent suppliers and are not directly regulated, but they will be affected by the rules as well. The parts manufacturing sector will be involved primarily in providing "add-on" parts, or components for replacement parts built internally. If demand for these parts increases due to the increased use of these parts, employment effects in this sector are expected to be positive. If the demand effect in the regulated sectors is significantly negative enough, it is possible that demand for other parts may decrease. As noted, the agencies do not predict a direction for the demand effect.

8.11.3 Employment Impacts in Other Affected Sectors

8.11.3.1 Transport and Shipping Sectors

Although not directly regulated by these proposed rules, employment effects in the transport and shipping sector are likely to result from these regulations. If the overall cost of shipping a ton of freight decreases because of increased fuel efficiency (taking into account the increase in upfront purchasing costs), in a perfectly competitive industry these costs savings, depending on the relative elasticities of supply and demand, will be passed along to customers. With lower prices, demand for shipping would lead to an increase in demand for truck shipping services (consistent with the VMT rebound effect analysis) and therefore an increase in employment in the truck shipping sector. In addition, if the relative cost of shipping freight via trucks becomes cheaper than shipping by other modes (*e.g.*, rail or barge), then employment in the truck transport industry is likely to increase. If the trucking industry is more labor intensive than other modes, we would expect this effect to lead to an overall increase in employment in the transport and shipping sectors.[178,179] Such a shift would, however, be at the expense of employment in the sectors that are losing business to trucking. The first effect – a gain due to lower shipping costs – is likely to lead to a net increase in employment. The second effect, due to mode-shifting, may increase employment in trucking, but decrease employment in other shipping sectors (e.g., rail or barge), with the net effects dependent on the labor-intensity of the sectors and the volumes.

8.11.3.2 Fuel Suppliers

In addition to the effects on the trucking industry and related truck parts sector, these proposed rules will result in reductions in fuel use that lower GHG emissions. Fuel saving, principally reductions in liquid fuels such as diesel and gasoline, will affect employment in the fuel suppliers industry sectors, principally the Petroleum Refinery sector.

Chapter 7.2 of this draft RIA provides estimates of the effects of these proposed standards on expected fuel consumption. While reduced fuel consumption represents savings for purchasers of fuel, it also represents a loss in value of output for the petroleum refinery industry, which will result in reduced sectoral employment. Because this sector is material-intensive, the employment effect is not expected to be large.[UU]

[UU] In the 2012 BLS ERM cited above, the Petroleum and Coal Products Manufacturing sector has a ratio of workers per $1 million of 0.242, lower than all but two of the 181 sectors with non-zero employment per $1 million.

8.11.3.3 Fuel Savings

As a result of this proposed rulemaking, it is anticipated that trucking firms will experience fuel savings. Fuel savings lower the costs of transportation goods and services. In a competitive market, some of the fuel savings that initially accrue to trucking firms are likely to be passed along as lower transportation costs that, in turn, could result in lower prices for final goods and services. Some of the savings might also be retained by firms for investments or for distributions to firm owners. Again, how much accrues to customers versus firm owners will depend on the relative elasticities of supply and demand. Regardless, the savings will accrue to some segment of consumers: either owners of trucking firms or the general public, and the effect will be increased spending by consumers in other sectors of the economy, creating jobs in a diverse set of sectors, including retail and service industries.

As described in Chapter 7.2, the value of fuel savings from this proposed rulemaking is projected to be $15.1 billion (2012$) in 2027, according to Table 7-19. If all those savings are spent, the fuel savings will stimulate increased employment in the economy through those expenditures. If the fuel savings accrue primarily to firm owners, they may either reinvest the money or take it as profit. Reinvesting the money in firm operations could increase employment directly. If they take the money as profit, to the extent that these owners are wealthier than the general public, they may spend less of the savings, and the resulting employment impacts would be smaller than if the savings went to the public. Thus, while fuel savings are expected to decrease employment in the refinery sector, they are expected to increase employment through increased consumer expenditures.

8.11.4 Summary of Employment Impacts

The primary employment effects of these rules are expected to be found throughout several key sectors: truck and engine manufacturers, the trucking industry, truck parts manufacturing, fuel production, and consumers. These rules initially take effect in model year 2018, a time period sufficiently far in the future that the unemployment rate at that time is unknowable. In an economy with full employment, the primary employment effect of a rulemaking is likely to be to move employment from one sector to another, rather than to increase or decrease employment. For that reason, we focus our partial quantitative analysis on employment in the regulated sector, to examine the impacts on that sector directly. We discuss the likely direction of other impacts in the regulated sector as well as in other directly related sectors, but we do not quantify those impacts, because they are more difficult to quantify with reasonable accuracy, particularly so far into the future.

For the regulated sector, we have not quantified the output effect. The substitution effect is associated with potential increased employment from none to a few thousand jobs per year between 2018 and 2027, depending on the share of employment impacts in the affected sectors (Motor Vehicle Manufacturing, Motor Vehicle Body and Trailer Manufacturing, and Motor Vehicle Parts Manufacturing). These estimates do not include potential changes, either greater or less, in labor intensity of production. As mentioned above, some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff to prepare to comply with the standard.

Lower prices for shipping are expected to lead to an increase in demand for truck shipping services and, therefore, an increase in employment in that sector, though this effect may be offset somewhat by changes in employment in other shipping sectors. Reduced fuel production implies less employment in the fuel provision sectors. Finally, any net cost savings would be expected to be passed along to some segment of consumers: either the general public or the owners of trucking firms, who are expected then to increase employment through their expenditures. Under conditions of full employment, any changes in employment levels in the regulated sector due to this program are mostly expected to be offset by changes in employment in other sectors.

8.12 Oil Price Sensitivity Analysis using Method B

In this section, EPA presents a sensitivity analysis examining the impact on net benefits using AEO's "low oil price" and "high oil price" cases. The sensitivity analysis is based on the preferred alternative relative to the less dynamic baseline as the "primary" case using Method B. Fuel price changes were not used as an input to technology application rates (i.e., a constant $/vehicle has been used throughout this sensitivity analysis). The primary analysis (presented earlier in this chapter) uses the AEO reference case oil prices. The primary case and both high and low oil price case $/gallon values are shown in Table 8-44.

Table 8-44 AEO Fuel Prices in the Low Oil Price Case, our Primary Analysis Case, and the AEO High Oil Price Case (2012$)

YEAR	RETAIL						UNTAXED					
	Diesel			Gasoline			Diesel			Gasoline		
	Low	Primary	High	Low	Primary	High	Low	Primary	High	Low	Primary	High
2018	$2.94	$3.53	$4.89	$2.54	$3.02	$4.10	$2.48	$3.07	$4.43	$2.13	$2.61	$3.68
2019	$2.95	$3.61	$4.94	$2.54	$3.03	$4.13	$2.49	$3.15	$4.49	$2.13	$2.62	$3.71
2020	$2.96	$3.67	$4.99	$2.55	$3.08	$4.16	$2.51	$3.22	$4.54	$2.15	$2.67	$3.74
2021	$3.00	$3.74	$5.03	$2.59	$3.12	$4.17	$2.55	$3.29	$4.59	$2.19	$2.71	$3.76
2022	$3.01	$3.82	$5.08	$2.59	$3.17	$4.18	$2.56	$3.37	$4.64	$2.19	$2.77	$3.77
2023	$3.01	$3.87	$5.10	$2.57	$3.22	$4.19	$2.57	$3.43	$4.67	$2.18	$2.82	$3.78
2024	$3.02	$3.92	$5.14	$2.56	$3.26	$4.21	$2.58	$3.48	$4.70	$2.16	$2.86	$3.80
2025	$3.03	$3.98	$5.17	$2.55	$3.29	$4.23	$2.59	$3.54	$4.74	$2.16	$2.89	$3.82
2026	$3.04	$4.02	$5.24	$2.55	$3.32	$4.26	$2.60	$3.59	$4.81	$2.16	$2.92	$3.86
2027	$3.03	$4.08	$5.30	$2.54	$3.36	$4.31	$2.60	$3.65	$4.88	$2.15	$2.96	$3.91
2028	$3.03	$4.12	$5.39	$2.54	$3.37	$4.38	$2.61	$3.69	$4.97	$2.16	$2.98	$3.98
2029	$3.04	$4.16	$5.47	$2.54	$3.40	$4.43	$2.61	$3.74	$5.06	$2.16	$3.01	$4.03
2030	$3.06	$4.20	$5.51	$2.55	$3.43	$4.45	$2.64	$3.79	$5.09	$2.17	$3.04	$4.06
2031	$3.06	$4.25	$5.58	$2.55	$3.46	$4.51	$2.64	$3.84	$5.17	$2.17	$3.08	$4.12
2032	$3.06	$4.30	$5.66	$2.56	$3.50	$4.57	$2.64	$3.89	$5.25	$2.18	$3.12	$4.18
2033	$3.07	$4.36	$5.72	$2.57	$3.54	$4.62	$2.66	$3.95	$5.32	$2.20	$3.16	$4.24
2034	$3.08	$4.43	$5.77	$2.58	$3.61	$4.66	$2.67	$4.02	$5.37	$2.21	$3.24	$4.28
2035	$3.08	$4.47	$5.83	$2.58	$3.65	$4.71	$2.67	$4.06	$5.44	$2.22	$3.27	$4.33
2036	$3.09	$4.51	$5.89	$2.59	$3.69	$4.77	$2.68	$4.11	$5.50	$2.23	$3.32	$4.39
2037	$3.09	$4.54	$5.96	$2.59	$3.73	$4.81	$2.69	$4.15	$5.57	$2.23	$3.36	$4.44
2038	$3.10	$4.58	$6.03	$2.60	$3.77	$4.87	$2.70	$4.19	$5.65	$2.24	$3.40	$4.49
2039	$3.11	$4.65	$6.12	$2.61	$3.83	$4.95	$2.71	$4.26	$5.74	$2.25	$3.47	$4.57
2040	$3.11	$4.73	$6.23	$2.61	$3.90	$5.04	$2.72	$4.34	$5.85	$2.26	$3.54	$4.67

Note:

Our Primary case values are the AEO reference case values and are taken from AEO2014 Early Release; other values from AEO2014.

The impacts of using the low and high oil price cases on our estimated fuel savings and net benefits are shown in Table 8-45.

Table 8-45 MY2018-2029 Lifetime Sensitivity on Net Benefits using AEO2014 Low and High Oil Price Cases for the Preferred Alternative Relative to the Less Dynamic Baseline and using Method B (Billions of 2012$) [a]

	LOW OIL PRICE CASE	PRIMARY CASE	HIGH OIL PRICE CASE
Vehicle program	-$25	-$25	-$25
Maintenance	-$1.1	-$1.1	-$1.1
Fuel	$117	$171	$230
Benefits	$93	$97	$101
Net benefits	$184	$242	$305

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

References

[1] Environmental Protection Agency and Department of Transportation, "Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards; Final Rule," Federal Register 75(88) (May 7, 2010), especially Sections III.H.1 (pp. 25510-25513) and IV.G.6 (pp. 25651-25657); Environmental Protection Agency and Department of Transportation, "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule," Federal Register 77(199) (October 15, 2012), especially Sections III.H.1 (pp. 62913-62919) and IV.G.5.a (pp. 63102-63104).

[2] *State of Massachusetts v. EPA*, 549 U.S. at 533.

[3] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," (hereafter, "NAS 2010"). Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (accessed September 10, 2010).

[4] Klemick, Heather, Elizabeth Kopits, Keith Sargent, and Ann Wolverton (2014). "Heavy-Duty Trucking and the Energy Efficiency Paradox." US EPA NCEE Working Paper Series. Working Paper 14-02; Roeth, Mike, Dave Kircher, Joel Smith, and Rob Swim (2013). "Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector." NACFE report for the International Council on Clean Transportation; Aarnink, Sanne, Jasper Faber, and Eelco den Boer (2012). "Market Barriers to Increased Efficiency in the European On-road Freight Sector." CE Delft report for the International Council on Clean Transportation.

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6 Blumstein, Carl and Margaret Taylor (2013). "Rethinking the Energy-Efficiency Gap: Producers, Intermediaries, and Innovation," Energy Institute at Haas Working Paper 243, University of California at Berkeley; Tirole, Jean (1998). *The Theory of Industrial Organization.* Cambridge, MA: MIT Press, pp.400, 402. This first-mover disadvantage must large enough to overcome the incentive normally offered by the potential to for first movers to earn unusually high (but temporary) profit levels.

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[8] Transport Canada, Operating Cost of Trucks, 2005. See http://www.tc.gc.ca/eng/policy/report-acg-operatingcost2005-2005-e-2-1727.htm, accessed on July 16, 2010.

[9] Winebrake, J.J., Green, E.H., Comer, B., Corbett, J.J., Froman, S., 2012. Estimating the direct rebound effect for on-road freight transportation. Energy Policy 48, 252-259.

[10] Greene, D.L., Kahn, J.R., Gibson, R.C., 1999, "Fuel economy rebound effect for U.S. household vehicles", The Energy Journal, 20.

[11] For a discussion of the wide range of definitions found in the literature, see Appendix D: Discrepancy in Rebound Effect Definitions, in EERA (2014), "Research to Inform Analysis of the Heavy-Duty vehicle Rebound Effect", Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025. (Docket ID: EPA-HQ-OAR-2014-0827). See also Greening, L.A., Greene, D.L., Difiglio, C., 2000, "Energy efficiency and consumption — the rebound effect — a survey", Energy Policy, 28, 389-401.

[12] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (last accessed September 10, 2010).

[13] American Transportation Research Institute, *An Analysis of the Operational Costs of Trucking*, September 2013.

[14] Transport Canada, Operating Cost of Trucks, 2005. See http://www.tc.gc.ca/eng/policy/report-acg-operatingcost2005-2005-e-2-1727.htm, accessed on July 16, 2010.

[15] These factors are discussed more fully in a report to EPA from EERA, which illustrates in a series of diagrams the complex system of decisions and decision-makers that could influence the magnitude and timing of the rebound effect. See Sections 2.2.2, 2.2.3, 2.2.4, and 2.3 in EERA (2014), "Research to Inform Analysis of the Heavy-Duty Vehicle Rebound Effect", Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025.

[16] A useful framework for understanding how various responses interact to determine the rebound effect is presented in Section 2 and Appendix B of De Borger, B. and Mulalic, I. (2012), "The determinants of fuel use in the trucking industry – volume, fleet characteristics and the rebound effect", Transportation Policy, Volume 24, pp. 284–295.

See also Section 3.4 of EERA (2014), "Research to Inform Analysis of the Heavy-Duty vehicle Rebound Effect", Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025.

[17] Gately, D., The U.S. Demand for Highway Travel and Motor Fuels, The Energy Journal, Volume 11, No. 3, July 1990, pp.59-73.

[18] Matos, F. J. F., and Silva, F. J. F., "The Rebound Effect on Road Freight Transport: Empirical Evidence from Portugal," Energy Policy, 39, 2011, pp. 2833–2841.

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[20] FHWA Travel Analysis Framework Development of VMT Forecasting Models for Use by the Federal Highway Administration May 12, 2014 http://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_model_dev.pdf. Volpe's work was advised by a panel of approximately 20 experts in the measurement, analysis, and forecasting of travel, including academic researchers, transportation consultants, and members of local, state, and federal government transportation agencies. It was also summarized in the paper "Developing a Multi-Level Vehicle Miles of Travel Forecasting Model," November, 2011, which was presented to the Transportation Research Board's 91st Annual Meeting in January, 2012.

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[26] See, for example, Appendix E in EERA (2014), "Research to Inform Analysis of the Heavy-Duty Vehicle Rebound Effect", Draft Final Report of Phase 1 under EPA contract EP-C-13-025.

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[172] Greenstone, M. (2002). "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures," Journal of Political Economy 110(6): 1175-1219 (Docket EPA-HQ-OAR-2011-0135); Walker, Reed. (2011)."Environmental Regulation and Labor Reallocation." American Economic Review: Papers and Proceedings 101(3): 442-447 (Docket EPA-HQ-OAR-2011-0135).

[173]List, J. A., D. L. Millimet, P. G. Fredriksson, and W. W. McHone (2003). "Effects of Environmental Regulations on Manufacturing Plant Births: Evidence from a Propensity Score Matching Estimator." The Review of Economics and Statistics 85(4): 944-952 (Docket EPA-HQ-OAR-2011-0135).

[174]Berman, E. and L. T. M. Bui (2001). "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." *Journal of Public Economics 79*(2): 265-295 (Docket EPA-HQ-OAR-2011-0135).

[175] http://www.bls.gov/emp/ep_data_emp_requirements.htm.

[176] http://www.census.gov/manufacturing/asm/index.html.

[177] http://www.bls.gov/emp/ep_data_emp_requirements.htm; this analysis used data for sectors 81 (Motor Vehicle Manufacturing), 82 (Motor Vehicle Body and Trailer Manufacturing), and 83 (Motor Vehicle Parts Manufacturing) from "Chain-weighted (2005 dollars) real domestic employment requirements tables."

[178] American Transportation Research Institute, "An Analysis of the Operational Costs of Trucking: 2011 Update." *See* http://www.atri-online.org/research/results/Op_Costs_2011_Update_one_page_summary.pdf.

[179] Association of American Railroads, "All Inclusive Index and Rail Adjustment Factor." June 3, 2011. *See* http://www.aar.org/~/media/aar/RailCostIndexes/AAR-RCAF-2011-Q3.ashx

Chapter 9. Safety Impacts

9.1 Summary of Supporting HD Vehicle Safety Research

NHTSA and EPA considered the potential safety impact of technologies that improve HD vehicle fuel efficiency and GHG emissions as part of the assessment of regulatory alternatives. The safety assessment of the technologies in this proposal was informed by two NAS reports, an analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and agency-sponsored safety testing and research. A summary of the literature and work considered by the agencies follows.

9.2 National Academy of Sciences HD Phase 1 and Phase 2 Reports

As required by EISA, the National Research Council has conducted two studies of the technologies and approaches for reducing the fuel consumption of medium- and heavy-duty vehicles. The first was documented in a report issued in 2010, "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles'' ("NAS Report").[A] The second was documented in a report issued in 2014, "Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two-First Report" ("NAS HD Phase 2 First Report").[B] While the reports primarily focused on reducing vehicle fuel consumption and emissions through technology application, and examined potential regulatory frameworks, both reports additionally contain findings and recommendations on safety. In developing this proposal, the agencies carefully considered both of the reports' findings related to safety. Some of the reports' key findings related to safety follow.

NAS commented that idle reduction strategies can be sophisticated to provide for the safety of the driver in hot and cold weather. The agencies considered this comment in our approach for idle reduction technologies (e.g., APUs, diesel fired heaters, and battery powered units with automatic engine shutoff (AES)) and allow override provisions, as discussed in Preamble Section III. Override of the automatic engine shutoff (AES) feature is allowed if the external ambient temperature reaches a level below which or above which the cabin temperature cannot be maintained within reasonable heat or cold exposure threshold limit values for the health and safety of the operator (not merely comfort).

[A] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles." Washington, D.C., The National Academies Press. Available electronically from the National Academy Press Website at http://www.nap.edu/catalog/12845/technologies-and-approaches-to-reducing-the-fuel-consumption-of-medium--and-heavy-duty-vehicles (last accessed June 4, 2015).

[B] Transportation Research Board 2014. "Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two." Washington, D.C., The National Academies Press. Available electronically from the National Academy Press Website http://www.nap.edu/catalog/18736/reducing-the-fuel-consumption-and-greenhouse-gas-emissions-of-medium--and-heavy-duty-vehicles-phase-two (last accessed June 4, 2015).

NAS commented extensively on the recent emergence of natural gas (NG) as a viable technology option for commercial vehicles, but alluded to the existence of uncertainties regarding its safety. The committee found that while the public crash databases do not contain information on vehicle fuel type, the existing information indicates that the crash-related safety risk for NG storage on vehicles does not appear to be appreciably different from diesel fuel risks. The committee also found that while there are two existing SAE-recommended practice standards for NG-powered HD vehicles, the industry could benefit from best practice directives to minimize crash risks for NG fuel tanks, such as on shielding to prevent punctures during crashes. As a final point, NAS stated that manufacturers and operators have a great incentive to prevent possible NG leakage from a vehicle fuel system because it would be a significant safety concern and reduce vehicle range. No recommendations were made for additional Federal safety regulations for these vehicles. In response, the agencies have reviewed and discuss the existing NG vehicle standards and best practices cited by NAS in Section XI.

In the NAS Committee's Phase 1 report, the Committee commented that aerodynamic fairings detaching from trucks on the road was a potential safety issue. However, the Phase 2 interim report stated that "Anecdotal information gained during the observations of on-road trailers indicates a few skirts badly damaged or missing from one side. The skirt manufacturers report no safety concerns (such as side skirts falling off) and little maintenance needed."

The NAS report also identified the link between tire inflation and condition and vehicle stopping distance and handling, which impacts overall safety. The committee found that tire pressure monitoring systems and automatic tire inflation systems are being adopted by fleets at an increasing rate. However, the committee noted that there are no standards for performance, display, and system validation. The committee recommended that NHTSA issue a white paper on the minimum performance of tire pressure systems from a safety perspective.

The agencies considered the safety findings in both NAS reports in developing this proposal and conducted additional research on safety to further examine information and findings of the reports.

9.3 DOT CAFE Model HD Pickup and Van Safety Analysis

This analysis considered the potential effects on crash safety of the technologies manufacturers may apply to their HD pickups and vans to meet each of the regulatory alternatives evaluated. NHTSA research has shown that vehicle mass reduction affects overall societal fatalities associated with crashes and, most relevant to this proposal, that mass reduction in heavier light- and medium-duty vehicles has an overall beneficial effect on societal fatalities. Reducing the mass of a heavier vehicle involved in a crash with another vehicle(s) makes it less likely that there will be fatalities among the occupants of the other vehicles. In addition to the effects of mass reduction, the analysis anticipates that the proposed standards, by reducing the cost of driving HD pickups and vans, would lead to increased travel by these vehicles and, therefore, more crashes involving these vehicles. The Method A analysis considers overall impacts from both of these factors, using a methodology similar to NHTSA's analyses for the MYs 2017 – 2025 CAFE and GHG emission standards.

The Method A analysis includes estimates of the extent to which HD pickups and vans produced during MYs 2014-2030 may be involved in fatal crashes, considering the mass, survival, and mileage accumulation of these vehicles, taking into account changes in mass and mileage accumulation under each regulatory alternative. These calculations make use of the same coefficients applied to light trucks in the MYs 2017-2025 CAFE rulemaking analysis. As discussed above, vehicle miles traveled may increase due to the fuel economy rebound effect, resulting from improvements in vehicle fuel efficiency and cost of fuel, as well as the assumed future growth in average vehicle use. Increases in total lifetime mileage increase exposure to vehicle crashes, including those that result in fatalities. Consequently, the modeling system computes total fatalities attributed to vehicle use for vehicles of a given model year based on safety class and weight threshold. These calculations also include a term that accounts for the fact that vehicles involved in future crashes will be certified to more stringent safety standards than those involved with past crashes upon which the base rates of involvement in fatal crashes were estimated. Since the use of mass reducing technology is present within the model, safety impacts may also be observed whenever a vehicle's base weight decreases. Thus, in addition to computing total fatalities related to vehicle use, the modeling system also estimates changes in fatalities due to reduction in a vehicle's curb weight.

The total fatalities attributed to vehicle use and vehicle weight change for vehicles of a given model year are then summed. Lastly, total fatalities occurring within the industry in a given model year are accumulated across all vehicles. In addition to using inputs to estimate the future involvement of modeled vehicles in crashes involving fatalities, the model also applies inputs defining other accident-related externalities estimated on a dollar per mile basis. For vehicles above 4,594 pounds—i.e., the majority of the HD pickup and van fleet—mass reduction is estimated to reduce the net incidence of highway fatalities by 0.34 percent per 100 pounds of removed curb weight. For the few HD pickups and vans below 4,594 pounds, mass reduction is estimated to increase the net incidence of highway fatalities by 0.52 percent per 100 pounds. Because there are many more HD pickups and vans above 4,594 pounds than below 4,594 pounds, the overall effect of mass reduction in the segment is estimated to reduce the incidence of highway fatalities. The estimated increase in vehicle miles traveled due to the fuel economy rebound effect is estimated to increase exposure to vehicle crashes and offset these reductions.

9.4 Volpe Research on MD/HD Fuel Efficiency Technologies

The 2010 NAS Report recommended that NHTSA perform a thorough safety analysis to identify and evaluate potential safety issues with fuel efficiency-improving technologies. The Department of Transportation Volpe Center's 2015 report titled "Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel Efficiency Technologies and Alternative Fuels in Medium- and Heavy-Duty Vehicles" [C] summarizes research and analysis findings on potential safety issues associated with both the diverse alternative fuels (natural gas-CNG and LNG, propane, biodiesel, and power train electrification), and the specific FE

[C] Brecher, A., Epstein, A. K., & Breck, A. (2015, June). "Review and analysis of potential safety impacts of and regulatory barriers to fuel efficiency technologies and alternative fuels in medium- and heavy-duty vehicles." (Report No. DOT HS 812 159). Washington, DC: National Highway Traffic Safety Administration.

technologies recently adopted by the MD/HDV fleets. These include Intelligent Transportation Systems (ITS) and telematics, speed limiters, idle reduction devices, tire technologies (single-wide tires, and tire pressure monitoring systems-TPMS and Automated Tire Inflation Systems-ATIS), aerodynamic components, vehicle light-weighting materials, and Long Combination Vehicles (LCVs).

Chapter 1 provides an overview of the study's rationale, background, and key objective, namely, to identify the technical and operational/behavioral safety benefits and disbenefits of MD/HDVs equipped with FE technologies and using emerging alternative fuels (AFs). Recent MD/HDV national fleet crash safety statistical averages are also provided for context, although no information exists in crash reports relating to specific vehicle FE technologies and fuels. (NHTSA/FARS and FMCSA/CSA databases do not include detailed information on vehicle fuel economy technologies, since the state crash report forms are not coded down to an individual fuel economy technology level).

Chapters 2 and 3 are organized by clusters of functionally-related FE technologies for vehicles and trailers (e.g., tire systems, ITS, light-weighting materials, and aerodynamic systems) and alternative fuels, which are described and their respective associated potential safety issues are discussed. Chapter 2 summarizes the findings from a comprehensive review of available technical and trade literature and Internet sources regarding the benefits, potential safety hazards, and the applicable safety regulations and standards for deployed FE technologies and alternative fuels. Chapter 2 safety-relevant fuel-specific findings include:

- Both CNG- and LNG-powered vehicles present potential hazards, and call for well-known engineering and process controls to assure safe operability and crashworthiness. However, based on the reported incident rates of NGVs and the experiences of adopting fleets, it appears that NGVs can be operated at least as safely as diesel MD/HDVs.

- There are no safety contraindications to the large scale fleet adoption of CNG or LNG fueled heavy duty trucks and buses, and there is ample experience with the safe operation of large public transit fleets. Voluntary industry standards and best practices suffice for safety assurance, though improved training of CMV operators and maintenance staff in natural gas safety of equipment and operating procedures is needed.

- Observing CNG and LNG fuel system and maintenance facility standards, coupled with sound design, manufacture, and inspection of natural gas storage tanks will further reduce the potential for leaks, tank ruptures, fires, and explosions.

- Biodiesel blends used as drop-in fuels have presented some operational safety concerns dependent on blending fraction, such as material compatibility, bio-fouling sludge accumulation, or cold-weather gelling. However, best practices for biodiesel storage, and improved gaskets and seals that are biodiesel resistant, combined with regular maintenance and leak inspection schedules for the fuel lines and components enable the safe use of biodiesel in newer MD/HDVs

- Propane (LPG, or autogas) presents well-known hazards including ignition (due to leaks or crash) that are preventable by using Overfill Prevention Devices (OPDs), which supplement the automatic stop-fill system on the fueling station side, and pressure release devices (PRDs). Established best practices and safety codes (e.g., NFPA) have proven that propane fueled MD/HDVs can be as operationally safe as the conventionally-fueled counterparts.

- As the market penetration of hybrid and electric drivetrain accelerates, and as the capacity and reliability of lithium ion batteries used in Rechargeable Energy Storage Systems (RESS) improve, associated potential safety hazards (e.g., electrocution from stranded energy, thermal runaway leading to battery fire) have become well understood, preventable, and manageable. Existing and emerging industry technical and safety voluntary standards, applicable NHTSA regulations and guidance, and the growing experience with the operation of hybrid and electric MD/HDVs will enable the safe operation and large-scale adoption of safer and more efficient power-train electrification technologies.

The safety findings from literature review pertaining to the specific FE technologies implemented to date in the MD/HDV fleet include:

- Telematics—integrating on-board sensors, video, and audio alerts for MD/HDV drivers—offer potential improvements in both driver safety performance and fuel efficiency. Both camera and non-camera based telematics setups are currently integrated with available crash avoidance systems (such as ESC, RSC, LDWS, etc.) and appear to be well accepted by MD/HDV fleet drivers.

- Both experience abroad and the cited US studies of trucks equipped with active speed limiters indicated a safety benefit, as measured by up to 50 percent reduced crash rates, in addition to fuel savings and other benefits, with good CMV driver acceptance. Any negative aspects were small and avoidable if all the speed limitation devices were set to the same speed, so there would be less need for overtaking at highway speeds.

- No literature reports of adverse safety impacts were found regarding implementation of on-board idle-reduction technologies in MD/HDVs (such as automatic start-stop, direct-fired heaters, and APUs).

- There was no clear consensus from the literature regarding the relative crash rates and highway safety impacts of LCVs, due to lack of sufficient data and controls and inconsistent study methodologies. Recent safety evaluations of LCVs and ongoing MAP-21 mandated studies will clarify and quantify this issue.

- Tire technologies for FE (including ATIS, TPMS, LRR and single-wide tires) literature raised potential safety concerns regarding lower stability or loss of control, e.g., when tire pressure is uneven or a single wide tire blows out on the highway. However, systems such as automated tire monitoring systems and stability enhancing electronic systems (ABS, ESC, RSC) may compensate and mitigate any adverse safety impacts.

- Aerodynamic technologies that offer significant fuel savings have raised potential concerns about vehicle damage or injury in case of detached fairings or skirts, although there were no documented incidents of this type in the literature.

- Some light weighting materials may pose some fire safety and crashworthiness hazards, depending on their performance in structural or other vehicle subsystem applications (chassis, power-train, and crash box or safety cage). Some composites (fiberglass, plastics, CFRC, foams) may become brittle on impact or due to weathering from UV exposure or extreme cold. Industry has developed advanced, high performance lightweight material options tailored to their automotive applications, e.g., thermoplastics resistant to UV and weathering. No examples of such lightweight material failures on MD/HDVs were identified in the literature.

Chapter 3 provides complementary inputs on the potential safety issues associated with FE technologies and alternative fuels obtained from Subject Matter Experts (SMEs). The broad cross-section of SMEs consulted had experience with the operation of “green” truck and bus fleets, were Federal program managers, or were industry developers of FE systems for MD/HDVs. Safety concerns raised by the SMEs can be prevented or mitigated by complying with applicable regulations and safety standards and best practices, and are being addressed by evolving technologies, such as electronic collision prevention devices. Although SMEs raised some safety concerns, their experience indicates that system- or fuel-specific hazards can be prevented or mitigated by observing applicable industry standards, and by training managers, operators and maintenance staff in safety best practices. Specific safety concerns raised by SMEs based on their experience included:

- Alternative fuels did not raise major safety concerns, but generally required better education and training of staff and operators. There was a concern expressed regarding high pressure (4000 psi) CNG cylinders that could potentially explode in a crash scenario or if otherwise ruptured. However, aging CNG fuel tank safety can be assured by enforcing regulations such as FMVSS No. 304, and by periodic inspection and end-of-life disposal and replacement. A propane truck fleet manager stated that the fuel was as safe as or safer than gasoline, and reported no safety issues with the company's propane, nor with hybrid gasoline-electric trucks. OEMs of drivetrain hybridization and electrification systems, including advanced Lithium Ion batteries for RESS, indicated that they undergo multiple safety tests and are designed with fail-safes for various misuse and abuse scenarios. Integration of hybrid components downstream by bodybuilders in retrofits, as opposed to new vehicles, was deemed a potential safety risk. Another potential safety concern raised was the uncertain battery lifetime due to variability of climate, duty-cycles, and aging. Without state-of-charge indicators, this could conceivably leave vehicles underpowered or stranded if the battery degrades and is not serviced or replaced in a timely manner.

- ITS and telematics raised no safety concerns; on the contrary, fleet managers stated that "efficient drivers are safer drivers." Monitoring and recording of driver behavior, combined with coaching, appeared to reduce distracted and aggressive driving and provided significant FE and safety benefits.

- A wide-base single tire safety concern was the decrease in tire redundancy in case of a tire blowout at highway speeds. For LRRs, a concern was that they could negatively affect truck stopping distance and stability control.

- A speed-limiter safety concern was related to scenarios when such trucks pass other vehicles on the highway instead of staying in the right-hand lane behind other vehicles. By combining speed limiters with driver training programs, overall truck safety could actually improve, as shown by international practice.

- Aerodynamic systems' safety performance to date was satisfactory, with no instances of on-road detaching. However, covering underside or other components with aerodynamic fairings can make them harder to inspect, such as worn lugs, CNG relief valve shrouds, wheel covers, and certain fairings. Drivers and inspectors need to be able to see through wheel covers and to be able to access lug nuts through them. These covers must also be durable to withstand frequent road abuse.

- For lightweighting materials, the safety concern raised was lower crashworthiness (debonding or brittle fracture on impact) and the potential for decreased survivability in vehicle fires depending on the specific material choice and its application.

The key finding from the literature review and SME interviews is that there appear to be no major safety hazards preventing the adoption of FE technologies, or the increased use of alternative fuels and vehicle electrification. In view of the scarcity of hard data currently available on actual highway crashes that can be directly or causally attributed to adoption of FE technologies and/or alternative fuels by MD/HDVs, and the limited experience with commercial truck and transit bus fleets operations equipped with these technologies, it was not possible to perform a quantitative, probabilistic risk assessment, or even a semi-quantitative preliminary hazard analysis (PHA).

Chapter 4 employs a deterministic scenario-based hazard analysis of potential crash or other safety concerns identified from the literature review or raised by subject matter experts (SMEs) interviewed (e.g., interfaces with charging or refueling infrastructure). For each specific hazard scenario discussed, the recommended prevention or mitigation options, including compliance with applicable NHTSA or FMCSA regulations, and voluntary industry standards and best practices are identified, along with FE technology or fuel-specific operator training. SMEs safety concerns identified in Sec 3.3 were complemented with actual incidents, and developed into the hazard scenarios analyzed in Chapter 4.

The scenario-based deterministic hazard analysis reflected not only the literature findings and SMEs' safety concerns, but also real truck or bus mishaps that have occurred in the past. Key hazard analysis scenarios included: CNG-fueled truck and bus vehicle fires or explosions due to tank rupture, when pressurized fuel tanks were degraded due to aging or when PRDs failed; LNG truck crashes leading to fires, or LNG refueling-related mishaps; the flammability or brittle fracture issues related to lightweighting materials in crashes; reduced safety performance for either LRR or wide-base tires; highway pile-ups when LCVs attempt to pass at highway speeds; aerodynamic components detaching while the vehicle traveled on a busy highway or urban roadway; and fires resulting in overheated lithium ion batteries in electric or hybrid buses. These hypothetical worst case scenarios appear to be preventable or able to be mitigated by observing safety regulations and voluntary standards, or with engineering and operational best practices.

Chapter 5 reviews and discusses the existing federal and state regulatory framework for safely operating MD/HDVs equipped with FE technologies or powered by alternative fuels. The review identifies potential regulatory barriers to their large-scale deployment in the national fleet that could delay achievement of desired fuel consumption and environmental benefits, while ensuring equal or better safety performance.

Chapter 6 summarizes the major findings and recommendations of this preliminary safety analysis of fuel efficiency technologies and alternative fuels adopted by MD/HDVs. The scenario-based hazard analysis, based on the literature review and experts' inputs, indicates that MD/HDVs equipped with advanced FE technologies and/or using alternative fuels have manageable potentially adverse safety impacts. The findings suggest that the potential safety hazards identified during operation, maintenance, and crash scenarios can be prevented or mitigated by complying with safety regulations and voluntary standards and industry best practices. The study also did not identify any major regulatory barriers to rapid adoption of FE technologies and alternative fuels by the MD/HDV fleet.

9.5 Oak Ridge National Laboratory (ORNL) Research on Low Rolling Resistance Truck Tires

DOT's Federal Motor Carrier Safety Administration and NHTSA sponsored a test program conducted by Oak Ridge National Laboratory to explore the effects of tire rolling resistance levels on Class 8 tractor-trailer stopping distance performance over a range of loading and surface conditions.[D] The objective was to determine whether there is a relationship between tire rolling resistance and stopping distance for vehicles of this type. The overall results of this research suggest that tire rolling resistance is not a reliable indicator of Class 8 tractor-trailer stopping distance. The correlation coefficients (R2 values) for linear regressions of wet and dry stopping distance versus overall vehicle rolling resistance values did not meet the minimum threshold for statistical significance for any of the test conditions. Correlation between CRR and stopping distance was found to be negligible for the dry tests for both loading conditions. While correlation was higher for the wet testing (showing a slight trend in which lower CRRs correspond to longer stopping distances), it still did not meet the minimum threshold for statistical significance. In terms of compliance with Federal safety standards, it was found that the stopping distance performance of the vehicle with the four tire sets studied in this research (with estimated tractor CRRs which varied by 33 percent), were well under the FMVSS No. 121 stopping distance requirements.

9.6 Additional Safety Considerations

The agencies' considered the Organic Rankine Cycle waste heat recovery (WHR) as a fuel saving technology in the rulemaking timeframe. The basic approach of these systems is to use engine waste heat from multiple sources to evaporate a working fluid through a heat exchanger, which is then passed through a turbine or equivalent expander to create mechanical or electrical power. The working fluid is then condensed as it passes through a heat exchanger and returns to back to the fluid tank, and pulled back to the flow circuit through a pump to continue the cycle. Despite the promising performance of pre-prototype WHR systems, manufacturers have not yet arrived at a consensus on which working fluid(s) to be used in WHR systems to balance concerns regarding performance, global warming potential (GWP), and safety. Current working fluids have a high GWP (conventional refrigerant), are expensive (low GWP refrigerant), are hazardous (ammonia, etc.), are flammable (ethanol/methanol), or can freeze (water). One of the challenges is determining how to seal the working fluid properly under the vacuum condition with high temperature to avoid safety issues for flammable/hazardous working fluids. Because of these challenges, choosing a working fluid will be an important factor for system safety, efficiency, and overall production viability. The agencies believe manufacturers will require additional time and development effort to assure that a working fluid that is both appropriate, given the noted challenges, and has a low GWP for use in waste heat recovery systems. Based on this and other factors, the analysis for the Preferred Alternative assumes that WHR would not achieve a significant market penetration for diesel tractor engines (i.e., greater than 5 percent) until 2027, which would provide time for these considerations to be addressed.

[D] Lascurain, M.B. (2015, June). "Effects of tire rolling resistance levels on Class 8 tractor trailer stopping distance performance." Washington, DC: National Highway Traffic Safety Administration.

The agencies assume no use of this technology in the HD pickups and vans and vocational vehicle segments.

9.7 The Agencies' Assessment of Potential Safety Impacts

NHTSA and EPA considered the potential safety impact of technologies that improve HD vehicle fuel efficiency and GHG emissions as part of the assessment of regulatory alternatives. The safety assessment of the technologies in this proposal was informed by two NAS reports, an analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and agency-sponsored safety testing and research. The agencies considered safety from the perspective of both direct effects and indirect effects.

In terms of direct effects on vehicle safety, research from NAS and Volpe, and direct testing of technologies like the ORNL tire work, indicate that there are no major safety hazards associated with the adoption of technologies that improve HD vehicle fuel efficiency and GHG emissions or the increased use of alternative fuels and vehicle electrification. The findings suggest that the potential safety hazards identified during operation, maintenance, and crash scenarios can be prevented or mitigated by complying with safety regulations, voluntary standards and industry best practices. Tire testing showed tire rolling resistance did not impact of Class 8 tractor-trailer stopping distance for the tires tested. Also, because the majority of HD pickup and van fleet are above 4,594 pounds, the vehicle mass reduction in HD pickup and vans is estimated to reduce the net incidence of highway fatalities. Taken together, these studies suggest that the fuel efficiency improving technologies assessed in the studies can be implemented with no degradation in overall safety.

However, analysis anticipates that the indirect effect of the proposed standards, by reducing the operating costs, would lead to increased travel by tractor-trailers and HD pickups and vans and, therefore, more crashes involving these vehicles.

Chapter 10: CAFE Model for HD Pickups and Vans

For this rule, the agencies conducted coordinated and complementary analyses using two analytical methods for the heavy-duty pick up and van segment by employing both DOT's CAFE model and EPA's MOVES model. For heavy-duty pickups and vans, the agencies performed complementary analyses, which we refer to as "Method A" and "Method B". In Method A, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative and the estimated effects on fuel consumption, emissions, benefits and costs. In Method B, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative, along with resultant impacts on per vehicle costs, and the MOVES model was used to calculate corresponding changes in total fuel consumption and annual emissions. Additional calculations were performed to determine corresponding monetized program costs and benefits. NHTSA considered Method A as its central analysis and Method B as a supplemental analysis. EPA considered the results of both methods. The agencies concluded that both methods led the agencies to the same conclusions and the same selection of the proposed standards. See Section VII of the preamble for additional discussion of these two methods.

In this chapter, the CAFE modeling system is described and used to analyze technology use and per-vehicle costs under each regulatory alternative, including the no action alternative (which reflects continuation of previously-promulgated standards). However, this model is more comprehensive and also projects other impacts. NHTSA addresses these other impacts in the Draft EIS and these are also presented here.[1]

2.1 HD Pickup and Van Fleet

2.1.1 Why did the Agencies Develop the Analysis Fleet?

The modeling system relies on many inputs, including an analysis fleet. In order to estimate the impacts of potential standards, it is necessary to estimate the composition of the future vehicle fleet. Doing so enables estimation of the extent to which each manufacturer may need to add technology in response to a given series of attribute-based standards, accounting for the mix and fuel consumption of vehicles in each manufacturer's regulated fleet. The agencies create an analysis fleet in order to track the volumes and types of fuel economy-improving and CO_2-reducing technologies that are already present in the existing vehicle fleet. This aspect of the analysis fleet helps to keep the CAFE model from adding technologies to vehicles that already have these technologies, which would result in "double counting" of technologies' costs and benefits. An additional step involved projecting the fleet sales into MYs 2019-2030. This represents the fleet volumes that the agencies believe would exist in MYs 2019-2030. The following presents an overview of the information and methods applied to develop the analysis fleet, and some basic characteristics of that fleet. Details appear in the input file.

[1] EPA uses its MOVES model to project these other impacts as discussed in Chapters 5 through 8 of this draft RIA. Note that the results of both modeling approaches corroborate the results of the overall analysis.

2.1.2 How the MY2014 Based Analysis Fleet Was Developed?

Most of the information about the vehicles that make up the 2014 analysis fleet was gathered from the 2014 Pre-Model Year Reports submitted to EPA by the manufacturers under Phase 1 of Fuel Efficiency and GHG Emission Program for Medium- and Heavy-Duty Trucks, MYs 2014-2018.

The major manufactures of class 2b and class 3 trucks (Chrysler, Ford and GM) were asked to voluntarily submit updates to their Pre-Model Year Reports. Updated data were provided by Chrysler and GM. These updated data were used in constructing the analysis fleet for these manufacturers.

The agencies agreed to treat this information as Confidential Business Information (CBI) until the publication of the NPRM. This information can be made public at this time because by now all MY2014 vehicle models have been produced, which makes data about them essentially public information.

These data (by individual vehicle configuration produced in MY2014) include: Projected Production Volume/MY2014 Sales, Drive Type, Axle Ratio, Work Factor, Curb Weight[2], Test Weight[3], GVWR, GCWR, Fuel Consumption (gal/100 mile)[4], engine type (gasoline or diesel), engine displacement, transmission type and number of gears[5].

The column "Engine" of the Pre-Model Year report for each OEM was copied to the column "Engine Code" of the vehicle sheet of the CAFE model market data input file.[6] Values of "Engine" were changed to Engine Codes for use in the CAFE model. The codes indicated on the vehicle sheet map the detailed engine data on the engine sheet to the appropriate vehicle on the vehicle sheet of the CAFE model input file.

The column "Trans Class" of the Pre-Model Year report for each OEM was copied to the column "Transmission Code" of the vehicle sheet of the market data input file. Values of "Trans Class" were changed to Transmission Codes for use in the CAFE model. The codes indicated on the vehicle sheet map the detailed transmission data on the transmission sheet to the appropriate vehicle on the vehicle sheet of the CAFE model input file.

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[2] GM did not provide curb weight in its submittal. GM did provide "Payload." Curb weight for GM vehicles was calculated as GVWR – Payload.

[3] Chrysler and GM did not provide test weights in their submittals. Test weights were calculated as the average of GVWR and curb weight rounded up to the nearest 100 lbs.

[4] These values were converted to mile/gal for use in the Volpe model. In their supplemental data submission GM provided the data as mpg in its report column "Fuel Consumption Performance". In its supplemental data submission Fiat provided "Fuel Economy on Primary Fuel (Unadjusted combined CO_2 g/mi)." These values were converted to mpg using the factors 8,887 gCO_2/gal for gas engines and 10.180 gCO_2/gal for diesel engines.

[5] GM did not provide transmission data in its submittal. Specific transmissions associated with each of GM's trucks were identified using information from GM's websites.

[6] The GM data was an exception. In its case the column "Disp" of the Pre-Model Year report was copied to the column "Engine Code."

In addition to information about each vehicle, the agencies need additional information about the fuel economy-improving/CO_2-reducing technologies already on those vehicles in order to assess how much and which technologies to apply to determine a path toward future compliance. Thus, the agencies augmented this information with publicly-available data that includes more complete technology descriptions. Specific engines and transmissions associated with each manufacturer's trucks were identified using their respective internet sites. Detailed technical data on individual engines and transmissions indicated on the engine sheet and transmission sheet of the CAFE model input file were then obtained from manufacturer internet sites, spec sheets and product literature, Ward's Automotive Group and other commercial internet sites such as cars.com, edmunds.com, and motortrend.com.[7]

"Fuel Economy on Secondary Fuel" was calculated as E85 = .74 gasoline fuel economy, or B20 = .98 diesel fuel economy. These values were duplicated in the columns "Fuel Economy (Ethanol-85)" and "Fuel Economy (Biodiesel-20)" of the CAFE market data input file.

Values in the columns "Fuel Share (Gasoline)", "Fuel Share (Ethanol-85)", "Fuel Share (Diesel)," and "Fuel Share (Biodiesel-20)" are Volpe assumptions.

The CAFE model also requires that values of Origin, Regulatory Class, Technology Class, Safety Class, and Seating (Max) be present in the file in order for the model to run. Placeholder values were added in these columns.

In addition to the data taken from the OEM Pre Model Year submittals, NHTSA added additional data for use by the CAFE model. These included Platform, Refresh Years, Redesign Years, MSRP, Style, Structure and Fuel Capacity.[8]

MSRP was obtained from web2carz.com and the OEM web sites.

Fuel capacity was obtained from OEM spec sheets and product literature.

[7] In their data update Chrysler provided much of the detailed engine data utilized in the Volpe model input file. These included Fuel Cycle, Fuel Delivery System, Aspiration, Cylinders, Valves/Cylinder, Deactivation, Displacement, Compression Ratio, Max. Horsepower, Max. Horsepower RPM, Max. Torque, and Max. Torque RPM. These were copied directly to the engine tab of the Volpe model input file.
GM provided similar engine data including Engine Oil Viscosity Fuel Cycle, Fuel Delivery System, Aspiration, Cylinders, Valves/Cylinder, Valvetrain Design, Valve Actuation/Timing, Valve Lift, Deactivation, Displacement, Compression Ratio, Max. Horsepower, Max. Horsepower RPM, Max. Torque, and Max. Torque RPM. These were copied directly to the engine tab of the Volpe model input file.

[8] Daimler, Fiat, GM and Nissan provided Truck Line Name (nameplate) information that could be used to distinguish individual vehicles and their associated characteristics. This level of disaggregation was needed in order to get data on fuel capacity and MSRP for individual vehicles from the OEM web sites or other commercial automotive web sites. Volpe created nameplates to distinguish vehicle types in order to get data on fuel capacity and MSRP for Ford. A comparison of the curb weights and GVWR in the Ford data with those in their product spec sheets (while controlling for drive and engine type) allowed us to make an educated guess as to which of the pickups were for example, 250/350series, regular/crew cab, short box/long box, SRW/DRW. These guesses appear in the column "Probable Name Plate" of the Volpe input file and are used in the assignment of appropriate values of the various data inputs.

The Structure values (Ladder, Unibody) used by the CAFE model were added. These were determined from OEM product literature and the automotive press. It should be noted that the new vans such as the Transit in fact utilize a ladder/unibody structure. Ford product literature uses the term "Uniladder" to describe the structure. Vans based on this structure are noted in the Vehicle Notes column of the NHTSA input file.

Style values used by the CAFE model were also added: Chassis Cab, Cutaway, Pickup and Van.

2.1.2.1 **Vehicle Redesign Schedules & Platforms**

2.1.2.2 **Pickup Trucks**

Product cadence in the Class 2b and 3 pickup market has historically ranged from 7-9 years between major redesigns. However, due to increasing competitive pressures and consumer demands the agency anticipates that manufacturers will generally shift to shorter design cycles resembling those of the light duty market. Pickup truck manufacturers in the Class 2b and 3 segments are shown to adopt redesign cycles of six years, allowing two redesigns prior to the end of the proposed regulatory period in 2027.

2.1.2.2.1 *Ford*

In the 2b/3 pickup truck market, Ford produces the F250, F350 and F450, currently based on the P3 platform. These models adopted the Super Duty moniker in 1999, and began using architecture and product cadence distinct from the F150 light-duty pickup models. The first full redesign of these models occurred in 2008, with smaller redesigns in 2005 and 2011.

The agencies estimate that the next major redesign of Ford's 2b/3 products will occur in or about 2017, trailing Ford's announced update of a redesigned F150 in its light-duty pickup portfolio, with a more rapid product cadence leading to a subsequent redesign in 2023 and refreshes in 2020 and 2029.

2.1.2.2.2 *General Motors*

General Motors HD pickup trucks, the Silverado and Sierra HD series, are based on the GMT910 platform and were introduced as a 2007 model. GM has announced a redesigned HD pickup for the 2015 model year. The agencies estimate that, like Ford, GM will adopt an approximate six-year product cadence in the HD truck market, with redesigns in 2015 and 2021.

2.1.2.2.3 *Fiat (Ram)*

The current Ram HD models, on the D2/DJ platform, are anticipated for a major redesign in the 2018 model year, and the agencies estimate that the product will adopt a similar, shorter life cycle of six years, with a subsequent redesign in the 2024 model year.

2.1.2.3 **Vans**

The 2b/3 van market has changed markedly from five years ago. Ford, Nissan, Ram and Daimler have adopted vans of “Euro Van” appearance, and in many cases now use smaller turbocharged gasoline or diesel engines in the place of larger, naturally-aspirated V8s. The 2014 Model Year used in this analysis represents a period where most manufacturers, with the exception of General Motors, have recently introduced a completely redesigned product after many years. The van segment has historically been one of the slowest to be redesigned of any product segment, with some products going two decades or more between redesigns.

Due to new entrants in the field and increased competition, the agencies anticipate that most manufacturers will increase the pace of product redesigns in the van segment, but that they will continue to trail other segments. The cycle time used in this analysis is approximately ten years between major redesigns, allowing manufacturers’ only one major redesign during the regulatory period.

2.1.2.3.1 *General Motors*

The GM Savana/Chevrolet Express, built on the GMT600 platform, has been produced since 1996 with a facelift in 2003. The van is currently due for a redesign, and while it is unknown when this will occur, the agencies anticipate a major redesign due to strong competitive pressure from other manufacturers will occur in or about 2017, with no further redesigns occurring until after 2025.

2.1.2.3.2 *Ford*

2014 marks the first year in more than three decades that Ford has used a completely new platform for its vans. The Transit replaces the Econoline except in Chassis Cab or cutaway configurations. The agencies anticipate that Ford will gradually shift production volume to the Transit, and will not redesign the Transit until 2025, with one intermediate product freshening.

2.1.2.3.3 *Fiat (Ram)*

The product cycle of the van from the Ram brand has less of a historical precedent. Fiat currently offers the Promaster (a variant of the Ducato van sold in other markets). Previously Chrysler sold Sprinter vans in an agreement with Daimler from 2003, and had previously manufactured its own full-sized van.

The Promaster has just been introduced to the US market, and the agencies anticipate that Fiat will offer a refreshed version in 2020 prior to a full redesign in 2025.

2.1.2.3.4 *Nissan*

The Nissan NV launched for the 2012 model using the F-alpha platform shared with the light-duty Nissan Titan pickup truck. Trade publications and internet sources suggest the next-generation Nissan Titan could debut in model year 2016, and the agencies anticipate that the NV van may adopt some of the features and components of the Titan for a mid-cycle freshening of the NV, with a full redesign in 2021.

2.1.2.3.5 *Daimler*

Daimler introduced its current Sprinter van for the 2007 model year on the NCV3 platform. U.S. models received an update across 2014 and 2015, with rear wheel drive models arriving one year ahead of AWD models. The agencies anticipate that Daimler will redesign the Sprinter for 2017 with a subsequent freshening in model year 2021.

2.1.2.4 **Sales Volume Forecast**

Since each manufacturer's required average fuel consumption and GHG levels are sales-weighted averages of the fuel economy/GHG targets across all model offerings, sales volumes play a critical role in estimating that burden. The CAFE model requires a forecast of sales volumes, at the vehicle model-variant level, in order to simulate the technology application necessary for a manufacturer to achieve compliance in each model year for which outcomes are simulated.

For today's analysis, the agencies relied on the MY 2014 pre-model-year compliance submissions from manufacturers to provide sales volumes at the model level based on the level of disaggregation in which the models appear in the compliance data. However, the agencies only use these reported volumes without adjustment for MY 2014. For all future model years, we combine the manufacturer submissions with sales projections from the 2014 Annual Energy Outlook Reference Case and IHS Automotive to determine model variant level sales volumes in future years.[9] Figure 10-1 shows the projected sales volumes by class that appear in the 2014 Annual Energy Outlook as a result of a collection of assumptions about economic conditions, demand for commercial miles traveled, and technology migration from light-duty pickup trucks in response to the concurrent light-duty CAFE/GHG standards.

For this analysis, the agencies have limited this analysis fleet to class 2b and 3 HD pickups and vans. However, especially considering interactions between the light-duty and HD pickup and van fleets (e.g., MDPVs being included in the light-duty fleet), the agencies could also evaluate the potential to analyze the fleets in an integrated fashion.

[9] Tables from AEO's forecast are available at http://www.eia.gov/oiaf/aeo/tablebrowser/. The agencies also made use of the IHS Automotive Light Vehicle Production Forecast (August 2014).

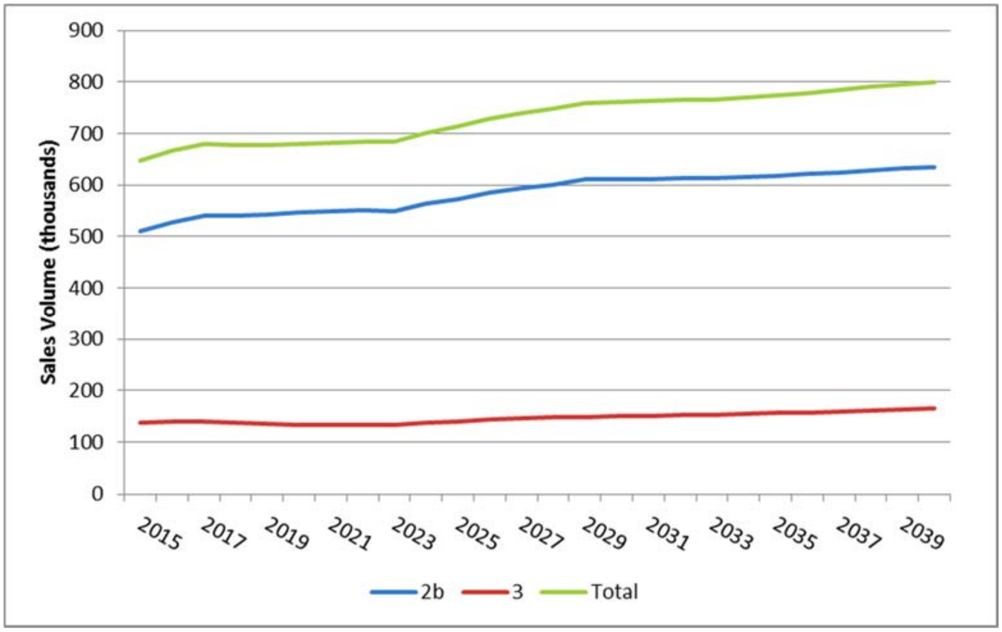

Figure 10-1 AEO2014 Sales Projections for 2b/3 Vehicles

The projection of total sales volumes for the Class 2b and 3 market segment was based on the total volumes in the 2014 AEO Reference Case. For the purposes of this analysis, the AEO2014 calendar year volumes have been used to represent the corresponding model-year volumes. While AEO2014 provides enough resolution in its projections to separate the volumes for the Class 2b and 3 segments (see Figure 10-1), the agencies deferred to the vehicle manufacturers and chose to rely on the relative shares present in the pre-model-year compliance data.

The relative sales share by vehicle type (van or pickup truck, in this case) was derived from a sales forecast that the agencies purchased from IHS Automotive, and applied to the total volumes in the AEO2014 projection. Table 10-1 shows the implied shares of the total new 2b/3 vehicle market broken down by manufacturer and vehicle type.

Table 10-1 IHS Automotive Market Share Forecast for 2b/3 Vehicles

		MODEL YEAR MARKET SHARE						
Manufacturer	**Style**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Daimler	Van	3%	3%	3%	3%	3%	3%	3%
Fiat	Van	2%	2%	2%	2%	2%	2%	3%
Ford	Van	16%	17%	17%	17%	18%	18%	18%
General Motors	Van	12%	12%	11%	12%	13%	13%	13%
Nissan	Van	2%	2%	2%	2%	2%	2%	2%
Daimler	Pickup	0%	0%	0%	0%	0%	0%	0%
Fiat	Pickup	14%	14%	14%	14%	11%	12%	12%
Ford	Pickup	28%	27%	30%	30%	30%	27%	26%
General Motors	Pickup	23%	23%	21%	21%	21%	22%	23%
Nissan	Pickup	0%	0%	0%	0%	0%	0%	0%

Within those broadly defined market shares, volumes at the manufacturer/model-variant level were constructed by applying the model-variant's share of manufacturer sales in the pre-model-year compliance data for the relevant vehicle style, and multiplied by the total volume estimated for that manufacturer and that style.

After building out a set of initial future sales volumes based on the sources described above, the agencies attempted to incorporate new information about changes in sales mix that would not be captured by either the existing sales forecasts or the simulated technology changes in vehicle platforms. In particular, Ford has announced intentions to phase out their existing Econoline vans, gradually shifting volumes to the new Transit platform for some model variants (notably chassis cabs and cutaways variants) and eliminating offerings outright for complete Econoline vans as early as model year 2015. In the case of complete Econoline vans, the volumes for those vehicles were allocated to MY2015 Transit vehicles based on assumptions about likely production splits for the powertrains of the new Transit platform. The volumes for complete Econoline vans were shifted at ratios of 50 percent, 35 percent, and 15 percent for 3.7 L, 3.5 L Eco-boost, and 3.2 L diesel, respectively. Within each powertrain, sales were allocated based on the percentage shares present in the pre-model-year compliance data. The chassis cab and cutaway variants of the Econoline were phased out linearly between MY2015 and MY2020, at which time the Econolines cease to exist in any form and all corresponding volume resides with the Transits.

2.1.2.5 **Selected Characteristics of the MY2014 Based Analysis Fleet**

The tables below summarize some of the characteristics of the MY2014 based analysis fleet for Class 2b and Class 3 trucks.

Table 10-2 shows production by manufacturer and indicates that Ford is dominant with 52 percent of this market.

Table 10-2 Estimated MY2014 Production by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	25,327	4.0%
Fiat	138,902	21.8%
Ford	330,919	51.9%
General Motors	129,435	20.3%
Nissan	13,526	2.1%
Total	638,109	100.0%

Table 10-3 shows production by class with 80 percent of production in class 2b, those trucks with a GVW between 8,501 and 10,000 lbs.

Table 10-3 Estimated MY2014 Production by Class

GVW CLASS	PRODUCTION	PERCENT
2b (8,501-10,000 lbs.)	506,989	79.5%
3 (10,001-14,000 lbs.)	131,120	20.5%
Total	638,109	100.0%

Table 10-4 shows production by style or body type. Pickup trucks make up 52 percent of production and vans 42 percent of production.

Table 10-4 Estimated MY2014 Production by Vehicle Style

STYLE	PRODUCTION	PERCENT
Chassis Cab	19,724	3.1%
Cutaway	20,539	3.2%
Pickup	333,100	52.2%
Van	264,746	41.5%
Total	638,109	100.0%

Table 10-5 shows production by engine type. Diesel powered trucks make up a significant share (40 percent) of this market in comparison to light duty vehicles.

Table 10-5 Estimated MY2014 Production by Engine Type

ENGINE TYPE	PRODUCTION	PERCENT
Diesel	252,744	39.6%
Gasoline	105,604	16.5%
FFV	279,761	43.8%
Total	638,109	100.0%

Table 10-6 shows production by drive type with an almost equal division between two wheel drive (55 percent) and four wheel drive (45 percent).

Table 10-6 Estimated MY2014 Production by Drive

DRIVE	PRODUCTION	PERCENT
4WD	286,122	44.8%
FWD	23,309	3.7%
RWD	328,678	51.5%
Total	638,109	100.0%

The following tables show some of the characteristics of the baseline analysis fleet at the manufacturer level. Table 10-7 and Table 10-8 show production by manufacturer for class 2b and class 3 trucks respectively. As noted above Ford is the dominant manufacturer with 52 percent of the market in both class 2b and class 3 trucks. While Fiat and General Motors have comparable shares of the class 2b market (20 percent and 22 percent respectively), Fiat (at 31 percent) has a significantly larger share of the class 3 market than General Motors (at 13 percent).

Table 10-7 Estimated MY2014 Production Class 2b by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	19,556	3.9%
Fiat	98,722	19.5%
Ford	262,687	51.8%
General Motors	112,498	22.2%
Nissan	13,526	2.7%
Total	506,989	100.0%

Table 10-8 Estimated MY2014 Production Class 3 by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	5,771	4.4%
Fiat	40,180	30.6%
Ford	68,232	52.0%
General Motors	16,937	12.9%
Nissan	-	0.0%
Total	131,120	100.0%

As noted above pickup trucks were the dominant body style in Class 2b and 3 trucks. Table 10-9 shows pickup truck production by manufacturer. Only three manufactures share this market with Ford the leader at 43 percent, followed by Fiat at 35 percent and General Motors at 22 percent.

Table 10-9 Estimated MY2014 Production Pickups by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	-	0.0%
Fiat	115,593	34.7%
Ford	142,580	42.8%
General Motors	74,927	22.5%
Nissan	-	0.0%
Total	333,100	100.0%

All five manufactures share the Class 2b and 3 van market. Table 10-10 shows van production by manufacturer. Ford is again dominant with 57 percent of the market followed by General Motors at 21 percent with the remainder divided among Fiat, Daimler and Nissan.

Table 10-10 Estimated MY2014 Production Vans by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	21,900	8.3%
Fiat	23,309	8.8%
Ford	151,503	57.2%
General Motors	54,508	20.6%
Nissan	13,526	5.1%
Total	264,746	100.0%

Table 10-11 and

Table **10-12** give an indication of the significance of diesel powered trucks in the class 2b and 3 market. Table 10-11shows the distribution of diesel trucks by manufacturer. Ford is the leader at 40 percent followed by Fiat at 34 percent.

Table **10-12** shows diesel production as a percent of total production for each manufacturer. At either end of the spectrum are Nissan at 0 percent and Daimler at 100 percent. Of the producers with significant market share Fiat leads with 62 percent of its production in diesels, followed by General Motors at 32 percent and Ford at 30 percent.

Table 10-11 Estimated MY2014 Production Diesel Powered Trucks by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	25,327	10.0%
Fiat	86,124	34.1%
Ford	100,208	39.6%
General Motors	41,085	16.3%
Nissan	-	0.0%
Total	252,744	100.0%

Table 10-12 Estimated MY2014 Diesel Penetration by Manufacturer

MANUFACTURER	DIESEL PRODUCTION	TOTAL PRODUCTION	PERCENT DIESEL
Daimler	25,327	25,327	100.0%
Fiat	86,124	138,902	62.0%
Ford	100,208	330,919	30.3%
General Motors	41,085	129,435	31.7%
Nissan	-	13,526	0.0%
Total	252,744	638,109	39.6%

The resultant analysis fleet is provided in detail at NHTSA's web site, along with all other inputs to and outputs from today's analysis.

2.2 CAFE Model Analysis of Regulatory Alternatives for HD Pickups and Vans

EPA and NHTSA have evaluated a range of potential regulatory alternatives since we are considering the proposal of new class 2b and 3 pickup and van fuel consumption and GHG standards to follow those already established through model year 2018. The agencies estimated the extent to which manufacturers might add fuel-saving (and, therefore, CO_2-reducing) technologies under each regulatory alternative, including the no-action alternative defined by Phase 1 standards. NHTSA also used the CAFE model to estimate the extent to which this additional technology would incrementally (compared to the no-action alternative) impact costs to manufacturers and vehicle buyers, reduce fuel consumption and greenhouse gas emissions, provide economic benefits and reduce costs to vehicle owners and society. The remainder of this section presents the regulatory alternatives the agencies have considered, summarizes the analysis, and explains the selection of the preferred alternative defined by today's proposed standards.

As discussed above, the agencies are proposing standards defined by fuel consumption and GHG targets that continue through model year 2020 unchanged from model year 2018, and then increase in stringency at an annual rate of 2.5 percent through model year 2027. In addition to this regulatory alternative, the agencies also considered a no-action alternative under which standards remain unchanged after model year 2018, as well as three other alternatives, defined by annual stringency increases of (1) 2.0 percent, (2), 3.5 percent, and (3) 4.0 percent during model years 2021-2025. For each of the "action alternatives" (i.e., those involving stringency increases beyond the no-action alternative), the annual stringency increases are applied as follows: an annual stringency increase of *r* is applied by multiplying the model year 2020 target functions (identical to those applicable to model year 2018) by 1 – *r* to define the model year 2021 target functions, multiplying the model year 2021 target functions by 1 – *r* to define the model year 2022 target functions, continuing through 2025 for all alternatives except for the preferred Alternative 3 which extends through 2027. In summary, the agencies have considered the following five regulatory alternatives:

REGULATORY ALTERNATIVE	ANNUAL STRINGENCY INCREASE		
	2019-2020	2021-2025	2026-2027
1: No Action	None	None	None
2: 2.0%/y	None	2.0%	None
3: 2.5%/y	None	2.5%	2.5%
4: 3.5%/y	None	3.5%	None
5: 4.0%/y	None	4.0%	None

2.2.1 Evaluation of the Regulatory Alternatives.

To conduct an analysis of potential standards for HD pickups and vans, the agencies have applied DOT's Corporate Average Fuel Economy (CAFE) Compliance and Effects Modeling System (sometimes referred to as "the CAFE model" or "the Volpe model"), which DOT's Volpe National Transportation Systems Center (Volpe Center) developed, maintains, and applies to support NHTSA CAFE analyses and rulemakings. DOT developed the model in 2002 to support the 2003 issuance of CAFE standards for MYs 2005-2007 light trucks. DOT has since significantly expanded and refined the model, and has applied the model to support every ensuing CAFE rulemaking:

- 2006: MYs 2008-2011 light trucks
- 2008: MYs 2011-2015 passenger cars and light trucks (final rule prepared but withheld)
- 2009: MY 2011 passenger cars and light trucks
- 2010: MYs 2012-2016 passenger cars and light trucks (joint rulemaking with EPA)
- 2012: MYs 2017-2021 passenger cars and light trucks (joint rulemaking with EPA)

Past analyses conducted using the CAFE model have been subjected to extensive and detailed review and comment, much of which has informed the model's expansion and refinement. NHTSA's use of the model was considered and supported in 2007 litigation (CBD v. NHTSA), and the model has been subjected to formal peer review and review by the General Accounting Office (GAO) and National Research Council (NRC). NHTSA makes public the model, source code, and—except insofar as doing so would compromise confidential business information (CBI) manufacturers have provided to NHTSA—all model inputs and outputs underlying published rulemaking analyses.[10]

Although the CAFE model can also be used for more aggregated analysis (e.g., involving "representative vehicles", single-year snapshots, etc.), NHTSA designed the model with a view toward (a) detailed simulation of manufacturers' potential actions given a defined set of standards, followed by (b) calculation of resultant impacts and economic costs and benefits. The model is intended to describe actions manufacturers could take in light of defined standards and other input assumptions and estimates, not to predict actions manufacturers will take.

As a starting point, the model makes use of an input file defining the analysis fleet—that is, a set of specific vehicle models (e.g., Toyota Tacoma) and model configurations (e.g., Toyota Tacoma with 4.0-liter V6 engine, 4WD, and 5-speed manual transmission) estimated or assumed to be produced by each manufacturer in each model year to be included in the analysis. The analysis fleet includes key engineering attributes (e.g., curb weight, payload and towing capacities, dimensions, presence of various fuel-saving technologies) of each vehicle model, engine, and transmissions, along with estimates or assumptions of future production volumes. It also specifies the extent to which specific vehicle models share engines, transmissions, and vehicle platforms, and describes each manufacturer's estimated or assumed product cadence (*i.e.*, timing for freshening and redesigning different vehicles and platforms). This input file also specifies a payback period used to estimate the potential that each manufacturer might apply technology to improve fuel economy beyond levels required by standards.

A second input file to the model contains a variety of contextual estimates and assumptions. Some of these inputs, such as future fuel prices and vehicle survival and mileage accumulation (versus vehicle age), are relevant to estimating manufacturers' potential application of fuel-saving technologies. Some others, such as fuel density and carbon content, vehicular and upstream emission factors, the social cost of carbon dioxide emissions, and the discount rate, are relevant to calculating physical and economic impacts of manufacturers' application of fuel-saving technologies.

A third input file contains estimates and assumptions regarding the future applicability, availability, efficacy, and cost of various fuel-saving technologies. Efficacy is expressed in terms of the percentage reduction in fuel consumption, cost is expressed in dollars, and both efficacy and cost are expressed on an incremental basis (i.e., estimates for more advanced technologies are specified as increments beyond less advanced technologies). The input file also includes "synergy factors" used to make adjustments accounting for the potential that some combinations of technologies may result fuel savings or costs different from those indicated by incremental values.

Finally, a fourth model input file specifies standards to be evaluated. Standards are defined on year-by-year basis separately for each regulatory class (passenger cars, light trucks, and heavy-duty pickups and vans). Regulatory alternatives are specified as discrete scenarios,

[10] Analyses can be found at http://www.nhtsa.gov/fuel-economy

with one scenario defining the no-action alternative or "baseline", all other scenarios defining regulatory alternatives to be evaluated relative to that no-action alternative.

Given these inputs, the model estimates each manufacturer's potential year-by-year application of fuel-saving technologies to each engine, transmission, and vehicle. Subject to a range of engineering and planning-related constraints (e.g., secondary axle disconnect can't be applied to 2-wheel drive vehicles, many major technologies can only be applied practicably as part of a vehicle redesign, and applied technologies carry forward between model years), the model attempts to apply technology to each manufacturers' fleet in a manner that minimizes "effective costs" (accounting, in particular, for technology costs and avoided fuel outlays), continuing to add improvements as long as doing so would help toward compliance with specified standards or would produce fuel savings that "pay back" at least as quickly as specified in the input file mentioned above.

Having estimated the extent to which each manufacturer might add fuel-saving technologies under each specified regulatory alternative, the model calculates a range of physical impacts, such as changes in highway travel (i.e., VMT), changes in fleetwide fuel consumption, changes in highway fatalities, and changes in vehicular and upstream greenhouse gas and criteria pollutant emissions. The model also applies a variety of input estimates and assumptions to calculate economic costs and benefits to vehicle owners and society, based on these physical impacts.

This analysis reflects several changes made to the model since 2012, when NHTSA used the model to estimate the effects, costs, and benefits of final CAFE standards for light-duty vehicles produced during MYs 2017-2021, and augural standards for MYs 2022-2025. Some of these changes specifically enable analysis of potential fuel consumption standards (and, hence, related CO_2 emissions standards harmonized with fuel consumption standards) for heavy-duty pickups and vans; other changes implement more general improvements to the model. Key changes include the following:

- Expansion and restructuring of model inputs, compliance calculations, and reporting to accommodate standards for heavy-duty pickups and vans, including attribute-based standards involving targets that vary with "work factor".

- Explicit calculation of test weight, taking into account test weight "bins" and differences in the definition of test weight for light-duty vehicles (curb weight plus 300 pound) and heavy-duty pickups and vans (average of GVWR and curb weight).

- Procedures to estimate increases in payload when curb weight is reduced, increases in towing capacity if GVWR is reduced, and calculation procedures to correspondingly update calculated work factors.

- Expansion of model inputs, procedures, and outputs to accommodate technologies not included in prior analyses.

- Changes to the algorithm used to apply technologies, enabling more explicit accounting for shared vehicle platforms and adoption and "inheritance" of major engine changes.

- Expansion of the Monte Carlo simulation procedures used to perform probabilistic uncertainty analysis.

These changes are reflected in updated model documentation available at NHTSA's web site, the documentation also providing more information about the model's purpose, scope, structure, design, inputs, operation, and outputs

10.1.1.1 **Accounting for Product Cadence**

Past comments on the CAFE model have stressed the importance of product cadence—i.e., the development and periodic redesign and freshening of vehicles—in terms of involving technical, financial, and other practical constraints on applying new technologies, and DOT has steadily made changes to the model with a view toward accounting for these considerations. For example, early versions of the model added explicit "carrying forward" of applied technologies between model years, subsequent versions applied assumptions that most technologies would be applied when vehicles are freshened or redesigned, and more recent versions applied assumptions that manufacturers would sometimes apply technology earlier than "necessary" in order to facilitate compliance with standards in ensuing model years. Thus, for example, if a manufacturer is expected to redesign many of its products in model years 2018 and 2023, and the standard's stringency increases significantly in model year 2021, the CAFE model will estimate the potential that the manufacturer will add more technology than necessary for compliance in MY 2018, in order to carry those product changes forward through the next redesign and contribute to compliance with the MY 2021 standard.

The model also accommodates estimates of overall limits (expressed as "phase-in caps" in model inputs) on the rates at which manufacturers' may practicably add technology to their respective fleets. So, for example, even if a manufacturer is expected to redesign half of its production in MY 2016, if the manufacturer is not already producing any strong hybrid electric vehicles (SHEVs), a phase-in cap can be specified in order to assume that manufacturer will stop applying SHEVs in MY 2016 once it has done so to at least 3 percent of its production in that model year.

After the light-duty rulemaking analysis accompanying the 2012 final rule regarding post-2016 CAFE standards and related GHG emissions standards, DOT staff began work on CAFE model changes expected to better reflect additional considerations involved with product planning and cadence. These changes, summarized below, interact with preexisting model characteristics discussed above.

10.1.1.2 **Platforms & Technology**

The term "platform" is used loosely in industry, but generally refers to a common structure shared by a group of vehicle variants. The degree of commonality varies, with some platform variants exhibiting traditional "badge engineering" where two products are differentiated by little more than insignias, while other platforms be used to produce a broad suite of vehicles that bear little outer resemblance to one another.

Given the degree of commonality between variants of a single platform, manufacturers do not have complete freedom to apply technology to a vehicle: while some technologies (e.g. low rolling resistance tires) are very nearly “bolt-on” technologies, others involve substantial changes to the structure and design of the vehicle, and therefore necessarily are constant between vehicles that share a common platform. DOT staff has, therefore, modified the CAFE model such that all mass reduction and aero technologies are forced to be constant between variants of a platform.

Within the analysis fleet, each vehicle is associated with a specific platform. As the CAFE model applies technology, it first defines a platform “leader” as the vehicle variant of a platform with the highest technology utilization vehicle of mass reduction and aerodynamic technologies. As the vehicle applies technologies, it effectively harmonizes to the highest common denominator of the platform. If there is a tie, the CAFE model begins applying aerodynamic and mass reduction technology to the vehicle with the lowest average sales across all available model years. If there remains a tie, the model begins by choosing the vehicle with the highest average MSRP across all available model years. The model follows this formulation due to previous market trends suggesting that many technologies begin deployment at the high-end, low-volume end of the market as manufacturers build their confidence and capability in a technology, and later expand the technology across more mainstream product lines.

In the HD pickup and van market, there is a relatively small amount of diversity in platforms produced by manufacturers: typically 1-2 truck platforms and 1-2 van platforms. However, accounting for platforms will take on greater significance in future analyses involving the light-duty fleet, and the agency requests comments on the general use of platforms within CAFE rulemaking.

10.1.1.3 Engine and Transmission Inheritance

In practice, manufacturers are limited in the number of engines and transmissions that they produce. Typically a manufacturer produces a number of engines—perhaps six or eight engines for a large manufacturer—and tunes them for slight variants in output for a variety of car and truck applications. Manufacturers limit complexity in their engine portfolio for much the same reason as they limit complexity in vehicle variants: they face engineering manpower limitations, and supplier, production and service costs that scale with the number of parts produced.

In previous usage of the CAFE model, engines and transmissions in individual models were allowed relative freedom in technology application, potentially leading to solutions that would, if followed, involve unaccounted-for costs associated with increased complexity in the product portfolio. The lack of a constraint in this area allowed the model to apply different levels of technology to the engine in each vehicle at the time of redesign or refresh, independent of what was done to other vehicles using a previously identical engine.

In the current version of the CAFE model, engines and transmissions that are shared between vehicles must apply the same levels of technology in all technologies dictated by engine or transmission inheritance. This forced adoption is referred to as “engine inheritance” in the model documentation.

As with platform-shared technologies, the model first chooses an “engine leader” among vehicles sharing the same engine. The leader is selected first by the vehicle with the lowest average sales across all available model years. If there is a tie, the vehicle with the highest average MSRP across model years is chosen. The model applies the same logic with respect to the application of transmission changes. As with platforms, this is driven by the concept that vehicle manufacturers typically deploy new technologies in small numbers prior to deploying widely across their product lines.

10.1.1.4 Interactions between Regulatory Classes

Like earlier versions, the current CAFE model provides for integrated analysis spanning different regulatory classes, accounting both for standards that apply separately to different classes and for interactions between regulatory classes. Light vehicle CAFE standards are specified separately for passenger cars and light trucks. However, there is considerable sharing between these two regulatory classes. Some specific engines and transmissions are used in both passenger cars and light trucks, and some vehicle platforms span these regulatory classes. For example, some sport-utility vehicles are offered in 2WD versions classified as passenger cars and 4WD versions classified as light trucks. Integrated analysis of manufacturers’ passenger car and light truck fleets provides the ability to account for such sharing and reduce the likelihood of finding solutions that could involve impractical levels of complexity in manufacturers’ product lines. In addition, integrated analysis provides the ability to simulate the potential that manufactures could earn CAFE credits by over complying with one standard and use those credits toward compliance with the other standard (i.e., to simulate credit transfers between regulatory classes).

HD pickups and vans are regulated separately from light-duty vehicles. While manufacturers cannot transfer credits between light-duty and MDHD classes, there is some sharing of engineering and technology between light-duty vehicles and HD pickups and vans. For example, some passenger vans with GVWR over 8,500 pounds are classified as medium-duty passenger vehicles (MDPVs) and thus included in manufacturers’ light-duty truck fleets, while cargo vans sharing the same nameplate are classified as HD vans.

While this analysis examines the HD pickup and van fleet in isolation, as a basis for analysis supporting the planned final rule, the agencies intend to develop an overall analysis fleet spanning both the light-duty and HD pickup and van fleets. Doing so could show some technology “spilling over” to HD pickups and vans due, for example, to the application of technology in response to current light-duty standards. More generally, modeling the two fleets together should tend to more realistically limit the scope and complexity of estimated compliance pathways.

NHTSA anticipates that the impact of modeling a combined fleet will primarily arise from engine-transmission inheritance. While platform sharing between the light-duty and MD pickup and van fleets is relatively small (MDPVs aside), there are a number of instances of engine and transmission sharing across the two fleets. When the fleets are modeled together, the agencies anticipate that engine inheritance will be implemented across the combined fleet, and therefore only one engine-transmission leader can be defined across the combined fleet. As with the fleets separately, all vehicles using a shared engine/transmission would automatically adopt technologies adopted by the engine-transmission leader.

10.1.1.5 **Phase-In Caps**

The CAFE model retains the ability to use phase-in caps (specified in model inputs) as proxies for a variety of practical restrictions on technology application. Unlike vehicle-specific restrictions related to redesign, refreshes or platforms/engines, phase-in caps constrain technology application at the vehicle manufacturer level. They are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process.

In previous CAFE rulemakings, redesign/refresh schedules and phase-in caps were the primary mechanisms to reflect an OEM's limited pool of available resources during the rulemaking time frame and the years leading up to the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. The newly-introduced representation platform-, engine-, and transmission-related considerations discussed above augment the model’s preexisting representation of redesign cycles and accommodation of phase-in caps. Considering these new constraints, inputs for today’s analysis de-emphasize reliance on phase-in caps.

In this application of the CAFE model, phase-in caps are used only for the most advanced technologies included in the analysis, i.e., SHEVs and lean-burn GDI engines, considering that these technologies are most likely to involve implementation costs and risks not otherwise accounted for in corresponding input estimates of technology cost. For these two technologies, the agencies have applied caps that begin at 3 percent (i.e., 3 percent of the manufacturer’s production) in MY 2017, increase at 3 percent annually during the ensuing nine years (reaching 30 percent in the MY 2026), and subsequently increasing at 5 percent annually for four years (reaching 50 percent in MY 2030). Note that the agencies did not feel that lean-burn engines were feasible in the timeframe of this rulemaking, so decided to reject any model runs where they were selected. Due to the cost ineffectiveness of this technology, it was never chosen.

10.1.1.6 **Impact of Vehicle Technology Application Requirements**

Compared to prior analyses of light-duty standards, these model changes, along with characteristics of the HD pickup and van fleet result in some changes in the broad characteristics of the model’s application of technology to manufacturers’ fleets. First, since the number of HD pickup and van platforms in a portfolio is typically small, compliance with standards may appear especially “lumpy” (compared to previous applications of the CAFE model to the more highly segmented light-duty fleet), with significant over compliance when widespread redesigns precede stringency increases, and/or significant application of carried-forward (aka “banked”) credits.

Second, since the use of phase-in caps has been de-emphasized and manufacturer technology deployment remains tied strongly to estimated product redesign and freshening schedules, technology penetration rates may jump more quickly as manufacturers apply technology to high-volume products in their portfolio.

By design, restrictions that enforce commonality of mass reduction and aerodynamic technologies on variants of a platform, and those that enforce engine inheritance, will result in fewer vehicle-technology combinations in a manufacturer's future modeled fleet. These restrictions are expected to more accurately capture the true costs associated with producing and maintaining a product portfolio.

10.1.1.7 **Example of Technology Application Estimated using Current Model and Inputs**

The example presented below illustrates how some of aspects of the current model and inputs impact estimation of technology application by a manufacturer within the context of a specified set of standards, focusing here on the model's estimate of GM's technology application under the 4.0 percent/y regulatory alternative (Alternative 5). Overall results for GM and other manufacturers are summarized below, after discussion of the analysis fleet used for today's analysis. Results for GM clearly reflect the analysis fleet's inclusion of just one HD pickup platform with redesigns estimated to occur in MYs 2021 and 2026 and one HD van platform with a redesign estimated to occur in MY 2020. The analysis suggests that GM could take some advantage of credit carry-forward provisions (e.g., to cover a shortfall projected to occur in MY 2016, when the HD pickup and van fleet first includes some vehicles not previously subject to chassis dynamometer testing), but that GM could need to significantly over comply with standards during MYs 2021-2024 in order take full advantage of the estimated MY 2021 HD pickup redesign and thereby carry forward enough technology to remain in compliance through MY 2030 (the last model year included in today's analysis). The results also reflect that credits earned during MY 2021-2024 expire before MY 2030, and that the Express/Savana vans inherit a new transmission in MY 2027.

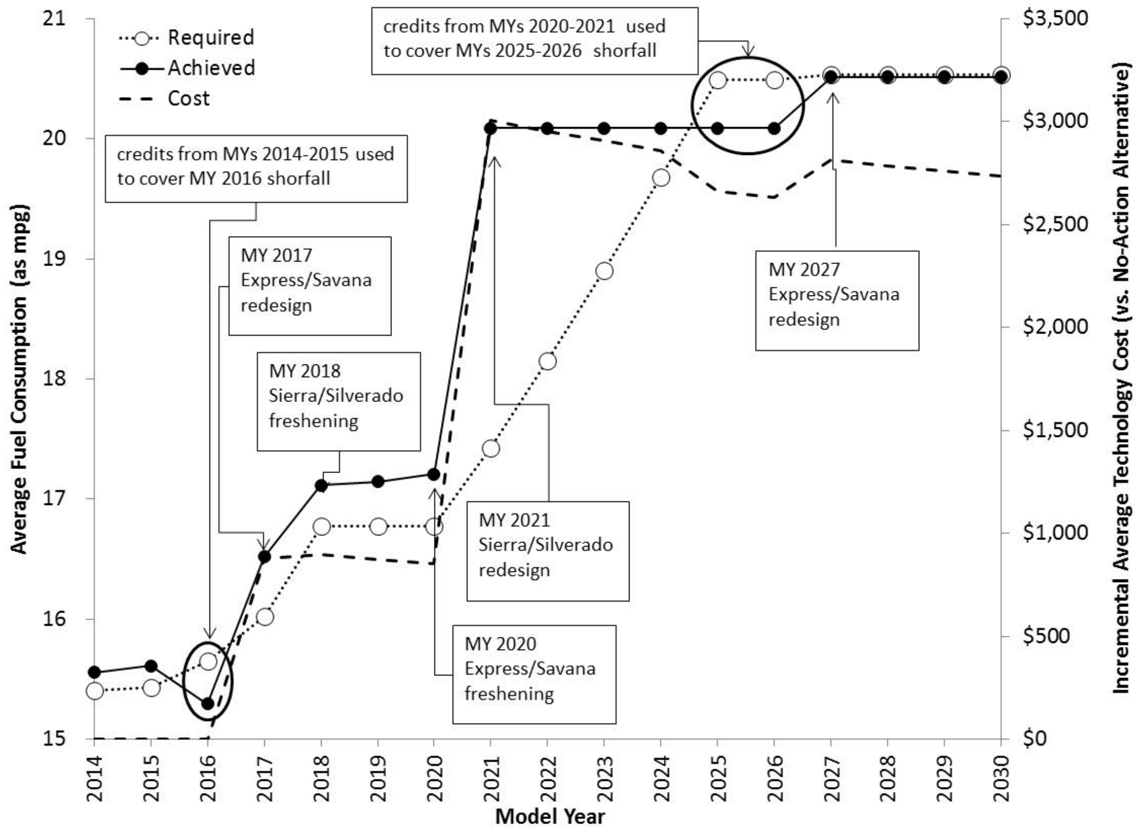

Figure 10-2 Example of technology application during redesigns

Specific steps estimated to be taken when these platforms are redesigned and freshened are as follows:

MY 2017 Express/Savana Redesign

- 4.8 liter gasoline engine: replace with smaller turbocharged direct injection engine
- 6.0 liter gasoline engine: add lower-friction lubricants, engine friction reduction, cylinder deactivation, variable valve actuation
- All Express/Savana vans: apply 5 percent mass reduction, aerodynamic improvements, electric power steering, improved accessories, integrated starter/generators, and low-drag brakes
- For Express/Savana vans, vs. MY 2014
  - additional $3,425-$4,473
  - avoided 0.94-2.05 gal./100 mi.

MY2018 Sierra/Silverado Freshening

- 6.0 liter gasoline engine: apply lower-friction lubricants and engine friction reduction
- All Sierra/Silverado pickups: apply 5 percent mass reduction, aerodynamic improvements, and electric power steering, and improved accessories
- For Sierra/Silverado pickups, vs. MY 2014
    - additional $383-$643
    - avoided 0.15-0.50 gal./100 mi.

MY 2020 Express/Savana Freshening

- Carry forward changes from MY 2017 (and through 2018-2019)
- All Express/Savana vans: apply reduced rolling resistance tires
- For Express/Savana vans, vs. MY 2014
    - additional $3,128-$4,033
    - avoided 1.01-2.11 gal./100 mi.

MY 2021 Sierra/Silverado Redesign

- Carry forward changes from MY 2018 (and through 2019-2020)
- 6.0 liter gasoline engine: apply cylinder deactivation and variable valve actuation
- 6.6 liter diesel engine: engine friction reduction and improved turbocharging
- All Sierra/Silverado pickups: apply 8-speed automatic transmission, 10 percent mass reduction, further aerodynamic improvements, low-drag brakes, secondary axle disconnect (on all 4WD units), low rolling resistance tires
- 76 percent of Sierra/Silverado pickups: apply integrated starter-generators
- 24 percent of Sierra/Silverado pickups: apply strong hybrid-electric systems (37k units)
- For Sierra/Silverado pickups, vs. MY 2014
    - additional $3,197-$5,805
    - avoided 1.12-3.09 gal./100 mi.

MY 2027 Express/Savana Redesign

- Carry forward changes from MY 2020 (and through 2021-2026)
- All Express/Savana vans: apply 8-speed transmission (inherited from 2021 Sierra/Silverado)
- 1.4 percent of Express/Savana vans: apply strong hybrid-electric systems (1.4k units)
- For Express/Savana vans, vs. MY 2014
    - additional $3,086-$5,226
    - avoided 1.03-3.29 gal./100 mi.

As discussed above, these results provide an estimate, based on analysis inputs, of one way GM could add fuel-saving technologies to its HD pickups and vans under one of the regulatory alternatives considered here, and are not a prediction of what GM would do under this regulatory alternative. In addition, it should be recognized that specific results vary among manufacturers and among regulatory alternatives (and under different analytical inputs). Still, the example should serve to illustrate how various inputs can impact results given the CAFE model's approach to estimating how fuel-saving technologies might be added to manufacturers' fleets.

10.1.1.8 Accounting for Test Weight, Payload, and Towing Capacity

As mentioned above, NHTSA has also revised the CAFE model to explicitly account for the regulatory "binning" of test weights used to certify light-duty fuel economy and HD pickup and van fuel consumption for purposes of evaluating fleet-level compliance with fuel economy and fuel consumption standards. For HD pickups and vans, test weight (TW) is based on adjusted loaded vehicle weight (ALVW), which is defined as the average of gross vehicle weight rating (GVWR) and curb weight (CW).[11] TW values are then rounded, resulting in TW "bins":

ALVW ≤ 4,000 lb.: TW rounded to nearest 125 lb.

4000 lb. < ALVW ≤ 5,500 lb.: TW rounded to nearest 250 lb.

ALVW > 5,500 lb.: TW rounded to nearest 500 lb.

This "binning" of TW is relevant to calculation of fuel consumption reductions accompanying mass reduction. Model inputs for mass reduction (as an applied technology) are expressed in terms of a percentage reduction of curb weight and an accompanying estimate of the percentage reduction in fuel consumption, setting aside rounding of test weight. Therefore, to account for rounding of test weight, NHTSA has modified these calculations as follows:

$$\Delta FC_{rounded\_TW} = \Delta TW \times \frac{\Delta FC_{unrounded\_TW}}{\Delta CW}$$

Where:

ΔCW = % change in curb weight (from model input),

$\Delta FC_{unrounded\_TW}$ = % change in fuel consumption (from model input), without TW rounding,

ΔTW = % change in test weight (calculated), and

$\Delta FC_{rounded\_TW}$ = % change in fuel consumption (calculated), with TW rounding.

[11] Or, equivalently, CW + ½ payload, where payload = GVWR – CW.

As a result, some applications of vehicle mass reduction will produce no compliance benefit at all, in cases where the changes in ALVW are too small to change test weight when rounding is taken into account. On the other hand, some other applications of vehicle mass reduction will produce significantly more compliance benefit than when rounding is not taken into account, in cases where even small changes in ALVW are sufficient to cause vehicles' test weights to increase by, e.g., 500 pounds when rounding is accounted for. Model outputs now include initial and final TW, GVWR, and GCWR (and, as before, CW) for each vehicle model in each model year, and the agencies invite comment on the extent to which these changes to account explicitly for changes in TW are likely to produce more realistic estimates of the compliance impacts of reductions in vehicle mass.

In addition, considering that the regulatory alternatives in the agencies' analysis all involve attribute-based standards in which underlying fuel consumption targets vary with "work factor" (defined by the agencies as the sum of three quarters of payload, one quarter of towing capacity, and 500 lb. for vehicles with 4WD), NHTSA has modified the CAFE model to apply inputs defining shares of curb weight reduction to be "returned" to payload and shares of GVWR reduction to be returned to towing capacity. The standards' dependence on work factor provides some incentive to increase payload and towing capacity, both of which are buyer-facing measures of vehicle utility. In the agencies' judgment, this provides reason to assume that if vehicle mass is reduced, manufacturers are likely to "return" some of the change to payload and/or towing capacity. For this analysis, the agencies have applied the following assumptions:

GVWR will be reduced by half the amount by which curb weight is reduced. In other words, 50 percent of the curb weight reduction will be returned to payload.

GCWR will not be reduced. In other words, 100 percent of any GVWR reduction will be returned to towing capacity.

GVWR/CW and GCWR/GVWR will not increase beyond levels observed among the majority of similar vehicles (or, for outlier vehicles, initial values):

	MAXIMUM RATIOS ASSUMED ENABLED BY MASS REDUCTION	
Group	**GVWR/CW**	**GCWR/GVWR**
unibody	1.75	1.50
gasoline pickups > 13k GVWR	2.00	1.50
other gasoline pickups	1.75	2.25
diesel SRW pickups	1.75	2.50
All other	1.75	2.25

The first of two of these inputs are specified along with standards for each regulatory alternative, and the GVWR/CW and GCWR/GVWR "caps" are specified separately for each vehicle model in the analysis fleet.

In addition, DOT has changed the model to prevent HD pickup and van GVWR from falling below 8,500 pounds when mass reduction is applied (because doing so would cause vehicles to be reclassified as light-duty vehicles), and to treat any additional mass for hybrid electric vehicles as reducing payload by the same amount (e.g., if adding a strong HEV package to a vehicle involves a 350 pound penalty, GVWR is assumed to remain unchanged, such that payload is also reduced by 350 pounds).

The agencies invite comment on these methods for estimating how changes in vehicle mass may impact fuel consumption, GVWR, and GCWR, and on corresponding inputs to today's analysis.

2.2.2 What Impacts Did the Agencies' Analysis Show for Different Regulatory Alternatives

10.1.1.9 Industry Impacts

As discussed above, the agencies' analysis fleet provides a starting point for estimating the extent to which manufacturers might add fuel-saving (and, therefore, CO_2-avoiding) technologies under various regulatory alternatives, including the no-action alternative that defines a baseline relative to which to measure estimated impacts of new standards. The analysis fleet is a forward-looking projection of production of new HD pickups and vans, holding vehicle characteristics (e.g., technology content and fuel consumption levels) constant at model year 2014 levels, and adjusting production volumes based on recent DOE and commercially-available forecasts. This analysis fleet includes some significant changes relative to fleet information underlying analysis supporting the establishment of Phase 1 standards applicable starting in model year 2014; in particular, the analysis fleet includes some new HD vans (e.g., Ford's Transit and Fiat/Chrysler's Promaster) that are considerable more fuel-efficient than HD vans these manufacturers have previously produced for the U.S. market.

While the proposed standards are scheduled to begin in model year 2021, the requirements they define are likely to influence planning decisions made by manufacturers several years before they begin, as illustrated by example above. This is true in light-duty planning, but accentuated by the comparatively long redesign cycles and small number of models and platforms offered for sale in the 2b/3 market segment. Additionally, manufacturers will respond to the cost and efficacy of available fuel consumption improvements, the price of fuel, and the requirements of the Phase 1 standards that specify maximum allowable average fuel consumption improvements and GHG levels for MY2014-MY2018 vehicles (the final standard for MY2018 is held constant for model years 2019 and 2020). The forward-looking nature of product plans that determine which vehicle models will be offered in the model years affected by the proposed standards lead to additional technology application to vehicles in the analysis fleet that occurs in the years prior to the start of the proposed standards. From the industry perspective, this means that manufacturers will incur costs to comply with the proposed standards in the baseline and that the total cost of the proposed regulations will include some costs that occur prior to their start, and represent incremental changes over a world in which manufacturers will have already modified their vehicle offerings compared to today.

Table 10-13 MY2021 Baseline Costs for Manufacturers in 2b/3 Market Segment in the Dynamic Baseline, or Alternative 1b

MANUFACTURER	AVERAGE TECHNOLOGY COST ($)	TOTAL COST INCREASE ($M)
Chrysler/Fiat	275	27
Daimler	18	0
Ford	258	78
General Motors	782	191
Nissan	282	3
Industry	442	300

As Table 10-13 shows, the industry as a whole is expected to add about $440 of new technology to each new vehicle model by 2021 under the no-action alternative defined by the Phase 1 standards. Reflecting differences in projected product offerings in the analysis fleet, some manufacturers (notably Daimler) are significantly less constrained by the Phase 1 standards than others and face lower cost increases as a result. General Motors (GM) shows the largest increase in average vehicle cost, but results for GM's closest competitors (Ford and Chrysler/Fiat) do not include the costs of their recent van redesigns, which are already present in the analysis fleet (discussed in greater detail below).

The above results reflect the assumption that manufacturers having achieved compliance with standards might act as if buyers are willing to pay for further fuel consumption improvements that "pay back" within 6 months. It is also possible that manufacturers will choose not to migrate cost-effective technologies to the 2b/3 market segment from similar vehicles in the light-duty market. To examine this possibility, all regulatory alternatives were also using the DOT CAFE model (Method A) with a 0-month payback period in lieu of the 6-month payback period discussed above. (A sensitivity analysis using Method A, discussed below, also explores longer payback periods, as well as the combined effect of payback period and fuel price on vehicle design decisions.) Resultant technology costs in model year 2021 results for the no-action alternative, summarized below, are quite similar to those shown above for the 6-month payback period:

Table 10-14 MY2021 Baseline Costs for HD Pickups and Vans in the Flat Baseline, or Alternative 1a

MANUFACTURER	AVERAGE TECHNOLOGY COST ($)	TOTAL COST INCREASE ($M)
Chrysler/Fiat	268	27
Daimler	0	0
Ford	248	75
General Motors	767	188
Nissan	257	3
Industry	431	292

The results below represent the impacts of other regulatory alternatives, including those defined by the proposed standards, as incremental changes over the baseline, where the baseline is defined as the state of the world in the absence of the proposed regulatory action. Large-scale, macroeconomic conditions like fuel prices are constant across all alternatives, including the baseline, as are the fuel economy improvements under the no-action alternative defined by the Phase 1 MDHD rulemaking that covers model years 2014 – 2018 and is constant from model year 2018 through 2020. In the baseline scenario, the Phase 1 standards are assumed to remain in place and at 2018 levels throughout the analysis (i.e. MY 2030). The only difference between the definitions of the alternatives is the stringency of the proposed standards for MYs 2021 – 2025, and all of the differences in outcomes across alternatives are attributable to differences in the standards.

The standards vary in stringency across regulatory alternatives (1 – 5), but as discussed above, all of the standards are based on the curve developed in the Phase 1 standards that relate fuel economy and GHG emissions to a vehicle's work factor. The alternatives considered here represent different rates of annual increase in the curve defined for model year 2018, growing from a 0 percent annual increase (Alternative 1, the baseline or "no-action" alternative) up to a 4 percent annual increase (Alternative 5). Table 10-15 shows a summary of outcomes by alternative incremental to the baseline (Alternative 1b) for Model Year 2030[12], with the exception of technology penetration rates, which are absolute.

The technologies applied by the CAFE model have been grouped (in most cases) to give readers a general sense of which types of technology are applied more frequently than others, and are more likely to be offered in MY2030 2b/3 vehicles. The summaries of technology penetration are also intended to reflect the relationship between technology application and cost increases across the alternatives. The table rows present the degree to which specific technologies will be present in new class 2b and class 3 vehicles in 2030, and correspond to: variable valve timing (VVT) and/or variable valve lift (VVL), cylinder deactivation, direct injection, engine turbocharging, 8-speed automatic transmissions, electric power-steering and accessory improvements, micro-hybridization (which reduces engine idle, but does not assist propulsion), full hybridization (integrated starter generator or strong hybrid that assists propulsion and recaptures braking energy), and aerodynamic improvements to the vehicle shape. In addition to the technologies in the following tables, there are some lower-complexity technologies that have high market penetration across all the alternatives and manufacturers; low rolling-resistance tires, low friction lubricants, and reduced engine friction, for example.

[12] The CAFE model estimates that redesign schedules will "straddle" model year 2025, the latest year for which the agencies are proposing increases in the stringency of fuel consumption and GHG standards. Considering also that today's analysis estimates some earning and application of "carried forward" compliance credits, the model was run extending the analysis through model year 2030.

Table 10-15 Summary of HD Pickup and Van Alternatives' Impact on Industry versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Total Stringency Increase	9.6%	16.2%	16.3%	18.5%
Average Fuel Economy (miles per gallon)				
Required	19.04	20.57	20.57	21.14
Achieved	19.14	20.61	20.83	21.27
Average Fuel Consumption (gallons /100 mi.)				
Required	5.25	4.86	4.86	4.73
Achieved	5.22	4.85	4.80	4.70
Average Greenhouse Gas Emissions (g/mi)				
Required	495	458	458	446
Achieved	491	458	453	444
Technology Penetration (%)				
VVT and/or VVL	46	46	46	46
Cylinder Deac.	29	21	21	21
Direct Injection	17	25	31	32
Turbocharging	55	63	63	63
8-Speed AT	67	96	96	97
EPS, Accessories	54	80	79	79
Stop Start	0	0	10	13
Hybridization[a]	0	8	35	51
Aero. Improvements	36	78	78	78
Mass Reduction (vs. No-Action)				
CW (lb.)	239	243	325	313
CW (%)	3.7	3.7	5.0	4.8
Technology Cost (vs. No-Action)				
Average ($) [b]	578	1,348	1,655	2,080
Total ($m) [c]	437	1,019	1,251	1,572
Payback period (m) [c]	25	31	34	38

Notes:
[a] Includes mild hybrids (ISG) and strong HEVs.
[b] Values used in Methods A & B
[c] Values used in Method A, calculated using a 3% discount rate.

In general, the standards cause manufacturers to produce HD pickups and vans that are lighter, more aerodynamic, and more technologically complex across all the alternatives. As Table 10-15 shows, there is a major difference between the relatively small increases in required fuel economy and average incremental technology cost between the alternatives, suggesting that the challenge of improving fuel consumption and CO_2 emissions accelerates as stringency increases (i.e., that there may be a "knee" in the dependence of the challenge and on the stringency). Despite the fact that the required average fuel consumption level only changes by about 3 percent between Alternative 4 and Alternative 5, average technology cost increases by more than 25 percent. These differences help illustrate the clustered character of this market segment.

The contrast between alternatives 3 and 4 is even more prominent, with an identical required fuel economy improvement leading to price increases greater than 20 percent based on the more rapid rate of increase and shorter time span of Alternative 4, which achieves all of its increases by MY 2025 while Alternative 3 continues to increase at a slower rate until MY 2027. Despite these differences, the increase in average payback period when moving from Alternative 3 to Alternative 4 to Alternative 5 is fairly constant at around an additional three months for each jump in stringency.

Manufacturers offer few models, typically only a pickup truck and/or a cargo van, and while there are a large number of variants of each model, the degree of component sharing across the variants can make diversified technology application either economically impractical or impossible. This forces manufacturers to apply some technologies more broadly in order to achieve compliance than they might do in other market segments (passenger cars, for example). This difference between broad and narrow application – where some technologies must be applied to entire platforms, while some can be applied to individual model variants – also explains why certain technology penetration rates decrease between alternatives of increasing stringency (cylinder deactivation or mass reductions in Table 10-15, for example). For those cases, narrowly applying a more advanced (and costly) technology can be a more cost effective path to compliance and lead to reductions in the amount of lower-complexity technology that is applied.

One driver of the change in technology cost between Alternative 3 and Alternative 4 is the amount of hybridization resulting from the implementation of the standards. While only about 8 percent full hybridization (defined as either integrated starter-generator or strong hybrid) is expected to be required to comply with Alternative 3, the higher rate of increase and compressed schedule moving from Alternative 3 and Alternative 4 is enough to increase the percentage of the fleet adopting full hybridization to 35 percent. To the extent that manufacturers are concerned about introducing hybrid vehicles in the 2b and 3 market, it is worth noting that new vehicles subject to Alternative 3 achieves the same fuel economy as new vehicles subject to Alternative 4, with less hybridization required to achieve the improvement.

The alternatives also lead to important differences in outcomes at the manufacturer level, both from the industry average and from each other. General Motors, Ford, and Chrysler (Fiat), are expected to have approximately 95 percent of the 2b/3 new vehicle market during the years that the proposed standards are in effect. Due to their importance to this market and the similarities between their model offerings, these three manufacturers are discussed together and a summary of the way each is impacted by the standards appears below in Table 10-16, Table 10-17, and Table 10-18 for General Motors, Ford, and Chrysler/Fiat, respectively.

Table 10-16 Summary of Impacts on General Motors by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	18.38	19.96	20	20.53
Achieved	18.43	19.95	20.24	20.51
Average Fuel Consumption (gallons /100 mi.)				
Required	5.44	5.01	5	4.87
Achieved	5.42	5.01	4.94	4.87
Average Greenhouse Gas Emissions (g/mi)				
Required	507	467	467	455
Achieved	505	468	461	455
Technology Penetration (%)				
VVT and/or VVL	64	64	64	64
Cylinder Deac.	47	47	47	47
Direct Injection	18	18	36	36
Turbocharging	53	53	53	53
8-Speed AT	36	100	100	100
EPS, Accessories	100	100	100	100
Stop Start	0	0	2	0
Hybridization[c]	0	19	79	100
Aero. Improvements	100	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	325	161	158	164
CW (%)	5.3	2.6	2.6	2.7
Technology Cost (vs. No-Action)				
Average ($) [a]	785	1,706	2,244	2,736
Total ($m, undiscounted) [b]	214	465	611	746

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-17 Summary of Impacts on Ford by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	19.42	20.96	20.92	21.51
Achieved	19.5	21.04	21.28	21.8
Average Fuel Consumption (gallons /100 mi.)				
Required	5.15	4.77	4.78	4.65
Achieved	5.13	4.75	4.70	4.59
Average Greenhouse Gas Emissions (g/mi)				
Required	485	449	450	438
Achieved	482	447	443	433
Technology Penetration (%)				
VVT and/or VVL	34	34	34	34
Cylinder Deac.	18	0	0	0
Direct Injection	16	34	34	34
Turbocharging	51	69	69	69
8-Speed AT	100	100	100	100
EPS, Accessories	41	62	59	59
Stop Start	0	0	20	29
Hybridization[c]	0	2	14	30
Aero. Improvements	0	59	59	59
Mass Reduction (vs. No-Action)				
CW (lb.)	210	202	379	356
CW (%)	3.2	3	5.7	5.3
Technology Cost (vs. No-Action)				
Average ($) [a]	506	1,110	1,353	1,801
Total ($m, undiscounted) [b]	170	372	454	604

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-18 Summary of Impacts on Fiat/Chrysler by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	18.73	20.08	20.12	20.70
Achieved	18.83	20.06	20.10	20.70
Average Fuel Consumption (gallons /100 mi.)				
Required	5.34	4.98	4.97	4.83
Achieved	5.31	4.99	4.97	4.83
Average Greenhouse Gas Emissions (g/mi)				
Required	515	480	479	466
Achieved	512	481	480	467
Technology Penetration (%)				
VVT and/or VVL	40	40	40	40
Cylinder Deac.	23	23	23	23
Direct Injection	17	17	17	17
Turbocharging	74	74	74	74
8-Speed AT	65	88	88	88
EPS, Accessories	0	100	100	100
Stop-Start	0	0	0	0
Hybridization[c]	0	3	3	10
Aero. Improvements	0	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	196	649	648	617
CW (%)	2.8	9.1	9.1	8.7
Technology Cost (vs. No-Action)				
Average ($) [a]	434	1,469	1,486	1,700
Total ($m, undiscounted) [b]	48	163	164	188

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

The fuel consumption and GHG standards require manufacturers to achieve an average level of compliance, represented by a sales-weighted average across the specific targets of all vehicles offered for sale in a given model year, such that each manufacturer will have a unique required consumption/emissions level determined by the composition of its fleet, as illustrated above. However, there are more interesting differences than the small differences in required fuel economy levels among manufacturers. In particular, the average incremental technology cost increases with the stringency of the alternative for each manufacturer, but the size of the cost increase from one alternative to the next varies widely among them, with General Motors in particular showing considerably larger increases in cost than the other two manufacturers moving both from Alternative 2 to Alternative 3, and again moving from Alternative 3 to Alternative 4.

The simulation results show all three manufacturers facing large cost increases when the proposed standards move from 2.5 percent annual increases over the period from MY 2021 – 2027 to 3.5 percent annual increases from MY 2021 - 2025, but General Motors has the largest at 75 percent more than the industry average price increase for Alternative 4. GM also faces higher cost increases in Alternative 2, 2 about 50 percent more than either Ford or Fiat/Chrysler. And for the most stringent alternative considered, General Motors would face average cost increases of more than $2,700, in addition to the more than $700 increase in the baseline – approaching nearly $3,500 per vehicle over today's prices.

Technology choices also differ by manufacturer, and some of those decisions are directly responsible for the largest cost discrepancies. For example, GM is estimated to engage in the least amount of mass reduction among the Big 3 after Phase 1, and much less than Chrysler/Fiat, but reduces average vehicle mass by over 300 pounds in the baseline – suggesting that some of GM's easiest Phase 1 compliance opportunities can be found in lightweighting technologies. Similarly, Chrysler/Fiat applies less hybridization than the others, and much less than General Motors, which is simulated to have hybrids (either integrated starter generator or full hybrid system) on much of its fleet by 2030, nearly 20 percent of which will be strong hybrids, in Alternative 4 and the strong hybrid share decreases to about 18 percent in Alternative 5, as some lower level technologies are applied more broadly. Because the analysis applies the same technology inputs and the same logic for selecting among available opportunities to apply technology, the unique situation of each manufacturer determined which technology path was the most cost-effective.

In order to understand the differences in incremental technology costs and fuel economy achievement across manufacturers in this market segment, it is important to understand the differences in their starting position relative to the proposed standards. One important factor, made more obvious in the following figures, is the difference between the fuel economy and performance of the recently redesigned vans offered by Fiat/Chrysler and Ford (the Promaster and Transit, respectively), and the more traditionally-styled vans that continue to be offered by General Motors (the Express/Savannah). In MY 2014, Ford began the phase-out of the Econoline van platform, moving those volumes to the Euro-style Transit vans (discussed in more detail in Section 2.1.2). The Transit platform represents a significant improvement over the existing Econoline platform from the perspective of fuel economy, and for the purpose of complying with the standards, the relationship between the Transit's work factor and fuel economy is a more favorable one than the Econoline vans it replaces. Since the redesign of van offerings from both Chrysler/Fiat and Ford occur in (or prior to) the 2014 model year, the costs, fuel consumption improvements, and reductions of vehicle mass associated with those redesigns are included in the analysis fleet, meaning they are not carried as part of the compliance modeling exercise. By contrast, General Motors is simulated to redesign their van offerings after

2014, such that there is a greater potential for these vehicles to incur additional costs attributable to new standards, unlike the costs associated with the recent redesigns of their competitors. The inclusion of these new Ford and Chrysler/Fiat products in the analysis fleet is the primary driver of the cost discrepancy between GM and its competitors in both the baseline and Alternative 2, when Ford and Chrysler/Fiat have to apply considerably less technology to achieve compliance.

Figure 10-3 and Figure 10-4 show the relationship between work factor and fuel economy for the model variants offered by GM, Ford and Chrysler/Fiat for gasoline (Figure 10-3**Error! Reference source not found.**) and diesel (Figure 10-4) vehicles based on product information the manufacturers supplied to the agencies. In the figures, vans are represented by crosses and pickup trucks by circles, with a different color corresponding to each member of the Big 3 (blue, green, and orange for Fiat/Chrysler, Ford, and General Motors, respectively).

In Figure 10-3, the field of green crosses in the upper left shows the impact of the Transit vans on Ford's product mix. While Chrysler/Fiat has a single van below that cloud, the gasoline-powered Promaster, both have real separation from GM's van offerings which are generally higher in work factor and considerably lower in fuel economy. Ford has a cluster of gasoline pickup truck variants with among the highest work factors and lowest fuel economies, but another cluster of pickup trucks with work factors between 4500 and 6000 and higher fuel economy values than nearly all competitors' pickup trucks in that range.

The curves provide a sliding a scale of fuel economy targets for vehicle models based on work factor, but the changes in scale are not sufficient to overcome GM's poor starting position in fuel economy relative to its peers. As Figure 10-4 shows, this pattern is even stronger in the diesel market, where both GM and Chrysler/Fiat have multiple offerings above 20 MPG. These high MPG models are all vans and, as noted above, GM's van offerings would need changes in order to provide fuel economy competing with offerings of GM's peers – even in the absence of regulatory pressure.

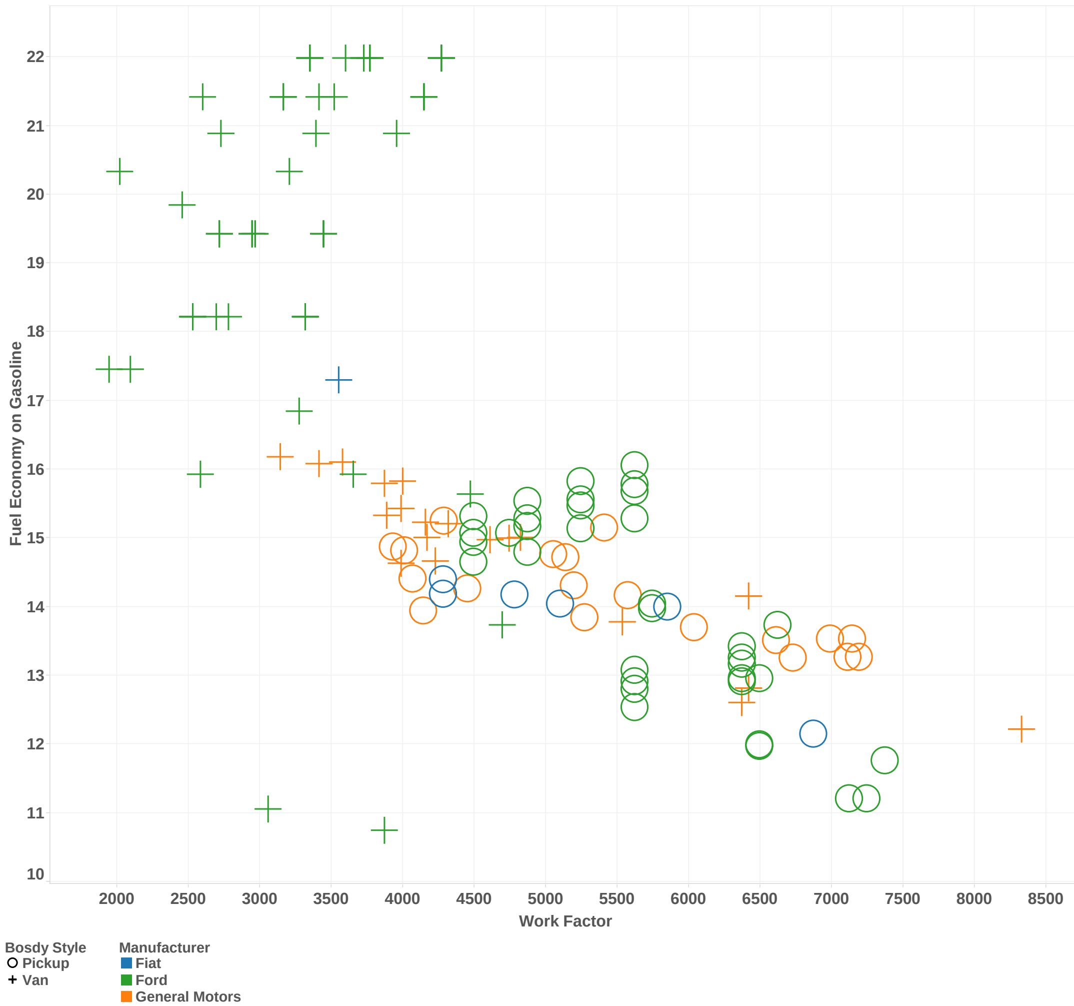

Figure 10-3 Comparison of Fuel Economy and Work Factor for Gasoline Vehicles in the Analysis Fleet

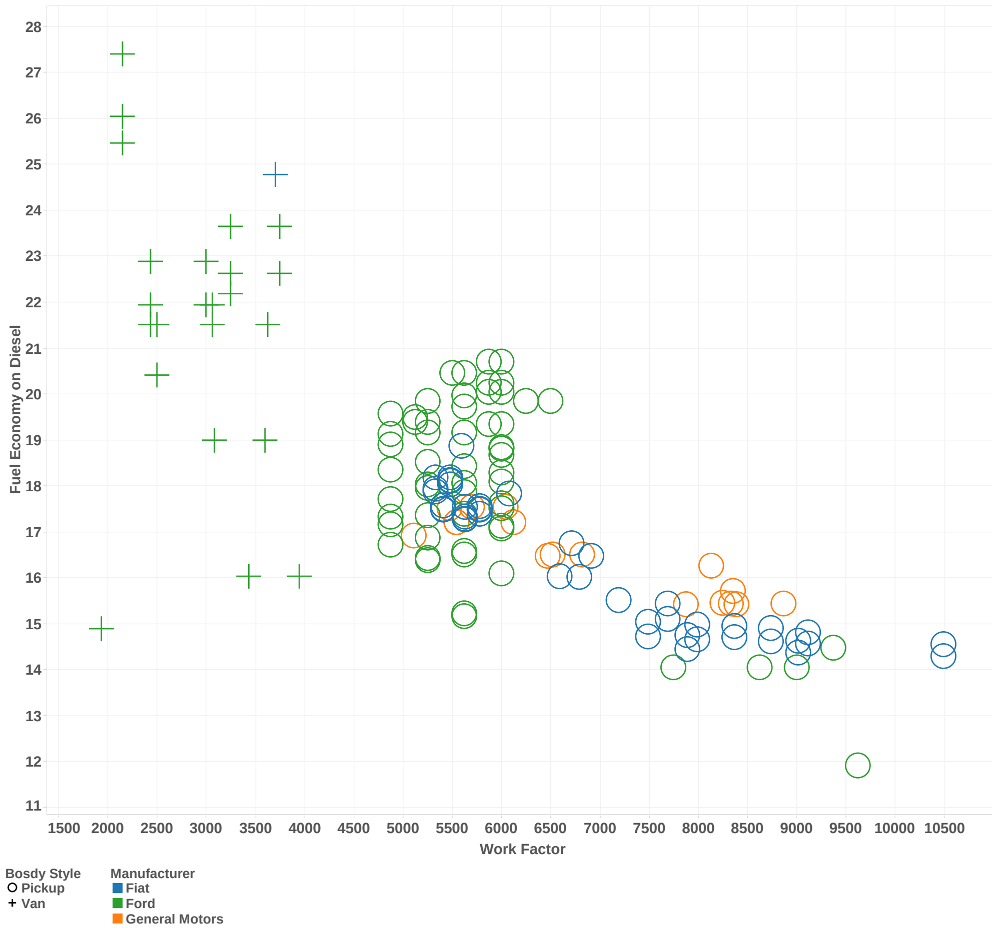

Figure 10-4 Comparison of Fuel Economy and Work Factor for Diesel Vehicles in the Analysis Fleet

In the context of an averaging such as under the fuel consumption and GHG standards, individual model offerings mean little without considering the sales volumes associated with those models. Figure 10-5 shows two pictures of empirical cumulative distributions, curves that show the sales weighted mix of work factor (on the left) and fuel economy (on the right) increasing from zero percent of sales to 100 percent of sales. At any given point in the curve, the value on the (vertical) y-axis shows the percentage of total sales that are less than or equal to the work factor (or fuel economy) at that point.

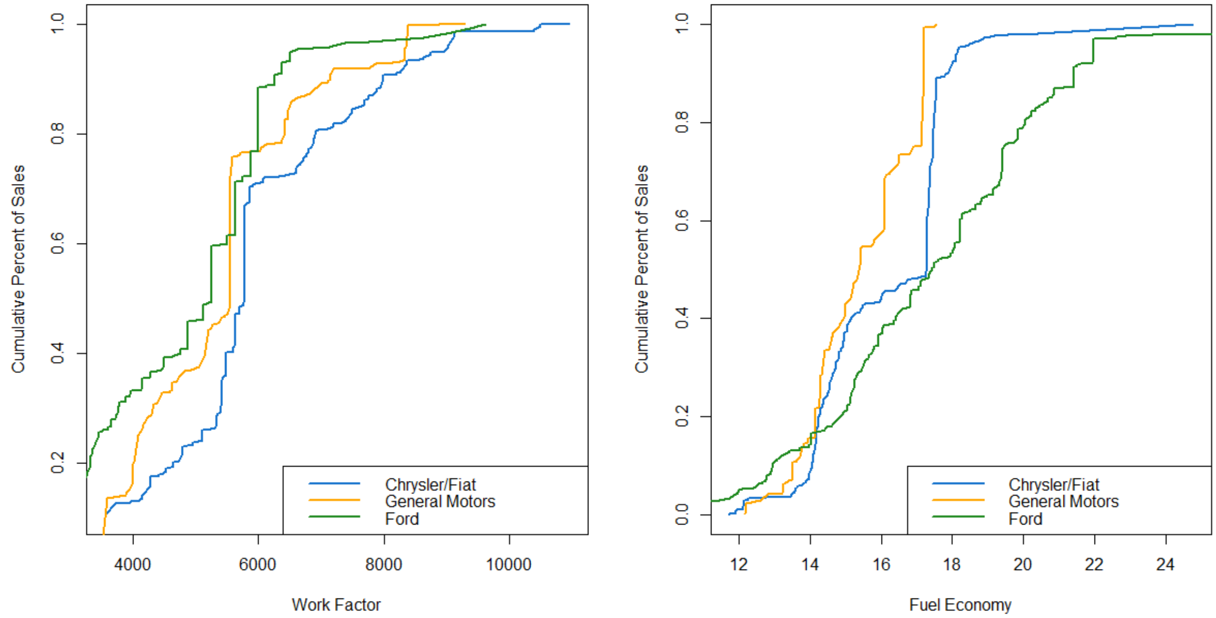

Figure 10-5 Comparing sales mix for Chrysler/Fiat, GM, and Ford

Since larger work factors correspond to lower fuel economy targets, the standards provide an incentive for a manufacturer to have more of its production closer to the right side of the work factor graph to reduce its required average fuel economy level (i.e., under the standards, to increase its required average fuel consumption and GHG levels), although this incentive is offset by the tendency of fuel consumption to increase as vehicle payload and towing capacity increase, and when 4WD is added. Figure 10-5 shows Chrysler/Fiat with the most favorable position, from the perspective of work factor, followed by GM. Although Ford's sales mix of work factors is the least favorable, Ford's sales mix generally has the highest fuel economy of the Big 3. As the graph on the right in Figure 10-5 shows, Ford has the most favorable sales mix of high fuel economy vehicles, and generally outperforms both other manufacturers at each fuel economy level. The sales distribution of fuel economies highlights the other important reason that GM appears to face much higher costs than their competitors in this segment: not only does GM have consistently lower fuel economy than Ford and Chrysler in their MY2014 vehicle fleet, they also have no models (at any significant level of sales) achieving more than 18 MPG, while both Ford and Chrysler/Fiat have about 40 percent and 10 percent of sales, respectively, at higher levels of fuel economy. Some of this discrepancy could be explained by measurement error in the pre-model-year compliance data; GM's final submission for model year 2014 may contain higher fuel economies as a result of more direct vehicle testing, or a different mix of final sales volumes that makes their starting position more favorable. The agencies intend to update the data in the analysis fleet before issuing the final rule.

The remaining 5 percent of the 2b/3 market is attributed to two manufacturers, Daimler and Nissan, which, unlike the other manufacturers in this market segment, only produce vans.

The vans offered by both manufacturers currently utilize two engines and two transmissions, although both Nissan engines are gasoline engines and both Daimler engines are diesels. Despite the logical grouping, these two manufacturers are impacted much differently by the proposed standards. For the least stringent alternative considered, Daimler adds no technology and incurs no incremental cost in order to comply with the standards. At stringency increases greater than or equal to 3.5 percent per year, Daimler only really improves some of their transmissions of its Sprinter vans. By contrast, Nissan's starting position is much weaker and their compliance costs closer to the industry average in Table 10-15. This difference could increase if the analysis fleet supporting the final rule includes forthcoming Nissan HD pickups.

Table 10-19 Summary of Impacts on Daimler by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	23.36	25.19	25.25	25.91
Achieved	25.23	25.79	25.79	26.53
Average Fuel Consumption (gallons /100 mi.)				
Required	4.28	3.97	3.96	3.86
Achieved	3.96	3.88	3.88	3.77
Average Greenhouse Gas Emissions (g/mi)				
Required	436	404	404	393
Achieved	404	395	395	384
Technology Penetration (%)				
VVT and/or VVL	0	0	0	0
Cylinder Deac.	0	0	0	0
Direct Injection	0	0	0	0
Turbocharging	44	44	44	44
8-Speed AT	0	44	44	100
EPS, Accessories	0	0	0	0
Stop-Start	0	0	0	0
Hybridization[c]	0	0	0	0
Aero. Improvements	0	0	0	0
Mass Reduction (vs. No-Action)				
CW (lb.)	0	0	0	0
CW (%)	0	0	0	0
Technology Cost (vs. No-Action)				
Average ($) [a]	0	165	165	374
Total ($m, undiscounted) [b]	0	4	4	9

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-20 Summary of Impacts on Nissan by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	19.64	21.19	20.92	21.46
Achieved	19.84	21.17	21.19	21.51
Average Fuel Consumption (gallons /100 mi.)				
Required	5.09	44.72	4.78	4.66
Achieved	5.04	4.72	4.72	4.65
Average Greenhouse Gas Emissions (g/mi)				
Required	452	419	425	414
Achieved	448	419	419	413
Technology Penetration (%)				
VVT and/or VVL	100	100	100	100
Cylinder Deac.	49	49	49	49
Direct Injection	51	51	51	100
Turbocharging	51	51	51	50
8-Speed AT	0	51	51	51
EPS, Accessories	0	100	100	100
Stop-Start	0	0	0	0
Hybridization[c]	0	0	0	28
Aero. Improvements	0	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	0	0	307	303
CW (%)	0	0	5	4.9
Technology Cost (vs. No-Action)				
Average ($) [a]	378	1,150	1,347	1,935
Total ($m, undiscounted) [b]	5	15.1	17.7	25.4

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

As Table 10-19 and Table 10-20 show, Nissan applies more technology than Daimler in the less stringent alternatives and significantly more technology with increasing stringency. The Euro-style Sprinter vans that comprise all of Daimler's model offerings in this segment put Daimler in a favorable position. However, those vans are already advanced – containing downsized diesel engines and advanced aerodynamic profiles. Much like the Ford Transit vans, the recent improvements to the Sprinter vans occurred outside the scope of the compliance modeling so the costs of the improvements are not captured in the analysis.

Although Daimler's required fuel economy level is much higher than Nissan's (in miles per gallon), Nissan starts from a much weaker position than Daimler and must incorporate additional engine, transmission, platform-level technologies (e.g. mass reduction and aerodynamic improvements) in order to achieve compliance. In fact, more than 25 percent of Nissan's van offerings become are projected to contain integrated starter generators by 2030 in Alternative 5.

10.1.1.10 **Estimated Consumer Impacts**

The consumer impacts of the rule are more straightforward. Table 10-21 shows the impact on the average consumer who buys a new class 2b or 3 vehicle in model year 2030. All dollar values are discounted at a rate of 7 percent per year from the time of purchase (except the average price increase, which occurs at the time of purchase). The additional costs associated with increases in taxes, registration fees, and financing costs are also captured in the table.

Table 10-21 Summary of Individual Consumer Impacts in MY 2030 in the HD Pickup and Van2b3 Market Segment using Method A and versus the Dynamic Baseline, Alternative 1b [a]

ANNUAL STRINGENCY INCREASE INCREASES	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Value of Lifetime Fuel Savings (discounted 2012 dollars)				
Pretax	2,068	3,924	4,180	4,676
Tax	210	409	438	491
Total	2,278	4,334	4,618	5,168
Economic Benefits (discounted 2012 dollars)				
Mobility Benefit	244	437	472	525
Avoided Refueling Time	86	164	172	193
New Vehicle Purchase (vs. No-Action Alternative)				
Avg. Cost Increase ($)	578	1,348	1,655	2,080
Avg. Payback (years)	2.5	3	3.4	3.9
Additional costs ($)	120	280	344	432
Net Lifetime Consumer Benefits (discounted $)				
Total Net Benefits	1,910	3,307	3,263	3,374

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

As expected, a consumer's lifetime fuel savings increase monotonically across the alternatives. The mobility benefit in Table 10-21 refers to the value of additional miles that an individual consumer travels as a result of reduced per-mile travel costs. The additional miles result in additional fuel consumption and represent foregone fuel savings, but are valued by consumers at the cost of the additional fuel plus the consumer surplus (a measure of the increase in welfare that consumers achieve by having more mobility). The refueling benefit measures the value of time saved through reduced refueling events, the result of improved fuel economy and range in vehicles that have been modified in response to the standards.

There are some limitations to using payback period as a measure, as it accounts for fuel expenditures and incremental costs associated with taxes, registration fees and financing, and increased maintenance costs, but not the cost of potential repairs or replacements, which may or may not be more expensive with more advanced technology.

Overall, the average consumer is likely to see discounted lifetime benefits that are multiples of the price increases faced when purchasing the new vehicle in MY 2030. In particular, the net present value of future benefits at the time of purchase are estimated to be 3.5, 3.0, 2.2, and 1.8 times the price increase of the average new MY2030 vehicle for Alternatives 2-5, respectively. As the table above illustrates, the preferred alternative has the highest ratio of discounted future consumer benefits to consumer costs.

10.1.1.11 **Social and Environmental Impacts**

Social benefits increase with the increasing stringency of the alternatives. As in the consumer analysis, the net benefits continue to increase with increasing stringency – suggesting that benefits are still increasing faster than costs for even the most stringent alternative.

Table 10-22 Summary of Total Social Costs and Benefits Through MY2029 in the HD Pickup and Van Market Segment using Method A and versus the Dynamic Baseline, Alternative 1b [a]

ALTERNATIVE	**2**	**3**	**4**	**5**
Annual Stringency Increase	2.0%	2.5%	3.5%	4.0%
Stringency Increase Through MY	2025	2027	2025	2025
Fuel Purchases ($billion)				
Pretax Savings	9.6	15.9	19.1	22.2
Fuel Externalities ($billion)				
Energy Security	0.5	0.9	1.1	1.3
CO_2 emissions[b]	1.9	3.2	3.8	4.4
VMT-Related Externalities ($billion)				
Driving Surplus	1.1	1.8	2.1	2.4
Refueling Surplus	0.4	0.7	0.8	0.9
Congestion	-0.2	-0.4	-0.4	-0.5
Accidents	-0.1	-0.2	-0.2	-0.3
Noise	0	0	0	0
Fatalities	0.1	-0.2	-0.2	-0.5
Criteria Emissions	0.6	1.1	1.3	1.6
Technology Costs vs. No-Action ($billion)				
Incremental Cost	2.5	5.0	7.2	9.7
Additional Costs	0.5	1.0	1.5	2.0
Benefit Cost Summary ($billion)				
Total Social Cost	3.3	6.8	9.5	13.0
Total Social Benefit	13.9	22.7	27.4	31.7
Net Social Benefit	10.6	15.9	17.9	18.7

[*]All dollar values are discounted at a rate of 3 percent per year from the time of purchase.
Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Using the 3% average social cost of CO_2 value. There are four distinct social cost of CO_2 values presented in the *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866 (2010 and 2013)*. The CO_2 emissions presented here would be valued lower with one of those other three values and higher at the other two values.

Table 10-22 provides a summary of benefits and costs, cumulative from MY2015 – MY2029 (although the early years of the series have nearly zero incremental costs and benefits over the baseline), for each alternative. In the social perspective, fuel savings are considered net of fuel taxes, which are a transfer from purchasers of fuel to society at large. The energy security component represents the risk premium associated with exposure to oil price spikes and the economic consequences of adapting to them. This externality is monetized on a per-gallon basis, just as the social cost of carbon is used in this analysis. Just as the previous two externalities are caused by fuel consumption, others are caused by travel itself. The additional VMT resulting from the increase in travel demand that occurs when the price of driving decreases (i.e. the rebound effect), not only leads to increased mobility, but also to increases in congestion, noise, accidents, and per-mile emissions of criteria pollutants like carbon monoxide and diesel particulates. Although increases in VMT lead to increases in tailpipe emissions of criteria pollutants, the proposed regulations decrease overall consumption enough that the emissions reductions associated with the remainder of the fuel cycle (extraction, refining, transportation and distribution) are large enough to create a net reduction in the emissions of criteria pollutants.[13] A full presentation of the costs and benefits, and the considerations that have gone into each cost and benefit category—such as how energy security premiums were developed, how the social costs of carbon and co-pollutant benefits were developed, etc.—is presented in Section IX of the preamble and in Chapters 7 and 8 of this draft RIA for each regulated segment (engines, HD pickups and vans, vocational vehicles, tractors and trailers).

Another side effect of increased VMT is the likely increase in traffic fatalities, which is a function of the total vehicle travel in each year. As

Table 10-22 illustrates, the positive social cost associated with traffic fatalities is the result of an additional -10 (implying that Alternative 2 actually leads to a reduction in fatalities over the baseline, due to the application of mass reduction technologies), 35, 36, and 66 fatalities for Alternatives 2-5, respectively. To put those numbers in context, the baseline contains nearly 25,000 fatalities attributable to 2b/3 vehicles over the same period. The incremental fatalities associated with the alternatives translate to less than -0.4, 0.1, 0.1, and 0.3 percent increases over the MY2015-2029 baseline, respectively.

The CAFE model was used to estimate the emissions impacts of the various alternatives that are the result of lower fuel consumption, but increased vehicle miles traveled for vehicle

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[13] For a more detailed discussion of the results from the CAFE Model on the proposed heavy duty pickups and vans regulation's impact on emissions of CO_2 and criteria pollutants, see NHTSA's accompanying Draft Environmental Impact Statement.

produced in model years subject to the standards in the alternatives. Criteria pollutants are largely the result of vehicle use, and accrue on a per-mile-of-travel basis, but the alternatives still generally lead to emissions reductions. Although vehicle use increases under each of the alternatives, upstream emissions associated with fuel refining, transportation and distribution are reduced for each gallon of fuel saved and that savings is larger than the incremental increase in emissions associated with increased travel. The net of the two factors is a savings of criteria (and other) pollutant emissions.

Table 10-23 Summary of Environmental Impacts Through MY2029 in the HD Pickup and Van Market Segment, using Method A and versus the Dynamic Baseline, Alternative 1b [a]

ANNUAL STRINGENCY INCREASE	2.0%	2.5%	3.5%	4.0%
Stringency Increase Through MY	2025	2027	2025	2025
Greenhouse Gas Emissions vs. No-Action Alternative				
CO_2 (MMT)	54	91	110	127
CH_4 and N2O (tons)	65,600	111,400	133,700	155,300
Other Emissions vs. No-Action Alternative (tons)				
CO	10,400	20,700	25,800	30,400
VOC and NO_X	23,800	43,600	53,500	62,200
PM	1,470	2,550	3,090	3,590
SO_2	11,400	19,900	24,100	28,000
Air Toxics	44	47	49	55
Diesel PM10	2,470	4,350	5,300	6,160
Other Emissions vs. No-Action Alternative (% reduction)				
CO	0.1	0.3	0.4	0.4
VOC and NO_X	1.1	2.1	2.6	3.0
PM	1.7	3.0	3.6	4.2
SO_2	2.9	5.1	6.2	7.2
Air Toxics	0.1	0.1	0.1	0.2
Diesel PM10	2.7	4.8	5.9	6.8

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

In addition to comparing environmental impacts of the alternatives against a dynamic baseline that shows some improvement over time, compared to today's fleet, even in the absence of the alternatives, the environmental impacts from the Method A analysis were compared against a flat baseline. This other comparison is summarized below, but both comparisons are discussed in greater detail in the Draft EIS.

Table 10-24 Summary of Environmental Impacts Through MY2029 in the HD Pickup and Van Market Segment, using Method A and versus the Flat Baseline, Alternative 1a [a]

ANNUAL STRINGENCY INCREASE	2.0%	2.5%	3.5%	4.0%
Stringency Increase Through MY	2025	2027	2025	2025
Greenhouse Gas Emissions vs. No-Action Alternative				
CO_2 (MMT)	66	105	127	142
CH_4 and N2O (tons)	79,700	127,400	154,800	172,800
Other Emissions vs. No-Action Alternative (tons)				
CO	11,630	22,160	28,030	32,370
VOC and NO_X	28,280	48,770	60,180	68,050
PM	1,780	2,900	3,550	3,980
SO2	13,780	22,580	27,660	31,020
Air Toxics	60	65	72	73
Diesel PM10	2,980	4,930	6,060	6,810
Other Emissions vs. No-Action Alternative (% reduction)				
CO	0.2	0.3	0.4	0.4
VOC and NO_X	1.4	2.3	2.9	3.3
PM	2.1	3.4	4.2	4.7
SO2	3.5	5.7	7.0	7.9
Air Toxics	0.2	0.2	0.2	0.2
Diesel PM10	3.3	5.4	6.7	7.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

10.1.1.12 Sensitivity Analysis to Different Inputs to the CAFE Model

This section describes some of the principal sensitivity results, obtained by running the various scenarios describing the policy alternatives with alternative inputs. OMB Circular A-4 indicates that "it is usually necessary to provide a sensitivity analysis to reveal whether, and to what extent, the results of the analysis are sensitive to plausible changes in the main assumptions and numeric inputs."[14] Considering this guidance, a number of sensitivity analyses were performed using analysis Method A to examine important assumptions and inputs, including the following:

1. Payback Period: In addition to the 0 and 6 month payback periods discussed above, also evaluated cases involving payback periods of 12, 18, and 24 months.
2. Fuel Prices: Evaluated cases involving fuel prices from the AEO 2014 low and high oil price scenarios. (See AEO-Low and AEO-High in the tables.)
3. Fuel Prices and Payback Period: Evaluated one side case involving a 0 month payback period combined with fuel prices from the AEO 2014 low oil price scenario, and one side case with a 24 month payback period combined with fuel prices from the AEO 2014 high oil price scenario.

[14] Available at http://www.whitehouse.gov/omb/circulars_a004_a-4/.

4. Benefits to Vehicle Buyers: The main Method A analysis assumes there is no loss in value to owner/operators resulting from vehicles that have an increase in price and higher fuel economy. NHTSA performed this sensitivity analysis assuming that there is a 25, or 50 percent loss in value to owner/operators – equivalent to the assumption that owner/operators will only value the calculated benefits they will achieve at 75, or 50 percent, respectively, of the main analysis estimates. (These are labeled as 75pctOwner/operatorBenefit and 50pctOwner/operatorBenefit.)
5. Value of Avoided GHG Emissions: Evaluated side cases involving lower and higher valuation of avoided CO_2 emissions, expressed as the social cost of carbon (SCC).
6. Rebound Effect: Evaluated side cases involving rebound effect values of 5 percent, 15 percent, and 20 percent. (These are labeled as 05PctReboundEffect, 15PctReboundEffect and 20PctReboundEffect.)
7. RPE-based Markup: Evaluated a side case using a retail price equivalent (RPE) markup factor of 1.5 for non-electrification technologies, which is consistent with the NAS estimation for technologies manufactured by suppliers, and a RPE markup factor of 1.33 for electrification technologies (mild and strong HEV).
8. ICM-based Post-Warranty Repair Costs: NHTSA evaluated a side case that scaled the frequency of repair by vehicle survival rates, assumes that per-vehicle repair costs during the post-warranty period are the same as in the in-warranty period, and that repair costs are proportional to incremental direct costs (therefore vehicles with additional components will have increased repair costs).
9. Mass-Safety Effect: Evaluated side cases with the mass-safety impact coefficient at the values defining the 5^{th} and 95^{th} percent points of the confidence interval estimated in the underlying statistical analysis. (These are labeled MassFatalityCoeff05pct and MassFatalityCoeff95pct.)
10. Strong HEVs: Evaluated a side case in which strong HEVs were excluded from the set of technology estimated to be available for HD pickups and vans through model year 2030. An additional "no strong HEV" case was run where all GM gasoline-engine vans were allowed to have turbo-downsized engines to provide a lower-cost option for compliance. These cases were all run for both 0-month and 6-month payback periods.
11. Diesel Downsizing: Evaluated a side case in which downsizing of diesel engines was estimated to be more widely available to HD pickups and vans.
12. Technology Effectiveness: Evaluated side cases involving inputs reflecting lower and higher impacts of technologies on fuel consumption.
13. Technology Direct Costs: Evaluated side cases involving inputs reflecting lower and higher direct incremental costs for fuel-saving technologies.
14. Fleet Mix: Evaluated a side case in which the shares of individual vehicle models and configurations were kept constant at estimated current levels.

Table 10-25 below summarizes key metrics for each of the cases included in the sensitivity analysis using Method A for the proposed alternative. The table reflects the percent change in the metrics (columns), relative to the main analysis, the proposed alternative 3. For each sensitivity run, the change in the metric can we described as the difference between the baseline and the preferred alternative for the sensitivity case, minus the difference between the preferred alternative and the baseline in the main analysis, divided by the difference between the preferred alternative and the baseline in the main analysis. Or,

$$Table\ Metric = \frac{\Delta_{Alt\ sen\ case} - \Delta_{Alt\ main\ run}}{\Delta_{Alt\ main\ run}} \cdot 100$$

Each metric represents the sum of the impact of the preferred alternative over the model years 2018 – 2029, and the percent changes in the table represent percent changes to those sums.

Table 10-25 Sensitivity Analysis Results from CAFE Model for the Proposed Standards in the HD Pickup and Van Market Segment using Method A and versus the Dynamic Baseline, Alternative 1b (Cells are percent change from base case) [a]

Sensitivity Case	Fuel Savings (gallons)	CO2 savings (MMT)	Fuel Savings ($)	Social Costs	Social Benefits	Social Net Benefits
0 Month Payback	14.0%	14.5%	15.1%	5.6%	15.1%	18.2%
12 Month Payback	-4.8%	-4.7%	-4.5%	-2.5%	-4.7%	-5.4%
18 Month Payback	-29.2%	-28.1%	-26.5%	-14.1%	-26.8%	-31.1%
24 Month Payback	-42.9%	-42.4%	-41.9%	-23.2%	-42.1%	-48.4%
AEO-Low	3.3%	3.5%	-27.9%	-10.8%	-22.2%	-26.1%
AEO-High	-7.0%	-7.2%	23.3%	1.4%	19.5%	25.6%
AEO-Low, 0 Month Payback	18.6%	19.3%	-16.5%	-3.4%	-10.1%	-12.3%
AEO-High, 24 Month Payback	-63.8%	-64.6%	-54.4%	-49.9%	-55.7%	-57.7%
50pct Owner/operator Benefit	0.0%	0.0%	-50.0%	0.0%	-34.6%	-46.2%
75pct Owner/operator Benefit	0.0%	0.0%	-25.0%	0.0%	-17.3%	-23.1%
Low SCC	0.0%	0.0%	0.0%	0.0%	-10.6%	-14.1%
Low SCC, 0 Month Payback	14.0%	14.5%	15.1%	5.6%	2.9%	2.0%
High SCC	0.0%	0.0%	0.0%	0.0%	7.8%	10.4%
High SCC, 0 Month Payback	14.0%	14.5%	15.1%	5.6%	24.0%	30.1%
Very High SCC	0.0%	0.0%	0.0%	0.0%	28.7%	38.4%
Very High SCC, 0 Month Payback	14.0%	14.5%	15.1%	5.6%	48.0%	62.2%
05 Pct Rebound Effect	4.6%	4.6%	4.6%	-12.9%	0.4%	4.8%
15 Pct Rebound Effect	-4.6%	-4.6%	-4.6%	12.9%	-0.4%	-4.8%
20 Pct Rebound Effect	-9.1%	-9.2%	-9.2%	25.7%	-0.8%	-9.7%
RPE-Based Markup	-3.2%	-1.5%	0.3%	31.4%	-0.1%	-10.6%
Mass Fatality Coeff 05pct	0.0%	0.0%	0.0%	-23.6%	0.0%	7.9%
Mass Fatality Coeff 95pct	0.0%	0.0%	0.0%	23.9%	0.0%	-8.0%
NoSHEVs,	-6.9%	-6.2%	-5.3%	19.2%	-5.4%	-13.7%

NoSHEVs, 0 Month Payback	7.7%	9.1%	10.7%	29.0%	10.5%	4.3%
NoSHEVs, GM Turbo Vans	-6.7%	-5.8%	-5.0%	2.3%	-5.1%	-7.6%
NoSHEVs, GM Turbo Vans, 0 Month Payback	8.2%	9.8%	11.5%	-1.2%	11.3%	15.4%
Lower Effectiveness	-7.8%	-7.8%	-8.1%	39.5%	-8.0%	-23.9%
Higher Effectiveness	-10.6%	-10.3%	-10.0%	-23.3%	-10.2%	-5.8%
Lower Direct Costs	0.9%	2.7%	4.8%	18.4%	4.3%	-0.4%
Higher Direct Costs	-4.1%	-3.8%	-3.5%	75.3%	-3.8%	-30.3%
Wider Diesel Downsizing	-1.5%	-1.0%	-0.6%	-10.3%	-0.8%	2.4%
07 Pct Discount Rate	0.0%	0.0%	-100.0%	-41.7%	-100.0%	-119.5%
07 Pct DR, 0 Month Payback	14.0%	14.5%	-37.9%	-30.7%	-30.7%	-30.7%
Allow Gas To Diesel	15.5%	5.3%	-100.0%	16.8%	-100.0%	-139.1%
Allow Gas To Diesel, 0 Month Payback	32.1%	22.6%	14.5%	46.8%	17.0%	7.0%
flat mix after 2016	1.1%	0.9%	0.7%	2.6%	0.8%	0.2%

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

For some of the cases for which results are presented above, the sensitivity of results to changes in inputs is simple, direct, and easily observed. For example, changes to valuation of avoided GHG emissions impact only this portion of the estimated economic benefits; manufacturers' responses and corresponding costs are not impacted. Similarly, a higher discount rate does not affect physical quantities saved (gallons of fuel and metric tons of CO2 in the table), but reduces the value of the costs and benefits attributable to the proposed standards in an intuitive way. Some other cases warrant closer consideration:

First, cases involving alternatives to the reference six-month payback period involve different degrees of fuel consumption improvement, and these differences are greatest in the no-action alternative defining the baseline. Because all estimated impacts of the proposed standards are shown as incremental values relative to this baseline, longer payback periods correspond to smaller estimates of incremental impacts, as fuel economy increasingly improves in the absence of the rule and manufacturers are compelled to add less technology in order to comply with the standards.

Second, cases involving different fuel prices similarly involve different degrees of fuel economy improvement in the absence of the standard, as more, or less, improvement occurs as a result of more, or fewer, technologies appearing cost effective to owner/operators. Lower fuel prices correspond to increases in fuel savings on a volumetric basis, as the standard is responsible for a greater amount of the fuel economy improvement, but the value of fuel savings decreases because each gallon saved is worth less when fuel prices are low. Higher fuel prices correspond to reductions in the volumetric fuel savings attributable to the proposed standards, but lead to increases in the value of fuel saved because each gallon saved is worth more when fuel prices are high.

Third, because the payback period and fuel price inputs work in opposing directions, the relative magnitude of each is important to consider for the combined sensitivity cases. While the low price and 0-month payback case leads to significant volumetric savings compared to the main analysis, the low fuel price is still sufficient to produce a negative change in net benefits. Similarly, the high price and 24-month payback case results in large reductions to volumetric savings that can be attributed to the proposed standards, but the presence of high fuel prices is not sufficient to lead to increases in either the dollar value of fuel savings or net social benefits.

Fourth, the cases involving different inputs defining the availability of some technologies do not impact equally the estimated impacts across all manufacturers. Section VI.C.8 of the Preamble provides a discussion of a sensitivity analysis that excludes strong hybrids and includes the use of downsized turbocharged engines in vans currently equipped with large V-8 engines. The modeling results for this analysis are provided in Section IV.C.8 and in the table above. The no strong hybrid analysis shows that GM could comply with the proposed preferred Alternative 3 without strong hybrids based on the use of turbo downsizing on all of their HD gasoline vans. Alternatively, when the analysis is modified to allow for wider application of diesel engines, strong HEV application for GM drops slightly (from 19 percent to 17 percent) in MY2030, average per-vehicle costs drop slightly (by about $50), but MY2030 additional penetration rates of diesel engines increase by about 10 percent. Manufacturer-specific model results accompanying today's rule show the extent to which individual manufacturers' potential responses to the standards vary with these alternative assumptions regarding the availability and applicability of fuel-saving technologies. However, across all of these sensitivity cases, the model projects social costs increase (as a result of increases in technology costs) when manufacturers choose to comply with the proposed regulations without the use of strong hybrids.

Fifth, the cases that vary the effectiveness and direct cost of available technologies produce nuanced results in the context of even the 0-month payback case. In the case of effectiveness changes, both sensitivity cases result in reductions to the volumetric fuel savings attributable to the proposal; lower effectiveness because the technologies applied in response to the standards save less fuel, and higher effectiveness because more of the increase in fuel economy occurs in the baseline. However, for both cases, social costs (a strong proxy for technology costs) move in the intuitive direction.

The cases that vary direct costs show volumetric fuel savings increasing under lower direct technology costs despite additional fuel economy improvements in the baseline, as more aggressive technology becomes cost effective. Higher direct costs lead to decreases in volumetric fuel savings, as more of the fuel economy improvement can be attributed to the rule. In both cases, social costs (as a result of technology costs) move in the intuitive direction.

If instead, the main analysis had used the same assumptions as the sensitivity cases described above, the impacts of the proposed standards for HD Pickups and Vans would be as described in Table 10-26.

Table 10-26: Costs and Benefits of Proposed Standards for HD Pickups and Vans Under Alternative Assumptions

Sensitivity Case	Fuel Savings (billion gallons)	CO2 Reduction (MMT)	Fuel Savings ($billion)	Social Costs ($billion)	Social Benefits ($billion)	Net Social Benefits ($billion)
6 Month Payback (main)	7.8	94.1	15.9	5.5	23.5	18.0
0 Month Payback	8.9	107.7	18.3	5.8	27.0	21.3
12 Month Payback	7.4	87.2	15.2	5.6	21.9	16.3
18 Month Payback	5.5	65.8	11.7	4.9	16.8	11.9
24 Month Payback	4.5	52.7	9.2	4.4	13.3	8.9
AEO-Low	8.1	94.7	11.5	5.1	17.8	12.7
AEO-High	7.3	84.9	19.6	5.8	27.4	21.6
AEO-Low, 0 Month Payback	9.3	109.1	13.3	5.6	20.6	15.1
AEO-High, 24 Month Payback	2.8	32.4	7.2	2.9	10.2	7.3
50pct Owner/operator Benefit	7.8	91.5	8.0	5.8	15.0	9.2
75pct Owner/operator Benefit	7.8	91.5	11.9	5.8	19.0	13.2
Low SCC	7.8	91.5	15.9	5.8	20.5	14.8
Low SCC, 0 Month Payback	8.9	104.7	18.3	6.1	23.6	17.5
High SCC	7.8	91.5	15.9	5.8	24.7	19.0
High SCC, 0 Month Payback	8.9	104.7	18.3	6.1	28.5	22.4
Very High SCC	7.8	91.5	15.9	5.8	29.5	23.8
Very High SCC, 0 Month Payback	8.9	104.7	18.3	6.1	34.0	27.9
05 Pct Rebound Effect	8.2	95.7	16.6	5.0	23.0	18.0
15 Pct Rebound Effect	7.5	87.2	15.2	6.5	22.9	16.4
20 Pct Rebound Effect	7.1	83.0	14.4	7.2	22.8	15.5
RPE-Based Markup	7.6	90.1	16.0	7.6	22.9	15.4
Mass Fatality Coeff 05pct	7.8	91.5	15.9	4.4	23.0	18.5
Mass Fatality Coeff 95pct	7.8	91.5	15.9	7.1	23.0	15.8
NoSHEVs	7.2	84.3	14.6	8.0	21.1	13.1
NoSHEVs, 0 Month Payback	7.0	82.0	14.3	4.4	20.6	16.2
Lower Effectiveness	7.9	94.0	16.7	6.8	23.9	17.1
Higher Effectiveness	7.5	88.0	15.3	10.1	22.1	12.0
Lower Direct Costs	7.7	90.5	15.8	5.2	22.8	17.6
Higher Direct Costs	7.8	91.5	8.5	3.8	13.8	10.0
Wider Diesel Downsizing	8.9	104.7	9.9	4.0	15.9	11.9
07 Pct Discount Rate	9.0	96.3	15.3	7.2	22.7	15.5
07 Pct DR, 0 Month Payback	10.3	112.2	18.2	8.5	26.9	18.4
Allow Gas To Diesel	7.9	92.3	16.0	5.9	23.1	17.2
Allow Gas To Diesel, 0 Month Payback	7.3	85.8	15.1	6.9	21.7	14.8
Flat mix after 2016	8.4	99.8	17.6	7.4	25.4	17.9

10.1.1.13 **Probabilistic Uncertainty Analysis**

OMB Circular A-4 directs agencies to conduct formal probabilistic uncertainty analysis of complex rules where there are large, multiple uncertainties whose analysis raises technical challenges or where effects cascade and where the impacts of the rule exceed $1 billion. The proposed increase in MD-HD vehicle fuel economy/GHG standards meets all of these criteria. As for previous rules, NHTSA has conducted an uncertainty analysis to determine the extent to which uncertainty about input assumptions could impact the costs and benefits attributable to the proposed rule. Throughout the course of the main analysis, input values were selected from a variety of often conflicting sources. Best estimates were selected based on the preponderance of data and analyses available, but there is inevitably a level of uncertainty in these selections, particularly given the time frame of the rulemaking. Some of these inputs contributed less to the overall variations of the outcomes, and, thus, are less significant. Some inputs depend on others or are closely related (e.g., oil import externalities), and thus can be combined. With the vast number of uncertainties embedded in this regulatory analysis, this uncertainty analysis identifies only the major independent uncertainty factors having appreciable variability and impact on the end results and quantifies them by probability distributions. The values of these uncertainties are then randomly selected and fed back into the CAFE model to determine the net benefits using the Monte Carlo statistical simulation technique.

Using point estimates for the large number of variables in this analysis provides only a limited view of the potential results, and provides, likewise, a limited measure of confidence in the estimated outcome, beyond the assertion that it is the “most likely.” Correctly estimating the exact total costs and benefits of a program as complex as the proposal, especially over such a long time frame, is, of course, not possible. This is why the direction in A-4 suggests analysis of the sources and consequences of uncertainty in the results. Using Monte Carlo simulations to explicitly consider the uncertainty around the important inputs to the analysis, enables decision-makers to see the probabilities associated with a large range of outcomes and develop confidence in achieving acceptable levels of net benefit from the existing program specification, even without perfect information about future conditions. Having confidence that a rule will perform as expected under a range of potential future states of the world is a valuable outcome.

Unlike the preceding sensitivity analysis, which is useful for understanding how alternative values of a single input assumption may influence the estimated impacts of the proposed standards, the uncertainty analysis considers multiple states of the world, characterized by specific values of all relevant inputs, based on their relative probability of occurrence. A sensitivity analysis varies a single parameter of interest, holding all others constant at whatever nominal values are used to generate the single point estimate in the main analysis, and measures the resulting deviation. However, the uncertainty analysis allows all of those parameters to vary simultaneously – relaxing the assumption that “all else is equal.”

Each trial, of which there are 14,000 in this analysis, represents a different state of the world in which the standards are implemented. To gauge the robustness of the estimates of impacts in the proposal, NHTSA varied technology costs and effectiveness, fuel prices, market demand for fuel economy improvements in the absence of the rule, the amount of additional driving associated with fuel economy improvements (the rebound effect), and the on-road gaps between realized fuel economy and laboratory test values for gasoline and diesel vehicles. The shapes and types of the probability distributions used in the analysis vary by uncertainty, though the costs and effectiveness values for technologies are sampled as groups to minimize issues associated with interdependence.

Similar technology costs are sampled in such a way that they are simultaneously at similar points in their respective cost distributions, even if the distributions themselves are different. For example, different levels of low rolling resistance tires might have different underlying distributions describing the degree of certainty associated with the point-estimate value of cost. The distributions of cost might be different to represent different degrees of technology readiness (for example). For tires, however, one would expect advances in technology to be shared across models, so the cost an advanced low rolling resistance tire would not be expected to diverge from the value in the main analysis. The sample design of technology costs (and effectiveness) for the proposal's Monte Carlo analysis attempts to account for such similarities.

The most important input to the uncertainty analysis, fuel prices (which drive the majority of benefits from the proposed standards), are drawn from a range of fuel prices characterized by permutations of the Low, Reference, and High fuel price cases in the Annual Energy Outlook 2014.

10.1.1.13.1 Summary of Uncertainties Varied in Analysis

NHTSA reviewed the inputs and relationships that drive the CAFE model to identify the factors that are both uncertain and important to the estimation of net benefits. Several factors were identified as potentially contributing to uncertainty to the estimated impacts of higher CAFE standards, although not all were ultimately selected to be run in the simulation. In particular, the social cost of damages caused by criteria pollutant and greenhouse gas emissions have been omitted from the analysis, the latter based on guidance from the interagency working group that developed the cost estimates used in the central analysis. The list of included uncertainties is:

(1) Technology costs;

(2) Technology effectiveness;

(3) Fuel prices;

(4) Manufacturers' decision to produce vehicles with fuel economies higher than the levels mandated by CAFE standards;

(5) The rebound effect;

(6) The on-road gap between achieved real-world fuel economy and the test cycle for gasoline and diesel vehicles.

10.1.1.13.2 Technology Costs and Effectiveness

The costs incurred by manufacturers to modify their vehicles to meet new CAFE levels are assumed to be passed on to consumers in the form of higher new vehicle prices. These technology costs are the primary determinant of the overall cost of improving fuel economy.

For each of the technologies considered applicable to this vehicle segment for the purpose of improving fuel economy, the agency used what it considered to be the most likely value in the main analysis. Unlike previous analyses of light-duty technology costs and effectiveness, that relied on a broader knowledge base, there are fewer studies of technology cost and effectiveness for medium-duty vehicles. As such, the distributions used to characterize the uncertainty are more agnostic than the set used in the last light-duty rule, for example. The cost distributions in this analysis are generally very flat Beta distributions, which behave like uniform distributions with fuzzy boundaries in practice – appropriate since even the range of potential values is unknown.

The effectiveness uncertainty, for the purpose of gauging compliance, is generally characterized by a normal distribution for each technology. The standard deviation of the normal distribution is based on the complexity assigned to the technology, where low, medium, and high complexity technologies are assigned normal distributions with standard deviations of 0.145, 0.29, and 0.435, respectively. Each draw results in a scalar that is used to modify the value in the main analysis through simple multiplication, values less than one represent lower cost/effectiveness, values greater than one represent higher cost/effectiveness. It is worth noting that cost and effectiveness are treated as independent – so a technology may simultaneously be less expensive and more effective (or vice versa) than anticipated in the main analysis for a given simulation in this exercise.

10.1.1.13.3 Fuel Prices

For this analysis, fuel prices are sampled as a scaling factor that determines a complete time series of prices for all years covered by the analysis. The scaling factor scales the inter-annual differences of fuel prices in the High Oil Price case for the 2014 Annual Energy Outlook. Values within the sampled range produce series that have shapes similar to the high, reference, and low oil price cases, and are generally bounded above and below by the high and low price case, respectively. As EIA makes no claims about the relative likelihood of the fuel price cases, we make none here – the range of values is sampled uniformly, suggesting that any single time series of prices within that range is as likely as another.

10.1.1.13.4 Market-Driven Fuel Economy Improvements in the Absence of the Proposed Standards

The CAFE model includes the capability to apply technology under varying fuel price cases by including a variable that represents manufacturers' assumption about consumer willingness-to-pay for fuel economy technology. In this case, "willingness-to-pay" is characterized as the payback period for fuel economy technology investments, meaning the number of years' worth of fuel savings necessary to balance the cost of the new technology. In the main analysis, the model alters that variable to be zero once a manufacturer reaches compliance (for baseline 1a) or six months (for baseline 1b). In the case of baseline 1a, no additional technology is added beyond the standards in the baseline, or in any of the other regulatory scenarios. In the case of baseline 1b, only those technologies whose fuel savings in the first six-months of ownership exceed the incremental cost of the technology would be added. For the main analysis, which uses a single fuel price projection and economic and technological parameter values consistent with it, the zero-year and six-month payback assumptions are generally consistent with the collection of other assumptions. However, under more extreme fuel price scenarios, short payback periods become increasingly unrealistic.

To address this limitation, NHTSA has included the length of the payback period (that manufacturers assume consumers desire) in the uncertainty analysis. Assuming some non-zero payback period ensures that when fuel prices are very high, manufacturers will continue to add cost-effective fuel economy technologies even when the standards are not sufficient to force these additions. As one might expect, higher fuel prices and longer payback periods result in more fuel economy technology being added beyond the level mandated by the standards, while lower fuel prices and shorter payback periods result in less.

The cases that most challenge internal consistency are naturally found at the extremes, low-price-long-payback, for example. In the low-price-long-payback case, the fuel savings would still be very low, technology would still not be very attractive, and only a small amount of additional fuel economy technology (if any at all) would be added to vehicles already in compliance. So one could credibly argue that there is uncertainty about the degree to which manufacturers understand consumers' willingness-to-pay for fuel economy and add slightly more than would be demanded.

Similarly, under the high-price-short-payback draws, fuel prices are high enough to make some technology additions occur in the baseline, but maybe not the ideal amount under those conditions because manufacturers assumed a shorter payback period than consumers have when faced with very high fuel prices. Since there is uncertainty about manufacturers' ability to perfectly respond to consumer preferences, these draws produce results that are still plausible (if less probable than others).

The payback period used in the analysis is drawn from a Beta distribution with shape parameters equal to 2 and 5. This places about 75 percent of the probability distribution's mass below 2 years, with steeply decreasing probabilities afterward.

10.1.1.13.5 The Rebound Effect

By reducing the amount of gasoline used and, thus, the cost of operating a vehicle, more stringent fuel economy and GHG standards are anticipated to result in a slight increase in annual miles driven per vehicle. This rebound effect impacts net societal benefits because the increase in miles driven offsets a portion of the fuel savings that results from more fuel-efficient vehicles. Although operators derive value from this extra driving, it also leads to increases in crashes, congestion, noise, and pollution costs associated with driving.

On the basis of previous studies devoted to the impact of fuel economy changes on the vehicle miles traveled of comparable light-duty trucks, NHTSA employed a rebound effect of 10 percent in the main analysis. A more complete discussion of the rebound effect is included in Chapter VIII. For the uncertainty analysis, a range of 5 to 30 percent was used and employed in a slightly skewed Beta distribution which produced a mean of approximately 14.2 percent. The difference reflects the more cost-conscious behavior of commercial vehicle operators, particularly for HD pickups and vans which are often registered at residences and may be used to substitute VMT for other household vehicles.

10.1.1.13.6 On-Road Gaps

As is the case of fuel economy ratings for light-duty vehicles, medium-duty work trucks can achieve different levels of fuel economy in real-world applications. Medium-duty vehicles may achieve lower fuel economy than their ratings because of driver habits (like faster acceleration) or terrain/conditions. However, unlike light-duty fuel economy, where vehicles are typically used for moving people, even when driving style and conditions vary from the test procedure, medium-duty vehicles are typically used for multiple purposes. Vehicle usage – in particular, loading – is an additional source of bias.

In order to estimate the impact of both driving profiles and vehicle loading on fuel consumption, we used simulation results from Southwest Research Institute, who conducted a simulation study under a NHTSA contract to estimate the fuel consumption improvement associated with applying specific technologies to medium and heavy-duty trucks.[15] We then computed the difference between each driving cycle and the corresponding test cycle, then created a distribution from those differences for each fuel type (gasoline and diesel). The resulting distributions were multi-modal for both fuel types, largely as a result of the different sources of discrepancy from the test cycle: city/highway splits, driving profile, vehicle loading, and a relatively sparse set of results. To smooth the distributions, we split the computed gaps into two bins – one of gaps (strictly) less than 0.2 and the other containing larger gaps. Then we bootstrapped the computed gaps by repeatedly sampling (with replacement) from each bin, randomly choosing a weighting parameter from a uniform distribution spanning [0.3, 0.7], then taking a weighted average of the low and high gap bins to create a distribution.

The resulting empirical distributions for both gasoline and diesel were then fit using gamma distributions, and the gamma distributions were sampled in the uncertainty analysis.

10.1.1.13.7 Results

Figure 10-6 displays the distribution of net benefits estimated by the ensemble of simulation runs. As Figure 10-6 indicates, the analysis produces a wide distribution of possible outcomes that are much broader than the range of estimates characterized by only the difference between the more and less dynamic baselines. While the expected value, the probability-weighted average outcome, is only about 70 percent of the net benefits estimated in the main analysis, almost all of the trials produce positive net benefits. In fact, the distribution suggests there is only a one percent chance of the proposal producing negative net benefits for HD pickups and vans. So, while the estimated net benefits in the main analysis may be higher than

[15] Reinhart, T.E. (2015, June). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1. (Report No. DOT HS 812 146). Washington, DC: National Highway Traffic Safety Administration.

the expected value when uncertainty is considered, net benefits at least as high as those estimated in the main analysis are still 20 times as likely as an outcome that results in net costs.

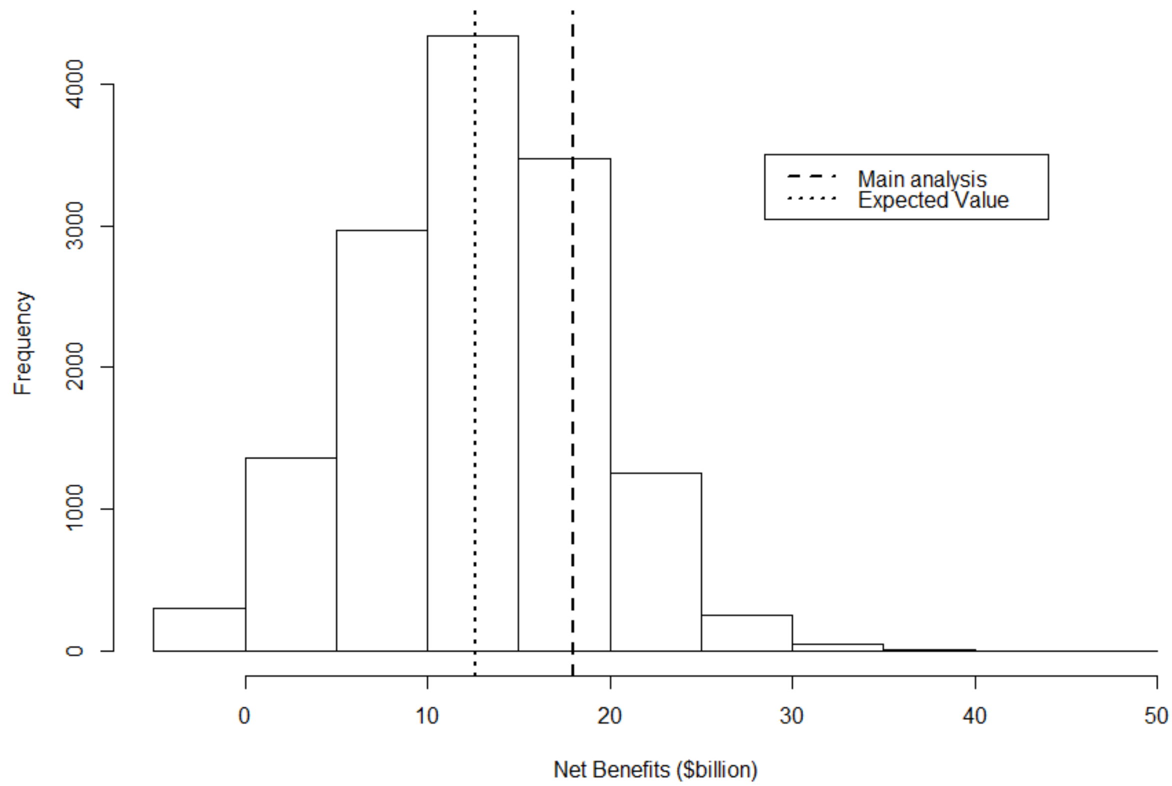

Figure 10-6 Distribution of Net Benefits from Proposed Standards for HD Pickups and Vans

Figure 10-7 shows the distribution of payback periods (in years) for Model Year 2029 trucks across 14,000 simulation runs. The "payback period" typically refers to the number of years of vehicle use that occur before the savings on fuel expenditures offset the additional technology cost associated with improved fuel economy. As Figure 10-7 illustrates, the incremental technology cost of both Phase 1 and Phase 2 is eclipsed by the value of fuel savings by year three of ownership in most cases.

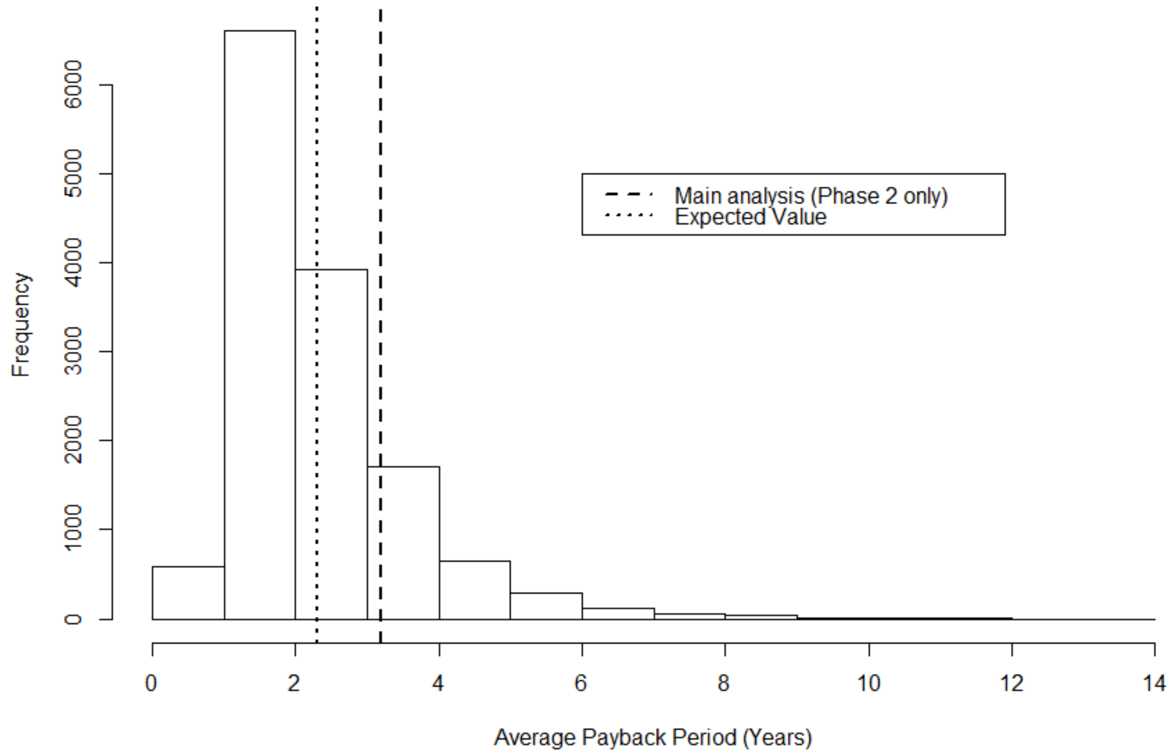

Figure 10-7 Average Payback Period for MY 2029 HD Pickup or Van based on Phase 1 and Phase 2 (combined) Technology Costs

This is an important metric for consumer acceptability and, though Figure 10-7 illustrates the long right tail of the payback distribution (where payback periods are likely to be unacceptably long), fewer than ten percent of the trials result in payback periods longer than four years. This suggests that, even in the face of uncertainty about future fuel prices and fuel economy in real-world driving conditions, buyers of the vehicles that are modified to comply with the requirements of the proposal will still see fuel savings greater than their additional vehicle cost in a relatively short period of time.

Chapter 11: Results of the Preferred and Alternative Standards

The heavy-duty truck segment is very complex. The sector consists of a diverse group of impacted parties, including engine manufacturers, chassis manufacturers, truck manufacturers, trailer manufacturers, truck fleet owners and the public. The proposed standards are largely shaped to optimize the environmental and fuel savings benefits of the program, while balancing the relevant statutory factors and respecting the unique and varied nature of the sector. In developing this proposed rulemaking, we considered a number of alternatives that could result in fewer or potentially greater GHG and fuel consumption reductions than the preferred alternative. This section summarizes the alternatives we considered and presents assessments of technology costs, CO_2 reductions, and fuel savings associated with each alternative. See the preamble for a discussion of how the agencies balanced the relevant statutory factors to select the preferred alternative.

For this rule, the agencies conducted coordinated and complementary analyses by employing both DOT's CAFE model and EPA's MOVES model. These models were used to project fuel consumption and GHG emissions impacts resulting from the proposed standards. The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed complementary analyses using the CAFE model ("Method A") and the MOVES model ("Method B") to estimate fuel consumption and emissions from these vehicles. For both methods, the agencies analyzed the impact of the proposed rules, relative to two different reference cases – less dynamic and more dynamic. The less dynamic baseline projects very little improvement in new vehicles in the absence of new Phase 2 standards. In contrast, the more dynamic baseline projects more improvements in vehicle fuel efficiency. See Chapter 5 for a discussion of the EPA's MOVES model (which was used for both methods) and Chapter 10 for discussion of the DOT's CAFE model (which was used for Method A).

11.1 What Are the Alternatives that the Agencies Considered?

The five alternatives below represent a broad range of potential stringency levels, and thus a broad range of associated technologies, costs and benefits for a HD vehicle fuel efficiency and GHG emissions program.

In developing alternatives, NHTSA must consider EISA's requirement for the MD/HD fuel efficiency program noted above. 49 U.S.C. 32902(k)(2) and (3) contain the following three requirements specific to the MD/HD vehicle fuel efficiency improvement program: (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 MD/HD vehicles; and (3) the standards adopted under the program must provide not less than four model years of lead time and three model years of regulatory stability. In considering these various requirements, NHTSA will also account for relevant environmental and safety considerations.

Each of the alternatives presented by NHTSA and EPA represents, in part, a different way the agencies could establish a HD program pursuant to EISA and the CAA. The agencies are proposing Alternative 3. The alternatives below represent a broad range of approaches under consideration for finalizing the HD vehicle fuel efficiency and GHG emissions standards.

Sections 11.1.1 through 11.2 summarize the alternatives that were analyzed and how they were modeled. See Section 11.3 for details about the technology mix projected for each alternative and each regulatory category.

11.1.1 Alternative 1: No Action (the Baseline for Phase 2)

OMB guidance regarding regulatory analysis indicates that proper evaluation of the benefits and costs of regulations and their alternatives requires agencies to identify a baseline:

> *"You need to measure the benefits and costs of a rule against a baseline. This baseline should be the best assessment of the way the world would look absent the proposed action. The choice of an appropriate baseline may require consideration of a wide range of potential factors, including:*
>
> *• evolution of the market,*
>
> *• changes in external factors affecting expected benefits and costs,*
>
> *• changes in regulations promulgated by the agency or other government entities, and*
>
> *• the degree of compliance by regulated entities with other regulations.*
>
> *It may be reasonable to forecast that the world absent the regulation will resemble the present. If this is the case, however, your baseline should reflect the future effect of current government programs and policies. For review of an existing regulation, a baseline assuming no change in the regulatory program generally provides an appropriate basis for evaluating regulatory alternatives. When more than one baseline is reasonable and the choice of baseline will significantly affect estimated benefits and costs, you should consider measuring benefits and costs against alternative baselines. In doing so you can analyze the effects on benefits and costs of making different assumptions about other agencies' regulations, or the degree of compliance with your own existing rules. In all cases, you must evaluate benefits and costs against the same baseline. You should also discuss the reasonableness of the baselines used in the sensitivity analyses. For each baseline you use, you should identify the key uncertainties in your forecast."*[1]

A no-action alternative is also required as a baseline against which to measure environmental impacts of the proposed standards and alternatives. NHTSA, as required by the National Environmental Policy Act, is documenting these estimated impacts in the draft EIS published with this NPRM.[2]

The No Action Alternative for today's analysis, alternatively referred to as the "baseline" or "reference case," assumes that the agencies would not issue new rules regarding MD/HD fuel efficiency and GHG emissions. That is, this alternative assumes that the Phase 1 MD/HD fuel efficiency and GHG emissions program's model year 2018 standards would be extended indefinitely and without change.

The agencies recognize that there are a number of factors that create uncertainty in projecting a baseline against which to compare the future effects of the proposed action and the remaining alternatives. The composition of the future fleet—such as the relative position of individual manufacturers and the mix of products they each offer—cannot be predicted with certainty at this time. As reflected, in part, by the market forecast underlying the agencies' analysis, we anticipate that the baseline market for medium- and heavy-duty vehicles will continue to evolve within a competitive market that responds to a range of factors. Additionally, the heavy-duty vehicle market is diverse, as is the range of vehicle purchasers.

Heavy-duty vehicle manufacturers have reported that their customers' purchasing decisions are influenced by their customers' own determinations of minimum total cost of ownership, which can be unique to a particular customer's circumstances. For example, some customers (e.g., less-than-truckload or package delivery operators) operate their vehicles within a limited geographic region and typically own their own vehicle maintenance and repair centers within that region. These operators tend to own their vehicles for long time periods, and sometimes for the entire service life of the vehicle. Their total cost of ownership is influenced by their ability to better control their own maintenance costs, and thus they can afford to consider fuel efficiency technologies that have longer payback periods, outside of the vehicle manufacturer's warranty period. Other customers (e.g. truckload or long-haul operators) tend to operate cross-country, and thus must depend upon truck dealer service centers for repair and maintenance. Some of these customers tend to own their vehicles for about four to seven years, so that they typically do not have to pay for repair and maintenance costs outside of either the manufacturer's warranty period or some other extended warranty period. Many of these customers tend to require seeing evidence of fuel efficiency technology payback periods on the order of 18 to 24 months before seriously considering evaluating a new technology for potential adoption within their fleet (NAS 2010, Roeth et al. 2013, Klemick et al. 2014). Purchasing decisions, however, are not based exclusively on payback period, but also include the considerations discussed in this section. For the baseline analysis, the agencies use payback period as a proxy for all of these considerations, and therefore the payback period for the baseline analysis is shorter than the payback period industry uses as a threshold for the further consideration of a technology.

Purchasers of HD pickups and vans that want better fuel efficiency will demand that fuel consumption improvements pay back within approximately one to three years, but not all purchasers fall into this category. Some HD pickup and van owners accrue relatively few vehicle miles traveled per year, such that they may be less likely to adopt new fuel efficiency technologies, while other owners who use their vehicle(s) with greater intensity may be even more willing to pay for fuel efficiency improvements. Regardless of the type of customer, their determination of minimum total cost of ownership involves the customer balancing their own unique circumstances with a heavy-duty vehicle's initial purchase price, availability of credit and lease options, expectations of vehicle reliability, resale value and fuel efficiency technology payback periods. The degree of the incentive to adopt additional fuel efficiency technologies also depends on customer expectations of future fuel prices, which directly impacts customer expectations of the payback period.

Another factor the agencies considered is that other federal and state-level policies and programs are specifically aimed at stimulating fuel efficiency technology development and deployment. Particularly relevant to this sector are DOE's 21st Century Truck Partnership, EPA's voluntary SmartWay Transport program, and California's AB32 fleet requirements.[3,4,5] The future availability of more cost-effective technologies to reduce fuel consumption could provide manufacturers an incentive to produce more fuel-efficient medium- and heavy-duty vehicles, which in turn could provide customers an incentive to purchase these vehicles. The availability of more cost-effective technologies to reduce fuel consumption could also lead to a substitution of less cost-effective technologies, where overall fuel efficiency could remain fairly flat if buyers are less interested in fuel consumption improvements than in reduced vehicle purchase prices and/or improved vehicle performance and/or utility.

Although we have estimated the cost and efficacy of fuel-saving technologies assuming performance and utility will be held constant, some uncertainty remains regarding whether these conditions will actually be observed. In particular, we have assumed payload will be preserved (and possibly improved via reduced vehicle curb weight); however, some fuel-saving technologies, such as natural gas fueled vehicles and hybrid electric vehicles, could reduce payload via increased curb weight due to the fuel tanks or added electrical machine, batteries and controls. It is also possible that under extended high power demand resulting from a vehicle towing up a road grade, certain types of hybrid powertrains could experience a temporary loss of towing capacity if the capacity of the hybrid's energy storage device (e.g., batteries, hydraulic accumulator) is insufficient for the extended power demand. We have also assumed that fuel-saving technologies will be no more or less reliable than technologies already in production. However, if manufacturers pursue risky technologies or if the agencies provide insufficient lead-time to fully develop new technologies, they could prove to be less reliable, perhaps leading to increased repair costs and out-of-service time. This was observed as an unintended consequence of certain manufacturers' initial introduction of certain emissions control technologies to meet EPA's most stringent heavy-duty engine standards. If the fuel-saving technologies considered here ultimately involve similar reliability problems, overall costs will be greater than we have estimated. We have assumed drivers will be as accepting of new fuel-saving technologies as they are of technologies already in service. However, drivers could be less accepting of newer technologies -- particularly any which must be deployed manually. Except for increased costs to replace more efficient tires, we have assumed that routine maintenance costs will not increase or decrease. However, maintenance of new technologies could involve unique tools and parts. Therefore, maintenance costs could increase, and maintenance could involve increased vehicle out-of-service time. On the other hand new technologies can sometimes prove to be more reliable and require less maintenance than the technologies they replace. One example of this is the auxiliary power unit (APU) frequently installed on heavy-duty sleeper cab tractors. In the past these have been typically powered by small nonroad diesel engines that can require more frequent maintenance than the main engine of the tractor itself. However, more recently, as electric battery technology has advanced, some tractor manufacturers have introduced battery APUs instead of engine-driven APUs. A comparison of recent sales of small engine driven APUs versus battery APUs suggests that customers may prefer battery APUs[6], and some operators and tractor dealerships have also told the agencies that the decrease in routine maintenance was an important factor in purchase decisions in favor of battery APUs. Again, insofar as these unaccounted-for costs or savings actually occur, overall costs could be larger or smaller than we have estimated. We have also applied the EIA's AEO estimates of future fuel prices; however, heavy-duty vehicle customers could have different expectations about future fuel prices, and could therefore be more inclined or less inclined to apply new technology to reduce fuel consumption than might be expected based on EIA's forecast. We expect that vehicle customers will be uncertain about future fuel prices, and that this uncertainty will be reflected in the degree of enthusiasm to apply new technology to reduce fuel consumption.

Considering all of these factors, the agencies have approached the definition of the No Action Alternative separately for each vehicle and engine category covered by today's proposal.

For trailers, the agencies considered two No Action alternatives to cover a nominal range of uncertainty. The trailer category is unique in the context of this rulemaking because it is the only heavy-duty category not regulated under Phase 1. In both No Action cases, the agencies projected that the combination of EPA's voluntary SmartWay program, DOE's 21st Century Truck Partnership, California's AB32 trailer requirements for fleets, and the potential for significantly reduced operating costs should result in continuing improvement to new trailers. Taking this into account, the agencies project that in 2018, 50 percent of new 53' dry van and reefer trailers would have technologies qualifying for the SmartWay label (5 percent aerodynamic improvements and lower rolling resistance tires) and 50 percent would have automatic tire inflation systems to maintain optimal tire pressure. We also project that adoption of those same technologies would increase 1 percent per year until each technology is being used on 60 percent of new trailers. In the first case, Alternative 1a, this means that the agencies project that in the absence of new standards, the new trailer fleet technology would stabilize in 2027 to a level of 60 percent adoption in 2027 for the No Action alternative. In the second case, Alternative 1b, the agencies projected that the fraction of the in-use fleet qualifying for SmartWay would continue to increase beyond 2027 as older trailers are replaced by newer trailers. We projected that these improvements would continue until 2040 when 75 percent of new trailers would be assumed to include skirts.

For vocational vehicles, the agencies considered one No Action alternative. For the vocational vehicle category the agencies recognized that these vehicles tend to operate over fewer vehicle miles travelled per year. Therefore, the projected payback periods for fuel efficiency technologies available for vocational vehicles are generally longer than the payback periods the agencies consider likely to lead to their adoption based solely on market forces. This is especially true for vehicles used in applications in which the vehicle operation is secondary to the primary business of the company using the vehicle. For example, since the fuel consumption of vehicles used by utility companies to repair power lines would generally be a smaller cost relative to the other costs of repairing lines, fuel saving technologies would generally not be as strongly demanded for such vehicles. Thus, the agencies project that fuel-saving technologies would either not be applied or only be applied as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards.

For tractors, the agencies considered two No Action alternatives to cover a nominal range of uncertainty. For Alternative 1a the agencies project that fuel-saving technologies would either not be applied or only be applied as a substitute for more expensive fuel efficiency technologies to tractors (thereby enabling manufacturers to offer tractors that are less expensive to purchase), except as necessitated by the Phase 1 fuel consumption and GHG standards. In Alternative 1b the agencies estimated that some available technologies would save enough fuel to pay back fairly quickly – within the first six months of ownership. The agencies considered a range of information to formulate these two baselines for tractors.

Both public[7] and confidential historical information shows that tractor trailer fuel efficiency improved steadily through improvements in engine efficiency and vehicle aerodynamics over the past 40 years, except for engine efficiency which decreased or was flat between 2000 and approximately 2007 as a consequence of incorporating technologies to meet engine emission regulations. Today vehicle manufacturers, the Federal Government, academia and others continue to invest in research to develop fuel efficiency improving technologies for the future.

There is also evidence that manufacturers have, in the past, applied technologies to improve fuel efficiency absent a regulatory requirement to do so. Some manufacturers have even taken regulatory risk in order to increase fuel efficiency; in the 1990s, when fuel was comparatively inexpensive, some tractor manufacturers designed tractor engine controls to determine when the vehicle was not being emissions tested and, under such conditions, shift to more fuel-efficient operation even though doing so caused the vehicles to violate federal standards for NO_X emissions. Also, some manufacturers have recently expressed concern that the Phase 1 tractor standards do not credit them for fuel-saving technologies they had already implemented before the Phase 1 standards were adopted.

In public meetings and in meetings with the agencies, the trucking industry stated that fuel cost for tractors is the number one or number two expense for many operators, and therefore is a very important factor for their business. However, the pre-Phase 1 market suggests that, tractor manufacturers and operators could be slow to adopt some new technologies, even where the agencies have estimated that the technology would have paid for itself within a few months of operation. Tractor operators have told the agencies they generally require technologies to be demonstrated in their fleet before widespread adoption so they can assess the actual fuel savings for their fleet and any increase in cost associated with effects on vehicle operation, maintenance, reliability, mechanic training, maintenance and repair equipment, stocking unique parts and driver acceptance, as well as effects on vehicle resale value. Tractor operators have publicly stated they would consider conducting an assessment of technologies when provided with data that show the technologies may payback costs through fuel savings within 18 to 24 months, based on their assumptions about future fuel costs. In these cases, an operator may first conduct a detailed paper study of anticipated costs and benefits. If that study shows likely payback in 18 to 24 months for their business, the fleet may acquire one or several tractors with the technology to directly measure fuel savings, costs and driver acceptance for their fleet. Small fleets may not have resources to conduct assessments to this degree and may rely on information from larger fleets or observations of widespread acceptance of the technology within the industry before adopting a technology. This uncertainty over the actual fuel savings and costs and the lengthy process to assess technologies significantly slows the pace at which fuel efficiency technologies are adopted.

The agencies believe that using the two baselines addresses the uncertainties we have identified for tractors. The six-month payback period of Alternative 1b reflects the agencies' consideration of factors, discussed above, that could limit—yet not eliminate—manufacturers' tendencies to voluntarily improve fuel consumption. In contrast, Alternative 1a reflects a baseline for vehicles other than trailers wherein manufacturers either do not apply fuel efficiency technologies or only apply them as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards.

For HD pickups and vans, the agencies considered two No Action alternatives to cover a nominal range of uncertainty: a less-dynamic baseline (designated Alternative 1a) where no improvements are modeled beyond those needed to meet Phase 1 standards and a dynamic baseline (designated Alternative 1b) where certain cost-effective technologies (i.e., those that payback within a 6 month period) are assumed to be applied by manufacturers to improve fuel efficiency beyond the Phase 1 requirements in the absence of new Phase 2 standards. In Alternative 1b the agencies considered additional technology application, which involved the explicit estimation of the potential to add specific fuel-saving technologies to each specific vehicle model included in the agencies' HD pickup and van fleet analysis, as discussed in Section VI of the Preamble. Estimated technology application and corresponding impacts depend on the modeled inputs. Also, under this approach a manufacturer that has improved fuel consumption and GHG emissions enough to achieve compliance with the standards is assumed to apply further improvements, provided those improvements reduce fuel outlays by enough (within a specified amount of time, the payback period) to offset the additional costs to purchase the new vehicle. These calculations explicitly account for and respond to fuel prices, vehicle survival and mileage accumulation, and the cost and efficacy of available fuel-saving technologies. Therefore, all else being equal, more technology is applied when fuel prices are higher and/or technology is more cost-effective. Manufacturers of HD pickups and vans have reported to the agencies that buyers of these vehicles consider the total cost of vehicle ownership, not just new vehicle price, and that manufacturers plan as if buyers will expect fuel consumption improvements to "pay back" within periods ranging from approximately one to three years. For example, some manufacturers made decisions to introduce more efficient HD vans and HD pickup transmissions before such vehicles were subject to fuel consumption and/or GHG standards. However, considering factors discussed above that could limit manufacturers' tendency to voluntarily improve HD pickup and van fuel consumption, Alternative 1b applies a 6-month payback period. In contrast for Alternative 1a the agencies project that fuel-saving technologies would either not be applied or only be applied as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards. The Method A sensitivity analysis presented Chapter 10 of this draft RIA also examines other payback periods. In terms of impacts under reference case fuel prices, the payback period input plays a more significant role under the No-Action Alternatives (defined by a continuation of model year 2018 standards) than under the more stringent regulatory alternatives described next.

11.1.1.1 Alternative 1a

For an explanation of analytical Methods A and B identified in some of the following tables, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1. The estimated reductions in

CO_2 emission rates[8] used in MOVES for Alternative 1a are presented inChapter 10 discusses the agencies' use of the CAFE model in greater detail.

Table **11-1** The projected use of auxiliary power units (APU) during extended idling for Alternative 1a is presented in Table 11-2. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-3. Chapter 10 discusses the agencies' use of the CAFE model in greater detail.

Table 11-1 Estimated Reductions in CO_2 Emission Rates for Method B Alternative 1a Modeling in MOVES

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2024	0.5%
		2025+	0.6%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018+	0.2%
Single-Frame Vocational[9]	Diesel and CNG	2021-2023	0%
		2024+	0%
	Gasoline	2021-2023	0%
		2024+	0%
HD Pickup Trucks and Vans[a]	Diesel and Gasoline	2021	0%
		2022	0%
		2023	0%
		2024	0%
		2025+	0%

Note:
[a] Chapter 10 presents CAFE model inputs for the Method A analysis.

Table 11-2 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 1a Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Tractors	2010+	30%

Table 11-3 Estimated Reductions in Road Load Factors for Alternative 1a Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018	2.1%	3.0%	-129
	2019-2020	2.2%	3.1%	-129
	2021	2.2%	3.2%	-129
	2022-2023	2.3%	3.3%	-129
	2024	2.4%	3.4%	-129
	2025	2.4%	3.5%	-129
	2026	2.5%	3.5%	-129
	2027+	2.5%	3.6%	-129
Combination Short-haul Tractor-Trailers[10]	2018	0.8%	1.1%	-49
	2019-2020	0.8%	1.2%	-49
	2021-2022	0.9%	1.2%	-49
	2023-2026	0.9%	1.3%	-49
	2027+	1.0%	1.4%	-49
Intercity Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Short-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Long-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Motor Homes	2021-2023	0%	0%	0
	2024+	0%	0%	0

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

11.1.1.2 Alternative 1b

The estimated reductions in CO_2 emission rates used in MOVES and the projected use of auxiliary power units (APU) during extended idling for Alternative 1b are presented in Table 11-4 and Table 11-5, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-6.

Table 11-4 Estimated Reductions in CO_2 Emission Rates for Method B Alternative 1b Modeling in MOVES

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long- and Short-Haul Tractor-Trailer and HHD Vocational	Diesel	2018+	0%
Single-Frame Vocational[11]	Diesel and CNG	2021-2023	0%
		2024+	0%
	Gasoline	2021-2023	0%
		2024+	0%
HD pickup trucks and vans[a]	Diesel and Gasoline	2021-2022	2.18%
		2023	2.71%
		2024+	2.86%

Note:
[a] Chapter 10 presents CAFE model inputs for the Method A analysis.

Table 11-5 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 1b Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Tractors	2010+	30%

Table 11-6 Estimated Reductions in Road Load Factors for Alternative 1b Modeling in MOVES

TRUCK TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2019	0.2%	0.5%	0
	2020	0.2%	0.7%	0
	2021	0.4%	1.2%	0
	2022	0.6%	1.7%	0
	2023	0.8%	2.5%	0
	2024	1.1%	3.4%	0
	2025	1.4%	4.4%	0
	2026	1.7%	5.3%	0
	2027	2.0%	6.1%	0
	2028	2.1%	6.6%	0
Combination Short-haul Tractor-Trailers[12]	2019	0.3%	0.4%	0
	2020	0.4%	0.7%	0
	2021	0.7%	1.0%	0
	2022	1.0%	1.6%	0
	2023	1.5%	2.2%	0
	2024	2.0%	3.1%	0
	2025	2.6%	3.9%	0
	2026	3.1%	4.8%	0
	2027	3.6%	5.4%	0
	2028	3.9%	6.0%	0
Intercity Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Short-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Long-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Motor Homes	2021-2023	0%	0%	0
	2024+	0%	0%	0

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

11.1.2 Alternative 2: Less Stringent than the Preferred Alternative

For vocational vehicles and combination tractor-trailers, Alternative 2 represents a stringency level which is approximately half as stringent overall as the preferred alternative. The agencies developed Alternative 2 to reflect a continuation of the Phase 1 approach of– applying off-the-shelf technologies rather than requiring the development of new technologies or fundamental improvements to existing technologies. For tractors and vocational vehicles, this also involved less integrated optimization of the vehicles and engines. Alternative 2 would not set standards for MY 2027.

The agencies' decisions regarding which technologies could be applied to comply with Alternative 2 considered not only assuming the use of off-the shelf technologies, but also considered other factors, as well, such as how broadly certain technologies fit in-use applications and regulatory structure. The resulting Alternative 2 could be met with most of the same technologies the agencies project could be used to meet the proposed standards, although at lower application rates. Alternative 2 is estimated to be achievable without the application of some technologies, at any level. These and other differences are described below by category.

The agencies project that Alternative 2 combination tractor standards could be met by applying lower adoption rates of the projected technologies for Alternative 3. This includes a projection of slightly lower per-technology effectiveness for Alternative 2 versus 3. Alternative 2 also assumes that there would be little optimization of combination tractor powertrains.

The agencies project that the Alternative 2 vocational vehicle standard could be met without any use of strong hybrids. Rather, it could be met with lower adoption rates of the other technologies that could be used to meet Alternative 3, our proposed standards. This includes a projection of slightly lower per-technology effectiveness for Alternative 2 versus 3 and little optimization of vocational vehicle powertrains.

The Alternative 2 trailer standards would apply to only 53-foot dry and refrigerated box trailers and could be met through the use of less effective aerodynamic technologies and higher rolling resistance tires versus what the agencies projected could be used to meet Alternative 3.

As discussed above in Chapter 5, the HD pickup truck and van alternatives are characterized by an annual required percentage change (decrease) in the functions defining attribute-based targets for per-mile fuel consumption and GHG emissions. Under the HD pickup and van standards in Alternative 2 and each other alternative, a manufacturer's fleet would, setting aside any changes in production mix, be required to achieve average fuel consumption/GHG levels that increase in stringency every year relative to the standard defined for MY2018 (and held constant through 2020) that establishes fuel consumption/GHG targets for individual vehicles. A manufacturer's specific fuel consumption/GHG requirement is the sales-weighted average of the targets defined by the work-factor curve in each year. Therefore, although the alternatives involve steady increases in the functions defining the targets, stringency increases faced by any individual manufacturer may not be steady if changes in the manufacturer's product mix cause fluctuations in the average fuel consumption and GHG levels required of the manufacturer. See Section VI.D. of the Preamble for additional discussion of this topic. Alternative 2 represents a 2.0 percent annual improvement in the target curve through

2025 in fuel consumption/GHG emissions relative to the work-factor curve in 2020.This would be 0.5 percent less stringent per year compared to the proposed standards of Alternative 3 and would not increase in stringency for MYs 2026 or 2027. For HD pickups and vans the agencies project that most manufacturers could comply with the standards defining Alternative 2 by applying technologies similar to those that could be applied in order to comply with the proposed standards, but at lower application rates than could be necessitated by the proposed standards. The biggest technology difference the agencies project between Alternative 2 and the proposed standards of Alternative 3 would be that we project that most manufacturers could meet the Alternative 2 standards without any use of stop-start or other mild or strong hybrid technologies.

The analytical inputs for Alternative 2 are shown in the following tables. The estimated reductions in CO_2 emission rates used in MOVES and the projected use of auxiliary power units (APU) during extended idling are presented in Table 11-7 **and Table 11-8, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in**

Table 11-9.

Table 11-7 Estimated Reductions in CO_2 Emission Rates for Method B Alternative 2 Modeling in MOVES

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.9%
		2021-2023	3.9%
		2024+	6.9%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.3%
		2021-2023	3.2%
		2024+	6.4%
Single-Frame Vocational[13]	Diesel and CNG	2021-2023	2.1%
		2024+	5.1%
	Gasoline	2021-2023	1.1%
		2024+	2.1%
HD pickup trucks and vans[a]	Diesel and Gasoline	2021	2.00%
		2022	3.96%
		2023	5.88%
		2024	7.76%
		2025+	9.61%

Note:
[a] Chapter 10 presents CAFE model inputs for the Method A analysis.

Table 11-8 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 2 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Tractors	2010-2020	30%
	2021-2023	60%
	2024+	80%

Table 11-9 Estimated Reductions in Road Load Factors for Alternative 2 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	4.0%	5.1%	-131
	2021-2023	5.8%	11.0%	-135
	2024+	9.0%	12.4%	-140
Combination Short-haul Tractor-Trailers[14]	2018-2020	1.2%	1.6%	-41
	2021-2023	5.3%	6.4%	-42
	2024+	6.6%	7.4%	-43
Intercity Buses	2021-2023	6.5%	0%	0
	2024+	7.6%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	2.7%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	2.7%	0%	0
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	0
	2024+	5.6%	0%	0
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	0
	2024+	7.6%	0%	0
Motor Homes	2021-2023	3.0%	0%	0
	2024+	5.9%	0%	0

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

11.1.3 Alternative 3: Preferred Alternative and Proposed Standards

Alternative 3 represents the agencies' preferred approach. This alternative consists of the preferred fuel efficiency and GHG standards for HD engines, HD pickup trucks and vans, Class 2b through Class 8 vocational vehicles, and Class 7 and 8 combination tractors.

Details regarding modeling of this preferred alternative are included in Chapter 5 of this draft RIA as the control case (Section 5.3.2.3.1). Note that the impacts of this alternative are summarized in RIA Chapter 0, along with the impacts of the other alternatives.

11.1.4 Alternative 4: Achieving Proposed Standards with Less Lead-Time

Alternative 4 represents standards that are effective on a more accelerated timeline in comparison to the timeline of the proposed standards in Alternative 3. Alternatives 3 and 4 were both designed to achieve similar fuel efficiency and GHG emission levels in the long term but with Alternative 4 being accelerated in its implementation timeline. Specifically, Alternative 4 reflects the same or similar standard stringency levels as Alternative 3, but 3 years sooner (2 years for heavy-duty pickups and vans), so that the final phase of the standards would occur in MY 2024, or (for heavy duty pickups and vans) 2025.

The estimated reductions in CO_2 emission rates used in MOVES and the projected use of auxiliary power units (APU) during extended idling for Alternative 4 are presented in Table 11-10 and Table 11-11, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-12.

Table 11-10 Estimated Reductions in CO_2 Emission Rates for Method B Alternative 4 Modeling in MOVES

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	1.3%
		2021-2023	6.6%
		2024+	10.4%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.9%
		2021-2023	6.9%
		2024+	10.4%
Single-Frame Vocational[15]	Diesel and CNG	2021-2023	7.7%
		2024+	13.3%
	Gasoline	2021-2023	5.2%
		2024+	10.3%
HD pickup trucks and vans[a]	Diesel and Gasoline	2021	3.50%
		2022	6.88%
		2023	10.14%
		2024	13.28%
		2025+	16.32%

Note:
[a] Chapter 10 presents CAFE model inputs for the Method A analysis.

Table 11-11 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 4 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Tractors	2010-2020	30%
	2021-2023	80%
	2024+	90%

Table 11-12 Estimated Reductions in Road Load Factors for Alternative 4 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	5.5%	5.1%	-131
	2021-2023	12.6%	19.3%	-246
	2024+	17.9%	26.9%	-304
Combination Short-haul Tractor-Trailers[16]	2018-2020	4.0%	1.6%	-41
	2021-2023	13.0%	11.6%	-100
	2024+	17.6%	15.9%	-127
Intercity Buses	2021-2023	6.5%	0%	0
	2024+	16.5%	0%	0
Transit Buses	2021-2023	0%	0%	0
	2024+	3.0%	0%	0
School Buses	2021-2023	0%	0%	0
	2024+	4.0%	0%	0
Refuse Trucks	2021-2023	0%	0%	20
	2024+	3.0%	0%	25
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	5.8
	2024+	13.0%	0%	7
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	20
	2024+	16.5%	0%	25
Motor Homes	2021-2023	3.0%	0%	0
	2024+	7.4%	0%	0

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

11.1.5 Alternative 5: More Stringent Standards

Alternative 5 represents even more stringent standards compared to Alternatives 3 and 4, as well as the same implementation timeline as Alternative 4. As discussed in the feasibility discussions in the preamble, we are not proposing Alternative 5 because we cannot project that manufacturers can develop and introduce in sufficient quantities the technologies that could be used to meet Alternative 5 standards. We believe that for some or all of the categories, the Alternative 5 standards are technically infeasible within the lead time allowed. We have not fully estimated costs for this alternative for tractors and vocational vehicles because we believe that there would be such substantial additional costs related to pulling ahead the development of so many additional technologies that we cannot accurately predict these costs. We also believe this alternative could result in a decrease in the in-use reliability and durability of new heavy-duty vehicles and that we do not have the ability to accurately quantify the costs that would be associated with such problems. Instead we merely note that costs would be significantly greater than the estimated costs for Alternatives 3 and 4.

The tractor and vocational vehicle standards would be based on higher adoption rates of the projected technologies and higher effectiveness. In addition, it assumes some adoption of all-electric vocational vehicles.

The trailer standards in Alternative 5 are more stringent than Alternatives 3 and 4, but rely on the same technologies. The greater reductions would be projected to be achieved through a combination of slightly higher effectiveness and higher adoption rates.

The Alternative 5 HD pickup truck and van standards would be based on more extensive use of mild and strong hybrid technology and its use by more manufacturers. The result would be that over half of the HD gasoline pickup fleet would need to incorporate some form of strong hybrid technology. If achievable, Alternative 5 would require the average pickup truck or van fuel consumption and GHG emissions to decrease by approximately 4.0 percent per year relative to Phase 1 for model years 2021, 2022, 2023, 2024 and 2025. This is more aggressive than Alternative 3 by 1.50 percent per year over the same model years. The estimated reductions in CO_2 emission rates used in MOVES and the projected use of auxiliary power units (APU) during extended idling for Alternative 5 are presented in Table 11-13 and Table 11-14, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-15.

Table 11-13 Estimated Reductions in CO_2 Emission Rates for Method B Alternative 5 Modeling in MOVES

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	1.3%
		2021-2023	10.3%
		2024+	13.5%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.9%
		2021-2023	11.3%
		2024+	14.9%
Single-Frame Vocational[17]	Diesel and CNG	2021-2023	14.0%
		2024+	18.5%
	Gasoline	2021-2023	11.0%
		2024+	15.0%
HD pickup trucks and vans[a]	Diesel and Gasoline	2021	4.00%
		2022	7.84%
		2023	11.53%
		2024	15.07%
		2025+	18.46%

Note:
[a] Chapter 10 presents CAFE model inputs for the Method A analysis.

Table 11-14 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 5 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	APU PENETRATION
Combination Long-Haul Tractors	2010-2020	30%
	2021+	100%

Table 11-15 Estimated Reductions in Road Load Factors for Alternative 5 Modeling in MOVES

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	5.4%	7.3%	-170
	2021-2023	14.3%	24.6%	936
	2024+	19.2%	31.4%	850
Combination Short-haul Tractor-Trailers[18]	2018-2020	3.9%	2.3%	-53
	2021-2023	14.5%	15.0%	997
	2024+	18.8%	19.0%	943
Intercity Buses	2021-2023	6.5%	0%	0
	2024+	16.5%	0%	0
Transit Buses	2021-2023	0%	0%	0
	2024+	8.0%	0%	0
School Buses	2021-2023	0%	0%	0
	2024+	9.1%	0%	0
Refuse Trucks	2021-2023	0%	0%	255
	2024+	8.0%	0%	255
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	58
	2024+	15.2%	0%	95
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	185
	2024+	16.5%	0%	185
Motor Homes	2021-2023	3.0%	0%	0
	2024+	12.4%	0%	0

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.

11.2 How Do These Alternatives Compare in Overall GHG Emissions Reductions and Fuel Efficiency and Cost?

As noted earlier, the agencies analyzed the impact of each alternative on both downstream and upstream emissions using two complementary methods. The results of Method A are shown in section 11.2.1. The results of Method B are shown in section 11.2.2.

11.2.1 Comparison of Alternatives Using Method A

The following tables compare the overall fuel consumption and GHG emissions reductions and benefits and costs of each of the regulatory alternatives the agencies considered.

Note that for tractors, trailers, pickups and vans the agencies compared overall fuel consumption and GHG emissions reductions and benefits and costs relative to two different baselines, described above in the section on the No Action alternative. Therefore, for tractors, trailers, pickups and vans two results are listed; one relative to each baseline, namely Alternative 1a and Alternative 1b.

Also note that the agencies analyzed pickup and van overall fuel consumption and emissions reductions and benefits and costs using the NHTSA CAFE model (Method A). In addition, the agencies used EPA's MOVES model to estimate pickup and van fuel consumption and emissions and a cost methodology that applied vehicle costs in different model years (Method B). In both cases, the agencies used the CAFE model to estimate average per vehicle cost, and this analysis extended through model year 2030.[A] The agencies concluded that in these instances the choice of baseline and the choice of modeling approach (Method A versus Method B) did not impact the agencies' decision to propose Alternative 3 as the preferred alternative and hence the proposed standards for HD pickups and vans.

Table 11-16 compares the fuel savings, technology costs, avoided GHG emissions, costs, and benefits (at three percent) for the above regulatory alternatives, as estimated under Method A. Table 11-17 provides the same comparisons for the alternative relative to baseline 1b. Table 11-18 and Table 11-19 show the same summary, discounted at seven percent. Subsequent tables (Table 11-20 and Table 11-21) summarize segment-specific impacts on fuel consumption and GHG emissions.

[A] Although the agencies have considered regulatory alternatives involving standards increasing in stringency through, at the latest, 2027, the agencies extended the CAFE modeling analysis through model year 2030 rather than model year 2027 in order to obtain more fully stabilized results given projected product cadence, multiyear planning, and application of earned credits.

Table 11-16 Summary of Costs and Benefits through MY 2029 by Alternative, Discounted at 3% (Relative to Baseline 1a), Method A[a]

VEHICLE SEGMENT	ALT 2	ALT 3	ALT 4	ALT 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	11.7	18.3	22.3	24.8
Vocational Vehicles	5.6	18.4	24.3	38.5
Tractors/Trailers	88.1	138.4	151.7	196.8
Total	105.4	175.1	198.3	260.2
Discounted Total technology costs ($billion)				
HD pickups and Vans	3.0	5.0	8.2	9.9
Vocational Vehicles	1.2	7.6	10.8	26.0
Tractors/Trailers	9.2	12.8	15.3	34.8
Total	13.4	25.4	34.3	70.6
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	3.1	5.0	6.1	6.8
Vocational Vehicles	0.6	2.6	3.5	5.7
Tractors/Trailers	21.5	32.7	35.1	45.1
Total	25.2	40.3	44.7	57.7
Total costs($billion)				
HD pickups and Vans	3.5	5.7	9.1	15.2
Vocational Vehicles	3.0	9.5	12.8	28.1
Tractors/Trailers	11.5	15.5	18.1	37.5
Total	18.0	30.8	40.0	80.8
Total benefits($billion)				
HD pickups and Vans	17.2	27.0	33.0	36.7
Vocational Vehicles	12.7	31.2	39.7	60.2
Tractors/Trailers	142.5	217.5	236.7	304.2
Total	172.4	275.8	309.4	401.1
Net benefits($billion)				
HD pickups and Vans	13.7	21.3	23.9	21.5
Vocational Vehicles	9.6	21.7	26.9	32.1
Tractors/Trailers	131.0	202.0	218.7	266.7
Total	154.3	245.0	269.4	320.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

Table 11-17 Summary of Program Benefits and Costs through MY 2029, Discounted at 3% (Relative to Baseline 1b) Method A [a]

VEHICLE SEGMENT	ALT 2	ALT 3	ALT 4	ALT 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	9.6	15.9	19.1	22.2
Vocational Vehicles	5.6	18.4	24.3	38.5
Tractors/Trailers	80.5	130.8	144.0	189.2
Total	95.6	165.1	187.4	250.0
Discounted Total technology costs ($billion)				
HD pickups and Vans	2.5	5.0	7.2	9.7
Vocational Vehicles	1.2	7.6	10.8	25.9
Tractors/Trailers	8.9	12.5	15.0	34.4
Total	12.5	25.0	32.9	70.0
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	2.8	4.5	5.4	6.3
Vocational Vehicles	1.7	6.1	8.1	13.1
Tractors/Trailers	37.5	59.4	64.6	84.4
Total	41.9	70.1	78.2	103.8
Total costs($billion)				
HD pickups and Vans	2.8	5.5	7.8	10.4
Vocational Vehicles	3.0	9.5	12.8	28.0
Tractors/Trailers	11.2	15.2	17.7	37.2
Total	17.0	30.3	38.4	75.7
Total benefits($billion)				
HD pickups and Vans	14.1	23.5	28.3	32.9
Vocational Vehicles	12.7	31.2	39.7	60.2
Tractors/Trailers	131.1	206.2	225.4	292.8
Total	157.9	260.9	293.3	385.9
Net benefits($billion)				
HD pickups and Vans	11.3	18.0	20.4	22.5
Vocational Vehicles	9.6	21.7	26.9	32.1
Tractors/Trailers	119.9	191.0	207.6	255.6
Total	140.9	230.7	254.9	310.3

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

The following two tables summarize results for each of the segments covered by today's proposal, discounted at 7 percent.

Table 11-18 Summary of Program Benefits and Costs through MY 2029, discounted at 7% (Relative to Baseline 1a) Method A [a]

VEHICLE SEGMENT	ALT 2	ALT 3	ALT 4	ALT 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	6.4	9.9	12.2	13.6
Vocational Vehicles	2.9	9.7	13.0	20.9
Tractors/Trailers	47.7	74.6	82.3	107.3
Total	57.0	94.2	107.5	141.8
Discounted Total technology costs ($billion)				
HD pickups and Vans	2.1	3.4	5.7	6.9
Vocational Vehicles	0.8	5.0	7.3	17.8
Tractors/Trailers	6.3	8.7	10.5	23.9
Total	9.1	17.1	23.5	48.6
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	2.7	4.3	5.3	5.9
Vocational Vehicles	1.4	5.0	6.6	10.6
Tractors/Trailers	29.9	46.3	50.4	65.4
Total	34.0	55.6	62.3	81.8
Total costs($billion)				
HD pickups and Vans	2.4	3.8	6.2	10.1
Vocational Vehicles	1.8	6.1	8.4	19.0
Tractors/Trailers	7.6	10.3	12.1	25.5
Total	11.8	20.2	26.7	54.6
Total benefits($billion)				
HD pickups and Vans	10.4	16.3	20.1	22.3
Vocational Vehicles	7.3	18.3	23.6	36.2
Tractors/Trailers	85.1	130.0	142.2	183.5
Total	102.9	164.6	185.8	242.1
Net benefits($billion)				
HD pickups and Vans	8.1	12.4	13.9	12.2
Vocational Vehicles	5.5	12.2	15.2	17.2
Tractors/Trailers	77.5	119.7	130.1	158.0
Total	91.1	144.4	159.1	187.5

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

Table 11-19 Summary of Program Benefits and Costs through MY 2029, discounted at 7% (Relative to Baseline 1b) Method A [a]

VEHICLE SEGMENT	ALT 2	ALT 3	ALT 4	ALT 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	5.2	8.5	10.4	12.2
Vocational Vehicles	2.9	9.7	13.0	20.9
Tractors/Trailers	44.0	71.0	78.6	103.7
Total	52.2	89.2	102.0	136.8
Discounted Total technology costs ($billion)				
HD pickups and Vans	1.7	3.4	4.9	6.7
Vocational Vehicles	0.8	5.0	7.3	17.8
Tractors/Trailers	6.0	8.4	10.3	23.7
Total	8.5	16.8	22.5	48.2
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	2.5	4.0	4.8	5.5
Vocational Vehicles	1.4	5.0	6.6	10.6
Tractors/Trailers	27.5	43.9	48.0	63.0
Total	31.4	52.9	59.4	79.1
Total costs($billion)				
HD pickups and Vans	1.9	3.7	5.3	7.1
Vocational Vehicles	1.8	6.1	8.4	19.0
Tractors/Trailers	7.3	10.0	11.9	25.3
Total	11.1	19.8	25.6	51.4
Total benefits($billion)				
HD pickups and Vans	8.6	14.1	17.1	20.0
Vocational Vehicles	7.3	18.3	23.6	36.2
Tractors/Trailers	78.9	123.7	135.9	177.3
Total	94.8	156.2	176.6	233.5
Net benefits($billion)				
HD pickups and Vans	6.7	10.5	11.9	12.9
Vocational Vehicles	5.5	12.2	15.2	17.2
Tractors/Trailers	71.5	113.7	124.0	152.0
Total	83.7	136.4	151.1	182.2

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

While the agencies' explicit analysis of manufacturers' potential responses to today's standards extends through model year 2030, the resulting fuel savings and avoided emissions summarized in the following two tables occur as those vehicles.

Table 11-20 Fuel Savings and GHG Emissions Reductions by Vehicle Segment, Relative to Baseline 1a, Method A[a]

MY 2018 - 2029 TOTAL	FUEL REDUCTIONS	UPSTREAM & DOWNSTREAM GHG REDUCTIONS
	(billion gallons)	(MMT)
Alternative 2		
HD Pickup Trucks/Vans	5.5	67.5
Vocational Vehicles	2.5	33.632.2
Tractors and Trailers	37.8	518.8493.0
Total	45.8	619.9592.7
Alt. 3 - Preferred Alternative		
HD Pickup Trucks/Vans	8.8	107.6
Vocational Vehicles	8.3	110.3107.0
Tractors and Trailers	59.5	816.4775.7
Total	76.7	1,034.3990.4
Alt. 4		
HD Pickup Trucks/Vans	10.7	130.5
Vocational Vehicles	10.9	143139.8
Tractors and Trailers	65.0	892.1847.7
Total	86.7	1,166.4118.0
Alt. 5		
HD Pickup Trucks/Vans	12.0	145.4
Vocational Vehicles	17.3	226.9221.0
Tractors and Trailers	84.2	1,155.1097.6
Total	113.4	1,527.4464.1

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

Table 11-21 Fuel Savings and GHG Emissions Reductions by Vehicle Segment, Relative to Baseline 1b Method A[a]

MY 2018 - 2029 TOTAL	FUEL REDUCTIONS	UPSTREAM & DOWNSTREAM GHG REDUCTIONS
	(billion gallons)	(MMT)
Alternative 2		
HD Pickup Trucks/Vans	4.5	55.5
Vocational Vehicles	2.5	33.6
Tractors and Trailers	34.4	471.9
Total	41.4	561.0
Alt. 3 - Preferred Alternative		
HD Pickup Trucks/Vans	7.8	94.1
Vocational Vehicles	8.3	110.3
Tractors and Trailers	56.1	769.4
Total	72.2	973.8
Alt. 4		
HD Pickup Trucks/Vans	9.3	112.8
Vocational Vehicles	10.9	143.8
Tractors and Trailers	61.6	845.2
Total	81.8	1,101.8
Alt. 5		
HD Pickup Trucks/Vans	10.8	130.5
Vocational Vehicles	17.3	226.9
Tractors and Trailers	80.7	1,108.2
Total	108.8	1,465.6

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1.

11.2.2 Comparison of Alternatives Using Method B

Method B analyzed the impact of each alternative on both downstream and upstream emissions, as shown in Table 11-22. The table contains the annual GHG and fuel consumption impacts and technology costs in 2035 and 2050 for each alternative (relative to the reference scenario of Alternative 1a), presenting both the total impacts across all regulatory categories and for each individual regulatory category. Note that by 2050 when all the alternative would be almost completely phased in, Alternatives 3 and 4 would provide essentially the same annual benefits.

Table 11-22 Annual GHG & Fuel Reductions and Technology Costs vs. the Less Dynamic Baseline and using Method B: Calendar Years 2035 and 2050 [a]

	UPSTREAM +DOWNSTREAM GHG REDUCTIONS (MMT)		FUEL REDUCTIONS (BILLION GALLONS)		TECHNOLOGY COST (MILLIONS OF 2012$)	
	2035	2050	2035	2050	2035	2050
Alternative 1a (relative to itself)	0	0	0	0	$0	$0
Alt. 2 Less Stringent- Total	72	101	5.2	7.3	$2,559	$3,090
Tractors	59	84	4.2	6.0	$1,855	$2,279
HD Pickups & Vans	8	11	0.7	0.9	$471	$541
Vocational Vehicles	5	7	0.3	0.5	$233	$271
Alt. 3 Preferred – Total	127	183	9.3	13.4	$5,856	$6,987
Tractors	97	141	7.0	10.1	$2,888	$3,548
HD Pickups & Vans	14	19	1.1	1.6	$892	$1,024
Vocational Vehicles	16	23	1.2	1.7	$2,076	$2,414
Alt. 4 More Stringent– Total	132	184	9.7	13.5	$6,180	$7,358
Tractors	100	141	7.2	10.1	$2,888	$3,548
HD Pickups & Vans	15	19	1.2	1.6	$1,215	$1,395
Vocational Vehicles	17	23	1.3	1.7	$2,077	$2,415
Alt. 5 More Stringent– Total	168	232	12.4	17.0	N/A	N/A
Tractors	126	176	9.0	12.6	N/A	N/A
HD Pickups & Vans	17	22	1.4	1.8	N/A	N/A
Vocational Vehicles	26	34	1.9	2.5	N/A	N/A

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 11-23 presents a summary of all costs and benefits for each program alternative relative to the Alternative 1a baseline case. Table 11-24 shows cost per ton of GHG reduced.

Table 11-23 Monetized Net Benefits Associated with Each Alternative Relative to the Less Dynamic Baseline and using Method B (Billions of 2012$, Except GHG Reductions) [a, b]

		Alt.1 Baseline	Alt.2 Less Stringent	Alt.3 Preferred	Alt.4 More Stringent	Alt.5 More Stringent
2035	Vehicle Program Costs[c]	$0	-$2.6	-$5.9	-$6.2	N/A
	Maintenance costs	$0	-$0.06	-$0.13	-$0.14	N/A
	Fuel Expenditures (pre-tax)	$0	$20.9	$37.2	$38.7	$49.4
	Benefits	$0	$12.8	$20.5	$21.1	$26.3
	Net Benefits	$0	$31.1	$51.7	$53.5	N/A
	GHG reductions (MMT)	0	71.9	127.1	132.0	168.3
2050	Vehicle Program Costs[c]	$0	-$3.1	-$7.0	-$7.4	N/A
	Maintenance costs	$0	-$0.06	-$0.13	-$0.14	N/A
	Fuel Expenditures (pre-tax)	$0	$31.5	$57.5	$57.6	$72.7
	Benefits	$0	$19.9	$32.9	$32.9	$40.6
	Net Benefits	$0	$48.3	$83.2	$83.0	N/A
	GHG Reductions (MMT)	0	101.2	183.4	183.8	231.8
NPV, 3%	Vehicle Program Costs[c]	$0	-$39.8	-$86.8	-$98.6	N/A
	Maintenance costs	$0	-$0.88	-$1.80	-$1.91	N/A
	Fuel Expenditures (pre-tax)	$0	$280.0	$495.6	$517.6	$664.3
	Benefits	$0	$175.2	$279.7	$289.7	$361.5
	Net Benefits	$0	$414.5	$686.8	$706.8	N/A
NPV, 7%	Vehicle Program Costs[c]	$0	-$19.3	-$41.1	-$48.4	N/A
	Maintenance costs	$0	-$0.42	-$0.86	-$0.92	N/A
	Fuel Expenditures (pre-tax)	$0	$118.1	$206.7	$219.0	$283.0
	Benefits	$0	$105.5	$173.5	$180.7	$228.0
	Net Benefits	$0	$203.8	$338.1	$350.5	N/A

Notes:

[a] Benefits and net benefits calculated using the 3% average Social Cost of CO_2 value. The net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[c] Vehicle program costs include compliance costs and R&D.

Table 11-24 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in Each Control Case Alternative Vs. the Less Dynamic Baseline and using Method B (Dollar Values are 2012$) [a]

YEAR		ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4 MORE STRINGENT	ALT.5 MORE STRINGENT
2035	$/metric ton w/o fuel	$36	$47	$48	N/A
	$/metric ton w/ fuel	-$250	-$250	-$250	N/A
2050	$/metric ton w/o fuel	$31	$39	$41	N/A
	$/metric ton w/ fuel	-$280	-$270	-$270	N/A

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

11.2.2.1 Tractors and Trailers

Table 11-25 presents a summary of all costs and benefits for each tractor/trailer program Alternative relative to the alternative 1a baseline case. Table 11-26 shows cost per ton of GHG reduced.

Table 11-25 Monetized Net Benefits Associated with Each Alternative Relative to the Less Dynamic Baseline and using Method B
Tractor/Trailers
(Billions of 2012$, Except GHG Reductions) [b]

		ALT.1 BASELINE	ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4 MORE STRINGENT	ALT.5 MORE STRINGENT
2035	Vehicle Program Costs[c]	$0	-$1.9	-$2.9	-$2.9	N/A
	Maintenance costs	$0	-$0.03	-$0.08	-$0.08	N/A
	Fuel Expenditures (pre-tax)	$0	$17.2	$28.4	$29.2	$36.8
	Benefits	$0	$10.3	$15.7	$16.0	$19.7
	Net Benefits	$0	$25.6	$41.0	$42.2	N/A
	GHG Reductions (MMT)	0	59.1	97.2	100.0	125.9
2050	Vehicle Program Costs[c]	$0	-$2.3	-$3.6	-$3.6	N/A
	Maintenance costs	$0	-$0.03	-$0.08	-$0.08	N/A
	Fuel Expenditures (pre-tax)	$0	$26.1	$44.0	$44.0	$54.8
	Benefits	$0	$16.1	$25.2	$25.2	$30.7
	Net Benefits	$0	$39.9	$65.5	$65.6	N/A
	GHG Reductions (MMT)	0	83.8	140.9	141.1	175.7
NPV, 3%	Vehicle Program Costs[c]	$0	-$28.8	-$43.7	-$46.2	N/A
	Maintenance costs	$0	-$0.47	-$1.19	-$1.22	N/A
	Fuel Expenditures (pre-tax)	$0	$231.7	$381.5	$394.5	$499.5
	Benefits	$0	$141.7	$215.7	$221.6	$274.2
	Net Benefits	$0	$344.1	$552.3	$568.8	N/A
NPV, 7%	Vehicle Program Costs[c]	$0	-$13.9	-$20.9	-$22.7	N/A
	Maintenance costs	$0	-$0.23	-$0.59	-$0.60	N/A
	Fuel Expenditures (pre-tax)	$0	$98.1	$160.1	$167.5	$213.4
	Benefits	$0	$85.8	$133.8	$138.1	$172.4
	Net Benefits	$0	$169.8	$272.4	$282.3	N/A

Notes:
[a] Benefits and net benefits calculated using the 3% average Social Cost of CO_2 value applied only to CO_2 reductions. The net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[c] Vehicle program costs include compliance costs and R&D.

Table 11-26 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in Each Control Case Alternative Vs. the Less Dynamic Baseline and using Method B
Tractor/Trailers
(Dollar Values are 2012$) [a]

YEAR		ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4 MORE STRINGENT	ALT.5 MORE STRINGENT
2035	$/metric ton w/o fuel	$32	$31	$30	N/A
	$/metric ton w/ fuel	-$260	-$260	-$260	N/A
2050	$/metric ton w/o fuel	$28	$26	$26	N/A
	$/metric ton w/ fuel	-$280	-$290	-$290	N/A

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

11.2.2.2 Vocational Vehicles

Table 11-27 presents a summary of all costs and benefits for each vocational program alternative relative to the Alternative 1a baseline case. Table 11-28 shows cost per ton of GHG reduced.

Table 11-27 Monetized Net Benefits Associated with Each Alternative Relative to the Less Dynamic Baseline and using Method B
Vocational Vehicles
(Billions of 2012$, Except GHG Reductions) [a, b]

		ALT.1 BASELINE	ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4	ALT.5 MORE STRINGENT
2035	Vehicle Program Costs[c]	$0	-$0.2	-$2.1	-$2.1	N/A
	Maintenance costs	$0	-$0.02	-$0.03	-$0.04	N/A
	Fuel Expenditures (pretax)	$0	$1.3	$4.7	$5.1	$7.6
	Benefits	$0	$1.1	$2.6	$2.8	$3.9
	Net Benefits	$0	$2.2	$5.2	$5.8	
	GHG Reductions (MMT)	0	4.7	16.1	17.4	25.8
2050	Vehicle Program Costs[c]	$0	-$0.3	-$2.4	-$2.4	N/A
	Maintenance costs	$0	-$0.02	-$0.03	-$0.04	N/A
	Fuel Expenditures (pretax)	$0	$2.0	$7.3	$7.3	$10.7
	Benefits	$0	$1.7	$4.2	$4.2	$5.9
	Net Benefits	$0	$3.4	$9.0	$9.1	N/A
	GHG Reductions (MMT)	0	6.5	23.2	23.3	33.9
NPV, 3%	Vehicle Program Costs[c]	$0	-$3.6	-$29.6	-$32.8	N/A
	Maintenance costs	$0	-$0.22	-$0.42	-$0.52	N/A
	Fuel Expenditures (pretax)	$0	$16.9	$60.6	$66.3	$99.9
	Benefits	$0	$14.8	$34.8	$37.4	$52.7
	Net Benefits	$0	$27.9	$65.4	$70.3	N/A
NPV, 7%	Vehicle Program Costs[c]	$0	-$1.7	-$13.8	-$16.0	N/A
	Maintenance costs	$0	-$0.10	-$0.19	-$0.24	N/A
	Fuel Expenditures (pretax)	$0	$6.9	$24.7	$27.9	$42.5
	Benefits	$0	$8.3	$21.5	$23.4	$33.8
	Net Benefits	$0	$13.4	$32.2	$35.0	N/A

Notes:
[a] Benefits and net impacts calculated using the 3% average Social Cost of CO_2 value. The net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[c] Vehicle program costs include compliance costs and R&D.

Table 11-28 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in Each Control Case Alternative Vs. the Less Dynamic Baseline and using Method B Vocational Vehicles (Dollar Values are 2012$) [a]

YEAR		ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4	ALT.5 MORE STRINGENT
2035	$/metric ton w/o fuel	$53	$130	$120	N/A
	$/metric ton w/ fuel	-$230	-$160	-$170	N/A
2050	$/metric ton w/o fuel	$44	$110	$110	N/A
	$/metric ton w/ fuel	-$260	-$210	-$210	N/A

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

11.2.2.3 HD Pickups and Vans

Table 11-29 presents a summary of all costs and benefits for each HD pickup and van program alternative relative to the Alternative 1a baseline case. Table 11-30 shows cost per ton of GHG reduced.

Table 11-29 Monetized Net Benefits Associated with Each Alternative Relative to the Less Dynamic Baseline and using Method B
HD Pickups and Vans
(Billions of 2012$, Except GHG Reductions) [a, b]

		ALT.1 BASELINE	ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4 MORE STRINGENT	ALT.5 MORE STRINGENT
2035	Vehicle Program Costs[c]	$0	-$0.5	-$0.9	-$1.2	N/A
	Maintenance costs	$0	-$0.01	-$0.01	-$0.01	N/A
	Fuel Expenditures (pretax)	$0	$2.5	$4.2	$4.4	$5.0
	Benefits	$0	$1.4	$2.2	$2.3	$2.6
	Net Benefits	$0	$3.4	$5.5	$5.5	N/A
	GHG Reductions (MMT)	0	8.1	13.9	14.6	16.6
2050	Vehicle Program Costs[c]	$0	-$0.5	-$1.0	-$1.4	N/A
	Maintenance costs	$0	-$0.01	-$0.01	-$0.01	N/A
	Fuel Expenditures (pretax)	$0	$3.5	$6.3	$6.3	$7.2
	Benefits	$0	$2.1	$3.5	$3.5	$4.0
	Net Benefits	$0	$5.1	$8.7	$8.4	N/A
	GHG Reductions (MMT)	0	10.8	19.3	19.4	22.1
NPV, 3%	Vehicle Program Costs[c]	$0	-$7.5	-$13.5	-$19.6	N/A
	Maintenance costs	$0	-$0.18	-$0.18	-$0.18	N/A
	Fuel Expenditures (pretax)	$0	$31.4	$53.5	$56.8	$64.9
	Benefits	$0	$18.7	$29.2	$30.7	$34.6
	Net Benefits	$0	$42.4	$69.1	$67.7	N/A
NPV, 7%	Vehicle Program Costs[c]	$0	-$3.7	-$6.5	-$9.7	N/A
	Maintenance costs	$0	-$0.08	-$0.08	-$0.08	N/A
	Fuel Expenditures (pretax)	$0	$13.1	$21.9	$23.7	$27.1
	Benefits	$0	$11.4	$18.2	$19.3	$21.8
	Net Benefits	$0	$20.7	$33.5	$33.2	N/A

Notes:
[a] Benefits and net impacts calculated using the 3% average Social Cost of CO_2 value. The net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
[c] Vehicle program costs include compliance costs and R&D.

Table 11-30 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in Each Control Case Alternative Vs. the Less Dynamic Baseline and using Method B
HD Pickups and Vans
(Dollar Values are 2012$) [a]

YEAR		ALT.2 LESS STRINGENT	ALT.3 PREFERRED	ALT.4 MORE STRINGENT	ALT.5 MORE STRINGENT
2035	$/metric ton w/o fuel	$59	$65	$84	N/A
	$/metric ton w/ fuel	-$240	-$240	-$220	N/A
2050	$/metric ton w/o fuel	$51	$53	$73	N/A
	$/metric ton w/ fuel	-$270	-$270	-$250	N/A

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

11.3 Detailed Technology Projections for Each Category

The alternatives were developed to reflect different levels of technology (in terms of effectiveness, adoption rate, and timing) that would be required to meet increasing levels of stringency. For each of these alternatives, the agencies projected a fleet mix of technologies that would be capable of meeting the standards. These projections are summarized below for each category. Note that for trailers, the alternatives differ in terms of which trailers would be subject to the standards, in addition to the level of technology necessary to the meet the standards. Note also that the same technology projections applied for both Method A and Method B. Details regarding the preferred alternative are included in Chapter 2 of this draft RIA (Sections 2.5-2.10).

11.3.1 Tractor Technology

Table 11-31 Alternative 2 2021MY Technology Adoption Rates for Tractors

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 2 Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	10%	10%	0%	10%	10%	0%	10%	10%	0%
Bin II	80%	80%	0%	80%	80%	0%	80%	80%	0%
Bin III	10%	10%	45%	10%	10%	45%	10%	10%	45%
Bin IV	0%	0%	35%	0%	0%	35%	0%	0%	35%
Bin V			20%			20%			20%
Bin VI			0%			0%			0%
Bin VII			0%			0%			0%
Steer Tires									
Base	15%	15%	5%	15%	15%	5%	15%	15%	15%
Level 1	60%	60%	65%	60%	60%	65%	60%	60%	65%
Level 2	25%	25%	30%	25%	25%	30%	25%	25%	20%
Level 3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Drive Tires									
Base	15%	15%	5%	15%	15%	5%	15%	15%	5%
Level 1	60%	60%	65%	60%	60%	65%	60%	60%	60%
Level 2	25%	25%	30%	25%	25%	30%	25%	25%	35%
Level 3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	30%	30%	30%
Other	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Transmission Type									
Manual	45%	45%	45%	45%	45%	45%	45%	45%	45%
AMT	40%	40%	40%	40%	40%	40%	40%	40%	40%
Auto	10%	10%	10%	10%	10%	10%	10%	10%	10%
Dual Clutch	5%	5%	5%	5%	5%	5%	5%	5%	5%
Driveline									
Axle Lubricant	20%	20%	20%	20%	20%	20%	20%	20%	20%
6x2 or 4x2 Axle				10%	10%	20%	10%	10%	10%
Downspeed	20%	20%	0%	0%	0%	0%	0%	0%	0%
Accessory Improvements									
A/C	10%	10%	10%	10%	10%	10%	10%	10%	10%
Electric Access.	10%	10%	10%	10%	10%	10%	10%	10%	10%

Other Technologies									
Predictive Cruise Control	20%	20%	20%	20%	20%	20%	20%	20%	20%
Automated Tire Inflation System	10%	10%	10%	10%	10%	10%	10%	10%	10%

Table 11-32 Alternative 2 2024MY Technology Adoption Rates for Tractors

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 2 Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	10%	10%	0%	10%	10%	0%	10%	10%	0%
Bin II	70%	70%	0%	70%	70%	0%	70%	70%	0%
Bin III	20%	20%	35%	20%	20%	35%	20%	20%	35%
Bin IV	0%	0%	45%	0%	0%	45%	0%	0%	45%
Bin V			20%			20%			20%
Bin VI			0%			0%			0%
Bin VII			0%			0%			0%
Steer Tires									
Base	10%	10%	5%	10%	10%	5%	10%	10%	10%
Level 1	60%	60%	60%	60%	60%	60%	60%	60%	60%
Level 2	30%	30%	35%	30%	30%	35%	30%	30%	30%
Level 3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Drive Tires									
Base	10%	10%	5%	10%	10%	5%	10%	10%	5%
Level 1	60%	60%	60%	60%	60%	60%	60%	60%	50%
Level 2	30%	30%	35%	30%	30%	35%	30%	30%	45%
Level 3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	40%	40%	40%
Other	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Transmission Type									
Manual	20%	20%	20%	20%	20%	20%	20%	20%	20%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	20%	20%	20%	20%	20%	20%	20%	20%	20%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 or 4x2 Axle				20%	20%	20%	20%	20%	20%
Downspeed	0%	0%	0%	0%	0%	0%	0%	0%	0%
Accessory Improvements									
A/C	20%	20%	20%	20%	20%	20%	20%	20%	20%
Electric Access.	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated	20%	20%	20%	20%	20%	20%	20%	20%	20%

Tire Inflation System									

Table 11-33 Alternative 4Adoption Rates for 2021 MY

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 4 2021MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	65%	65%	0%	65%	65%	0%	65%	65%	0%
Bin III	30%	30%	35%	30%	30%	35%	30%	30%	35%
Bin IV	5%	5%	30%	5%	5%	30%	5%	5%	30%
Bin V			25%			25%			25%
Bin VI			10%			10%			10%
Bin VII			0%			0%			0%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	35%	35%	35%	35%	35%	35%	35%	35%	35%
Level 2	45%	45%	45%	45%	45%	45%	45%	45%	45%
Level 3	15%	15%	15%	15%	15%	15%	15%	15%	15%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	35%	35%	35%	35%	35%	35%	35%	35%	35%
Level 2	45%	45%	45%	45%	45%	45%	45%	45%	45%
Level 3	15%	15%	15%	15%	15%	15%	15%	15%	15%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	80%	80%	80%
Transmission Type									
Manual	25%	25%	25%	25%	25%	25%	25%	25%	25%
AMT	40%	40%	40%	40%	40%	40%	40%	40%	40%
Auto	30%	30%	30%	30%	30%	30%	30%	30%	30%
Dual Clutch	5%	5%	5%	5%	5%	5%	5%	5%	5%
Driveline									
Axle Lubricant	20%	20%	20%	20%	20%	20%	20%	20%	20%
6x2 Axle				10%	10%	20%	10%	10%	30%
Downspeed	30%	30%	30%	30%	30%	30%	30%	30%	30%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	20%	20%	20%	20%	20%	20%	20%	20%	20%
Electric Access.	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other Technologies									
Predictive Cruise Control	30%	30%	30%	30%	30%	30%	30%	30%	30%
Automated Tire	30%	30%	30%	30%	30%	30%	30%	30%	30%

Inflation System									

Table 11-34 Alternative 4 Adoption Rates for 2024 MY

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 4 2024 MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	50%	50%	0%	50%	50%	0%	50%	50%	0%
Bin III	40%	40%	20%	40%	40%	20%	40%	40%	20%
Bin IV	10%	10%	20%	10%	10%	20%	10%	10%	20%
Bin V			35%			35%			35%
Bin VI			20%			20%			20%
Bin VII			5%			5%			5%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	25%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	25%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	100%	100%	100%
Transmission Type									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	30%	30%	30%	30%	30%	30%	30%	30%	30%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 Axle				20%	20%	60%	20%	20%	60%
Downspeed	60%	60%	60%	60%	60%	60%	60%	60%	60%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	30%	30%	30%	30%	30%	30%	30%	30%	30%
Electric Access.	30%	30%	30%	30%	30%	30%	30%	30%	30%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated Tire Inflation System	40%	40%	40%	40%	40%	40%	40%	40%	40%

Table 11-35 Alternative 5 Adoption Rates for 2021 MY

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 5 2021 MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Additional Waste Heat Recovery							10%	10%	10%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	50%	50%	0%	50%	50%	0%	50%	50%	0%
Bin III	40%	40%	20%	40%	40%	20%	40%	40%	20%
Bin IV	10%	10%	20%	10%	10%	20%	10%	10%	20%
Bin V			35%			35%			35%
Bin VI			20%			20%			20%
Bin VII			5%			5%			5%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	30%	30%	30%	30%	30%	30%	30%	30%	20%
Level 2	40%	40%	40%	40%	40%	40%	40%	40%	40%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	35%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	30%	30%	30%	30%	30%	30%	30%	30%	20%
Level 2	40%	40%	40%	40%	40%	40%	40%	40%	40%
Level 3	25%	25%	25%	25%	25%	25%	25%	25%	35%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	100%	100%	100%
Transmission Type									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	40%	40%	40%	40%	40%	40%	40%	40%	40%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 Axle				20%	20%	20%	20%	20%	30%
Downspeed	60%	60%	60%	60%	60%	60%	60%	60%	60%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	30%	30%	30%	30%	30%	30%	30%	30%	30%
Electric Access.	30%	30%	30%	30%	30%	30%	30%	30%	30%
Other Technologies									
Predictive Cruise	40%	40%	40%	40%	40%	40%	40%	40%	40%

Control									
Automated Tire Inflation System	40%	40%	40%	40%	40%	40%	40%	40%	40%
Hybrid Powertrain with Electrified Accessories	20%	20%	20%	20%	20%	20%	20%	20%	20%
Weight Reduction (lbs)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200

Table 11-36 Alternative 5 Adoption Rates for 2024 MY

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Alternative 5 2024 MY Engine Technology Package									
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Additional Waste Heat Recovery							10%	10%	10%
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	40%	40%	0%	40%	40%	0%	40%	40%	0%
Bin III	50%	50%	15%	50%	50%	15%	50%	50%	15%
Bin IV	10%	10%	15%	10%	10%	15%	10%	10%	15%
Bin V			35%			35%			35%
Bin VI			25%			25%			25%
Bin VII			10%			10%			10%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	40%	40%	40%	40%	40%	40%	40%	40%	40%
Level 3	35%	35%	35%	35%	35%	35%	35%	35%	35%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	20%	20%	20%	20%	20%	20%	20%
Level 2	40%	40%	40%	40%	40%	40%	40%	40%	40%
Level 3	35%	35%	35%	35%	35%	35%	35%	35%	35%
Extended Idle Reduction									
APU	N/A	N/A	N/A	N/A	N/A	N/A	100%	100%	100%
Transmission Type									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	40%	40%	40%	40%	40%	40%	40%	40%	40%

Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Lubricant	40%	40%	40%	40%	40%	40%	40%	40%	40%
6x2 Axle				20%	20%	60%	20%	20%	60%
Downspeed	60%	60%	60%	60%	60%	60%	60%	60%	60%
Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Accessory Improvements									
A/C	30%	30%	30%	30%	30%	30%	30%	30%	30%
Electric Access.	30%	30%	30%	30%	30%	30%	30%	30%	30%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated Tire Inflation System	40%	40%	40%	40%	40%	40%	40%	40%	40%
Hybrid Powertrain with Electrified Accessories	40%	40%	40%	40%	40%	40%	40%	40%	40%
Weight Reduction (lbs)	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200

11.3.2 Trailer Technology

Table 11-37 Alternative 1 Trailer Adoption Rates

TECHNOLOGY	LONG BOX DRY & REFRIGERATED VANS					SHORT BOX, NON-AERO BOX, & NON-BOX TRAILERS
Model Year	2018	2021	2024	2027	2040[a]	2018+
Aerodynamics						
Bin I	45%	41%	38%	35%	20%	100%
Bin II	-	-	-	-		-
Bin III	20%	20%	20%	20%	20%	-
Bin IV	30%	34%	37%	40%	55%	-
Bin V	5%	5%	5%	5%	5%	-
Bin VI	-	-	-	-	-	-
Bin VII	-	-	-		-	-
Bin VIII	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.2*	*0.3*	*0.3*	*0.3*	*0.4*	*0.0*
Tire Rolling Resistance						
Level 1 tires	50%	47%	43%	40%	25%	100%
Level 2 tires	50%	53%	57%	60%	75%	-
Level 3 tires	-	-	-	-	-	-
Avg CRR (kg/ton)	*5.6*	*5.5*	*5.5*	*5.5*	*5.3*	*6.0*
Tire Inflation						
ATI	50%	53%	57%	60%	75%	0%
Avg % Reduction	*0.8%*	*0.8%*	*0.9%*	*0.9%*	*1.1%*	*0.0%*
Weight Reduction (pounds)						
Weight	*0*	*0*	*0*	*0*	*0*	*0*

Note:
[a] Considered in Alternative 1b only

Table 11-38 Alternative 2 Trailer Adoption Rates

TECHNOLOGY	LONG BOX DRY & REFRIGERATED VANS			SHORT BOX, NON-AERO BOX, & NON-BOX TRAILERS
Model Year	2018	2021	2024	2018+
Aerodynamics				
Bin I	5%	5%	5%	100%
Bin II				-
Bin III	30%	20%	10%	-
Bin IV	60%	70%	75%	-
Bin V	5%	5%	10%	-
Bin VI	-	-	-	-
Bin VII	-	-	-	-
Bin VIII	-	-	-	-
Avg Delta CdA (m^2)	*0.4*	*0.4*	*0.5*	*0.0*
Tire Rolling Resistance				
Level 1 tires	15%	10%	5%	100%
Level 2 tires	85%	90%		-
Level 3 tires			95%	-
Avg CRR (kg/ton)	*5.2*	*5.2*	*4.8*	*6.0*
Tire Inflation				
ATI	85%	90%	95%	0%
Avg % Reduction	*1.3%*	*1.4%*	*1.4%*	*0.0%*
Weight Reduction (pounds)				
Weight	*0*	*0*	*0*	*0*

Table 11-39 Alternative 3 Long Box Trailer Adoption Rates

TECHNOLOGY	LONG BOX DRY VANS				LONG BOX REFRIGERATED VANS			
Model Year	2018	2021	2024	2027	2018	2021	2024	2027
Aerodynamic Technologies								
Bin I	5%	-	-	-	5%	-	-	-
Bin II	-	-	-	-	-	-	-	-
Bin III	30%	5%	-	-	30%	5%	-	-
Bin IV	60%	55%	25%	-	60%	55%	25%	-
Bin V	5%	10%	10%	10%	5%	10%	10%	20%
Bin VI	-	30%	65%	50%	-	30%	65%	60%
Bin VII	-	-	-	40%	-	-	-	20%
Bin VIII	-	-	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.4*	*0.7*	*0.8*	*1.1*	*0.4*	*0.7*	*0.8*	*1.0*
Trailer Tire Rolling Resistance								
Level 1 tires	15%	5%	5%	5%	15%	5%	5%	5%
Level 2 tires	85%	95%	-	-	85%	95%	-	-
Level 3 tires	-	-	95%	95%	-	-	95%	95%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*4.8*	*5.2*	*5.1*	*4.8*	*4.8*
Tire Inflation System								
ATI	85%	95%	95%	95%	85%	95%	95%	95%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.4%*
Weight Reduction (pounds)								
Weight	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Table 11-40 Alternative 3 Short Box Trailer Adoption Rates

TECHNOLOGY	SHORT BOX DRY VANS				SHORT BOX REFRIGERATED VANS			
Model Year	2018	2021	2024	2027	2018	2021	2024	2027
Aerodynamic Technologies								
Bin I	100%	5%	-	-	100%	5%	-	-
Bin II	-	95%	70%	30%	-	95%	70%	55%
Bin III	-	-	30%	60%	-	-	30%	40%
Bin IV	-	-	-	10%	-	-	-	5%
Bin V	-	-	-	-	-	-	-	-
Bin VI	-	-	-	-	-	-	-	-
Bin VII	-	-	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.4*	*0.7*	*0.8*	*1.1*	*0.4*	*0.7*	*0.8*	*1.0*
Trailer Tire Rolling Resistance								
Level 1 tires	15%	5%	5%	5%	15%	5%	5%	5%
Level 2 tires	85%	95%	-	-	85%	95%	-	-
Level 3 tires	-	-	95%	95%	-	-	95%	95%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*4.8*	*5.2*	*5.1*	*4.8*	*4.8*
Tire Inflation System								
ATI	85%	95%	95%	95%	85%	95%	95%	95%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.4%*
Weight Reduction (pounds)								
Weight	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Table 11-41 Alternative 3 Non-Aero Box and Non-Box Trailer Adoption Rates

TECHNOLOGY	NON-AERO BOX & NON-BOX TRAILERS			
Model Year	2018	2021	2024	2027
Aerodynamic Technologies				
Bin I	100%	100%	100%	100%
Bin II	-	-	-	-
Bin III	-	-	-	-
Bin IV	-	-	-	-
Bin V	-	-	-	-
Bin VI	-	-	-	-
Bin VII	-	-	-	-
Bin VIII	-	-	-	-
Avg Delta CdA (m^2)	*0.0*	*0.0*	*0.0*	*0.0*
Trailer Tire Rolling Resistance				
Level 1 tires	-	-	-	-
Level 2 tires	100%	100%	-	-
Level 3 tires	-	-	100%	100%
Avg CRR (kg/ton)	*5.1*	*5.1*	*4.7*	*4.7*
Tire Inflation System				
ATI	100%	100%	100%	100%
Avg ATI Reduction (%)	1.5%	1.5%	1.5%	1.5%
Weight Reduction (pounds)				
Weight	*0*	*0*	*0*	*0*

Table 11-42 Alternative 4 Long Box Trailer Adoption Rates

TECHNOLOGY	LONG BOX DRY VANS			LONG BOX REFRIGERATED VANS		
Model Year	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies						
Bin I	5%	-	-	5%	-	-
Bin II	-	-	-	-	-	-
Bin III	30%	-	-	30%	-	-
Bin IV	60%	25%	-	60%	25%	-
Bin V	5%	10%	10%	5%	10%	20%
Bin VI	-	65%	50%	-	65%	60%
Bin VII	-	-	40%	-	-	20%
Bin VIII	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.4*	*0.8*	*1.1*	*0.4*	*0.8*	*1.0*
Trailer Tire Rolling Resistance						
Level 1 tires	15%	5%	5%	15%	5%	5%
Level 2 tires	85%	95%	-	85%	95%	-
Level 3 tires	-	-	95%	-	-	95%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*
Tire Inflation System						
ATI	85%	95%	95%	85%	95%	95%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*
Weight Reduction (pounds)						
Weight	*0*	*0*	*0*	*0*	*0*	*0*

Table 11-43 Alternative 4 Short Box Trailer Adoption Rates

TECHNOLOGY	SHORT BOX DRY VANS			SHORT BOX REFRIGERATED VANS		
Model Year	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies						
Bin I	100%	-	-	100%	-	-
Bin II	-	70%	30%	-	70%	55%
Bin III	-	30%	60%	-	30%	40%
Bin IV	-	-	10%	-	-	5%
Bin V	-	-	-	-	-	-
Bin VI	-	-	-	-	-	-
Bin VII	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.4*	*0.8*	*1.1*	*0.4*	*0.8*	*1.0*
Trailer Tire Rolling Resistance						
Level 1 tires	15%	5%	5%	15%	5%	5%
Level 2 tires	85%	95%	-	85%	95%	-
Level 3 tires	-	-	95%	-	-	95%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*
Tire Inflation System						
ATI	85%	95%	95%	85%	95%	95%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*
Weight Reduction (pounds)						
Weight	*0*	*0*	*0*	*0*	*0*	*0*

Table 11-44 Alternative 4 Non-Aero Box and Non-Box Trailer Adoption Rates

TECHNOLOGY	NON-AERO BOX & NON-BOX TRAILERS		
Model Year	2018	2021	2024
Aerodynamic Technologies			
Bin I	100%	100%	100%
Bin II	-	-	-
Bin III	-	-	-
Bin IV	-	-	-
Bin V	-	-	-
Bin VI	-	-	-
Bin VII	-	-	-
Bin VIII	-	-	-
Avg Delta CdA (m^2)	*0.0*	*0.0*	*0.0*
Trailer Tire Rolling Resistance			
Level 1 tires	-	-	-
Level 2 tires	100%	100%	-
Level 3 tires	-	-	100%
Avg CRR (kg/ton)	*5.1*	*5.1*	*4.7*
Tire Inflation System			
ATI	100%	100%	100%
Avg ATI Reduction (%)	1.5%	1.5%	1.5%
Weight Reduction (pounds)			
Weight	*0*	*0*	*0*

Table 11-45 Alternative 5 Box Trailer Adoption Rates

TECHNOLOGY	LONG BOX DRY VANS			LONG BOX REFRIGERATED VANS			SHORT BOX DRY & REFRIGERATED VANS		
Model Year	2018	2021	2024	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies									
Bin I	5%	-	-	5%	0%	0%	100%	-	-
Bin II	-	-	-	-	-	-	-	65%	10%
Bin III	5%	-	-	5%	-	-	-	25%	90%
Bin IV	55%	15%	-	55%	15%	-	-	-	-
Bin V	10%		-	10%	-	-	-	-	-
Bin VI	25%	85%	10%	25%	85%	100%	-	-	-
Bin VII	-	-	90%	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.6*	*0.9*	*1.4*	*0.6*	*0.9*	*1.0*	*0.0*	*0.1*	*0.3*
Trailer Tire Rolling Resistance									
Level 1 tires	15%	5%	5%	15%	5%	5%	15%	5%	5%
Level 2 tires	85%	95%	-	85%	95%	-	85%	95%	-
Level 3 tires	-	-	95%	-	-	95%	-	-	95%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*
Tire Inflation System									
ATI	85%	95%	95%	85%	95%	95%	85%	95%	95%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*
Weight Reduction (pounds)									
Weight	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Table 11-46 Alternative 5 Non-Box Trailer Adoption Rates

TECHNOLOGY	CONTAINER CHASSIS			FLATBED			TANKS			NON-AERO BOX & OTHER NON-BOX		
Model Year	2018	2021	2024	2018	2021	2024	2018	2021	2024	2018	2021	2024
Aerodynamic Technologies												
Bin I	100%	80%	30%	100%	80%	30%	100%	67%	0%	100%	100%	100%
Bin II	-	-	-	-	-	-	-	-	-	-	-	-
Bin III	-	20%	55%	-	20%	55%	-	33%	-	-	-	-
Bin IV	-	-	15%	-	-	15%	-	-	100%	-	-	-
Bin V	-	-	-	-	-	-	-	-	-	-	-	-
Bin VI	-	-	-	-	-	-	-	-	-	-	-	-
Bin VII	-	-	-	-	-	-	-	-	-	-	-	-
Bin VIII	-	-	-	-	-	-	-	-	-	-	-	-
Avg Delta CdA (m^2)	*0.0*	*0.1*	*0.2*	*0.0*	*0.1*	*0.2*	*0.0*	*0.1*	*0.5*	*0.0*	*0.0*	*0.0*
Trailer Tire Rolling Resistance												
Level 1 tires	15%	5%	5%	15%	5%	5%	15%	5%	5%	-	-	-
Level 2 tires	85%	95%	-	85%	95%	-	85%	95%	-	100%	100%	-
Level 3 tires	-	-	95%	-	-	95%	-	-	95%	-	-	100%
Avg CRR (kg/ton)	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*	*5.2*	*5.1*	*4.8*	*5.1*	*5.1*	*4.7*
Tire Inflation System												
ATI	85%	95%	95%	85%	95%	95%	85%	95%	95%	100%	100%	100%
Avg ATI Reduction (%)	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	*1.3%*	*1.4%*	*1.4%*	1.5%	1.5%	1.5%
Weight Reduction (pounds)												
Weight	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

11.3.3 Vocational Vehicle Technology

Table 11-47 Alternative 2 Technology Adoption Rates for All Vocational Subcategories

TECHNOLOGY	2021	2024
HFC Leakage	100%	100%
Axle - Low Friction Lubes	40%	75%
Baseline Drive Tire CRR	50%	30%
Baseline Steer Tire CRR	20%	10%
5% better Drive Tire CRR	50%	70%
10% better Steer Tire CRR	80%	60%
15% better Steer Tire CRR	0%	30%
Neutral-idle	43%	80%

Table 11-48 Alternative 3 Technology Adoption Rates for Vocational Subcategories: LHD, MHD, HHD Multipurpose & Urban

TECHNOLOGY	2021	2024	2027
Add Two Trans Gears	5%	5%	5%
HFC Leakage	100%	100%	100%
Axle - Low Friction Lubes	75%	75%	75%
Strong Hybrid	4%	7%	18%
Baseline Drive Tire CRR	50%	20%	10%
Baseline Steer Tire CRR	20%	10%	0%
5% better Drive Tire CRR	50%	50%	25%
10% better Drive Tire CRR	0%	30%	50%
10% better Steer Tire CRR	80%	30%	20%
15% better Drive Tire CRR	0%	0%	15%
15% better Steer Tire CRR	0%	60%	30%
20% better Steer Tire CRR	0%	0%	50%
Neutral-idle	70%	85%	30%
Stop-start	5%	15%	70%
Dual Clutch Transmission	5%	15%	5%
Trans_Improved	15%	30%	70%
200 Pounds Lightweighting	4%	4%	5%

Note:
[a] Idle reduction values in MY 2027 are for multipurpose vehicles. For Urban vehicles, Neutral Idle is 25% and Stop-Start is 75% in MY 2027.

Table 11-49 Alternative 3 Technology Adoption Rates for Vocational Subcategories: LHD & MHD Regional

TECHNOLOGY	2021	2024	2027
Add Two Trans Gears	5%	5%	5%
HFC Leakage	100%	100%	100%
Axle - Low Friction Lubes	75%	75%	75%
Baseline Drive Tire CRR	50%	20%	10%
Baseline Steer Tire CRR	20%	10%	0%
5% better Drive Tire CRR	50%	50%	25%
10% better Drive Tire CRR	0%	30%	50%
10% better Steer Tire CRR	80%	30%	20%
15% better Drive Tire CRR	0%	0%	15%
15% better Steer Tire CRR	0%	60%	30%
20% better Steer Tire CRR	0%	0%	50%
Neutral-idle	70%	85%	30%
Stop-start	5%	15%	70%
Dual Clutch Transmission	5%	15%	5%
Trans_Improved	15%	30%	70%
200 Pounds Lightweighting	7%	7%	8%

Note:
[a] Weight reduction values are given for LHD. For MHD, adoption rates are 6% in MYs 2021 & 2024, and 7% in MY 2027.

Table 11-50 Alternative 3 Technology Adoption Rates for Vocational Subcategories: HHD Regional

TECHNOLOGY	2021	2024	2027
HFC Leakage	100%	100%	100%
Axle 6x2	45%	60%	60%
Axle - Low Friction Lubes	75%	75%	75%
Baseline Drive Tire CRR	50%	20%	10%
Baseline Steer Tire CRR	20%	10%	0%
5% better Drive Tire CRR	50%	50%	25%
10% better Drive Tire CRR	0%	30%	50%
10% better Steer Tire CRR	80%	30%	20%
15% better Drive Tire CRR	0%	0%	15%
15% better Steer Tire CRR	0%	60%	30%
20% better Steer Tire CRR	0%	0%	50%
Automatic Transmission	22%	33%	25%
Stop-start	0%	15%	70%
Automated Manual Transmission	22%	33%	25%
Dual Clutch Transmission	22%	33%	25%
Trans_Improved	15%	30%	70%
200 Pounds Lightweighting	5%	5%	6%

Notes:
[a] Adoption rates of Automatic, AMT, and DCT transmissions include those that would certify using GEM plus those that would certify using the powertrain test as improved/integrated.

Table 11-51 Alternative 4 Technology Adoption Rates for Vocational Subcategories: LHD, MHD, HHD Multipurpose & Urban

Technology	2021	2024
Add Two Trans Gears	11%	10%
HFC Leakage	100%	100%
Axle - Low Friction Lubes	75%	75%
Strong Hybrid	9%	18%
Baseline Drive Tire CRR	50%	10%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	25%
10% better Drive Tire CRR	0%	50%
10% better Steer Tire CRR	80%	20%
15% better Drive Tire CRR	0%	15%
15% better Steer Tire CRR	0%	30%
20% better Steer Tire CRR	0%	50%
Neutral-idle	88%	30%
Stop-start	12%	70%
Dual Clutch Transmission	10%	10%
Trans_improved	25%	70%
200 Pounds Lightweighting	4%	5%

Note:
1 Idle reduction values in MY 2024 are for multipurpose vehicles. For Urban vehicles, Neutral Idle is 25% and Stop-Start is 75% in MY 2024.

Table 11-52 Alternative 4 Technology Adoption Rates for Vocational Subcategories: LHD & MHD Regional

TECHNOLOGY	2021	2024
Add Two Trans Gears	11%	10%
HFC Leakage	100%	100%
Axle - Low Friction Lubes	75%	75%
Baseline Drive Tire CRR	50%	10%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	25%
10% better Drive Tire CRR	0%	50%
10% better Steer Tire CRR	80%	20%
15% better Drive Tire CRR	0%	15%
15% better Steer Tire CRR	0%	30%
20% better Steer Tire CRR	0%	50%
Neutral-idle	88%	30%
Stop-start	12%	70%
Dual Clutch Transmission	10%	10%
Trans_improved	25%	70%
200 Pounds Lightweighting	7%	8%

Note:
1 Weight reduction values are given for LHD. For MHD, adoption rates are 6% in MY 2021 & 7% in MY 2024.

Table 11-53 Alternative 4 Technology Adoption Rates for Vocational Subcategories: HHD Regional

TECH	2021	2024
HFC Leakage	100%	100%
Axle 6x2	60%	60%
Axle - Low Friction Lubes	75%	75%
Baseline Drive Tire CRR	50%	10%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	25%
10% better Drive Tire CRR	0%	50%
10% better Steer Tire CRR	80%	20%
15% better Drive Tire CRR	0%	15%
15% better Steer Tire CRR	0%	30%
20% better Steer Tire CRR	0%	50%
Automatic Transmission	15%	25%
Stop-start	0%	70%
Automated Manual Transmission	15%	25%
Dual Clutch Transmission	15%	25%
Trans_improved	25%	70%
200 Pounds Lightweighting	5%	6%

Notes:
1 Adoption rates of Automatic, AMT, and DCT transmissions include those that would certify using GEM plus those that would certify using the powertrain test as improved/integrated.

Table 11-54 Alternative 5 Technology Adoption Rates for Vocational Subcategories: LHD Regional, LHD & HHD Multipurpose, LHD & HHD Urban

TECH	2021	2024
Add Two Trans Gears	16%	11%
HFC Leakage	100%	100%
Axle - Low Friction Lubes	100%	100%
Electric Vehicle	3%	3%
Strong Hybrid	27%	36%
Baseline Drive Tire CRR	50%	0%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	10%
10% better Drive Tire CRR	0%	45%
10% better Steer Tire CRR	80%	0%
15% better Drive Tire CRR	0%	45%
15% better Steer Tire CRR	0%	20%
20% better Steer Tire CRR	0%	80%
Neutral-idle	60%	40%
Stop-start	40%	60%
Dual Clutch Transmission	10%	5%
Trans_improved	35%	60%

Notes:
1 Strong Hybrid is zero for the LHD Regional subcategory

Table 11-55 Alternative 5 Technology Adoption Rates for Vocational Subcategories: MHD Regional, MHD Multipurpose, & MHD Urban

TECHNOLOGY	2021	2024
Add Two Trans Gears	16%	11%
HFC Leakage	100%	100%
Axle - Low Friction Lubes	100%	100%
Electric Vehicle	3%	3%
Strong Hybrid	27%	36%
Baseline Drive Tire CRR	50%	0%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	10%
10% better Drive Tire CRR	0%	45%
10% better Steer Tire CRR	80%	0%
15% better Drive Tire CRR	0%	45%
15% better Steer Tire CRR	0%	20%
20% better Steer Tire CRR	0%	80%
Neutral-idle	60%	40%
Stop-start	40%	60%
Dual Clutch Transmission	10%	5%
Trans_improved	35%	60%
1,000 Pounds Lightweighting	28%	42%

Note:
1 Strong Hybrid is zero for the MHD Regional subcategory

Table 11-56 Alternative 5 Technology Adoption Rates for Vocational Subcategories: HHD Regional

TECHNOLOGY	2021	2024
HFC Leakage	100%	100%
Axle_disconnect	61%	61%
Axle - Low Friction Lubes	100%	100%
Baseline Drive Tire CRR	50%	0%
Baseline Steer Tire CRR	20%	0%
5% better Drive Tire CRR	50%	10%
10% better Drive Tire CRR	0%	45%
10% better Steer Tire CRR	80%	0%
15% better Drive Tire CRR	0%	45%
15% better Steer Tire CRR	0%	20%
20% better Steer Tire CRR	0%	80%
Automatic Transmission	33%	33%
Stop-start	40%	60%
Automated Manual Transmission	33%	33%
Dual Clutch Transmission	33%	33%
Trans_improved	29%	34%

Note:
1 Adoption rates of Automatic, AMT, and DCT transmissions include those that would certify using GEM plus those that would certify using the powertrain test as improved/integrated.

11.3.4 Pickup and Van Technology

11.3.4.1 Pickup and Van Technology for Method A

This section describes the penetration of selected technologies across the whole fleet, as well as across the fleet of the manufacturers as a percentage of the respective fleet. The model year represented for the Method A technology penetration is 2030.

Table 11-57 presents the fleet profile for the total industry as well as for each manufacturer showing total sales of HD vans and pickups, as well as share of different vehicle types within that total.

Table 11-57 Fleet Profile for Model Year 2030 under Method A using the Dynamic Baseline

	Overall Fleet	Daimler	Fiat	Ford	General Motors	Nissan
Total Vehicles Sales	755,787	24,188	110,622	335,385	272,441	13,152
Van Share	39.3%	100.0%	20.6%	41.4%	35.9%	100.0%
Pickup Share	60.7%	0.0%	79.4%	58.6%	64.1%	0.0%
Gasoline Share	56.4%	0.0%	40.1%	57.8%	64.3%	100.0%
Diesel Share	43.6%	100.0%	59.9%	42.2%	35.7%	0.0%
Gasoline Van Share	32.3%	0.0%	17.2%	34.0%	35.9%	100.0%
Diesel Van Share	6.9%	100.0%	3.3%	7.4%	0.0%	0.0%
Gasoline Pickup Share	24.1%	0.0%	22.8%	23.7%	28.4%	0.0%
Diesel Pickup Share	36.6%	0.0%	56.6%	34.9%	35.7%	0.0%

Table 11-58 presents the total penetration rates for select technologies in 2030 for the entire fleet. Table 11-59 through

Table 11-63 present the penetration rates for the same technologies for each manufacturer.

Table 11-58 Technology Penetration Rates for the Overall Fleet in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	25%	56%	56%	49%	49%
Engine friction reduction	29%	94%	94%	87%	87%
Cylinder deactivation	10%	29%	21%	21%	21%
Variable valve timing	19%	19%	19%	19%	19%
Gasoline direct injection	14%	17%	25%	31%	32%
Turbo Machinery Improvements	38%	38%	38%	38%	53%
8 speed transmission	33%	67%	96%	96%	97%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	23%	78%	78%	75%
Mass reduction and materials	0%	36%	38%	65%	65%
Electric power steering	24%	50%	92%	78%	76%
Improved accessories	22%	23%	63%	58%	73%
Stop/start engine systems	0%	0%	0%	3%	14%
Mild hybrid	0%	0%	0%	12%	34%
Strong hybrid	0%	0%	8%	13%	16%

Table 11-59 Technology Penetration Rates for the Daimler in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	0%	0%	0%	0%	0%
Engine friction reduction	44%	44%	44%	44%	44%
Cylinder deactivation	0%	0%	0%	0%	0%
Variable valve timing	0%	0%	0%	0%	0%
Gasoline direct injection	0%	0%	0%	0%	0%
Turbo Machinery Improvements	44%	44%	44%	44%	44%
8 speed transmission	0%	0%	44%	44%	100%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	0%	0%	0%	0%
Mass reduction and materials	0%	0%	0%	0%	0%
Electric power steering	0%	0%	0%	0%	0%
Improved accessories	0%	0%	0%	0%	0%
Stop/start engine systems	0%	0%	0%	0%	0%
Mild hybrid	0%	0%	0%	0%	0%
Strong hybrid	0%	0%	0%	0%	0%

Table 11-60 Technology Penetration Rates for the Fiat in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	0%	40%	40%	40%	40%
Engine friction reduction	18%	97%	97%	97%	97%
Cylinder deactivation	13%	23%	23%	23%	23%
Variable valve timing	17%	17%	17%	17%	17%
Gasoline direct injection	0%	17%	17%	17%	17%
Turbo Machinery Improvements	57%	57%	57%	57%	57%
8 speed transmission	48%	65%	88%	88%	88%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	0%	100%	100%	79%
Mass reduction and materials	0%	0%	100%	100%	100%
Electric power steering	0%	0%	100%	100%	83%
Improved accessories	0%	0%	63%	63%	72%
Stop/start engine systems	0%	0%	0%	0%	0%
Mild hybrid	0%	0%	0%	0%	0%
Strong hybrid	0%	0%	3%	3%	12%

Table 11-61 Technology Penetration Rates for the Ford in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	0%	58%	58%	41%	41%
Engine friction reduction	0%	93%	93%	76%	76%
Cylinder deactivation	0%	18%	0%	0%	0%
Variable valve timing	34%	34%	34%	34%	34%
Gasoline direct injection	16%	16%	34%	34%	34%
Turbo Machinery Improvements	35%	35%	35%	35%	69%
8 speed transmission	59%	100%	100%	100%	100%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	0%	59%	59%	59%
Mass reduction and materials	0%	0%	0%	59%	59%
Electric power steering	0%	30%	90%	59%	59%
Improved accessories	0%	0%	66%	59%	59%
Stop/start engine systems	0%	0%	0%	0%	32%
Mild hybrid	0%	0%	0%	0%	8%
Strong hybrid	0%	0%	2%	12%	18%

Table 11-62 Technology Penetration Rates for the General Motors in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	64%	64%	64%	64%	64%
Engine friction reduction	64%	100%	100%	100%	100%
Cylinder deactivation	18%	47%	47%	47%	47%
Variable valve timing	0%	0%	0%	0%	0%
Gasoline direct injection	18%	18%	18%	36%	36%
Turbo Machinery Improvements	36%	36%	36%	36%	36%
8 speed transmission	0%	36%	100%	100%	100%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	64%	100%	100%	100%
Mass reduction and materials	0%	100%	64%	64%	64%
Electric power steering	66%	100%	100%	100%	100%
Improved accessories	61%	63%	69%	63%	100%
Stop/start engine systems	0%	0%	0%	9%	0%
Mild hybrid	0%	0%	0%	34%	82%
Strong hybrid	0%	0%	19%	20%	18%

Table 11-63 Technology Penetration Rates for the Nissan in Model Year 2030 under Method A using the Dynamic Baseline

	Alternative 1a (0% per year)	Alternative 2 2% per year	Alternative 3 (2.5% per year)	Alternative 4 (3.5% per year)	Alternative 5 (4% per year)
Low friction lubricants	100%	100%	100%	100%	100%
Engine friction reduction	100%	100%	100%	100%	100%
Cylinder deactivation	100%	49%	49%	49%	49%
Variable valve timing	100%	100%	100%	100%	100%
Gasoline direct injection	0%	51%	51%	51%	100%
Turbo Machinery Improvements	0%	0%	0%	0%	0%
8 speed transmission	0%	0%	51%	51%	51%
Low rolling resistance tires	100%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	0%	100%	100%	100%
Mass reduction and materials	0%	0%	0%	100%	100%
Electric power steering	0%	0%	100%	100%	100%
Improved accessories	0%	0%	0%	0%	28%
Stop/start engine systems	0%	0%	0%	0%	0%
Mild hybrid	0%	0%	0%	0%	27%
Strong hybrid	0%	0%	0%	0%	1%

11.3.4.2 Pickup and Van Technology for Method B

This section describes the penetration of selected technologies as separated by pickups and vans, as well as separated by fuel type (gasoline or diesel) using Method B. The model year represented for the technology penetration is 2030.

The technology mix that is projected to be sufficient to meet the 2025/27 standards for each pickup and van alternative in the Method B analysis is shown in Table 11-65 through Table 11-67.

Table 11-64 Technology Penetration Rates for Gasoline Pickups using Method B

	ALTERNATIVE 1A (0% PER YEAR)	ALTERNATIVE 2 2% PER YEAR	ALTERNATIVE 3 (2.5% PER YEAR)	ALTERNATIVE 4 (3.5% PER YEAR)	ALTERNATIVE 5 (4% PER YEAR)
Low friction lubricants	42%	100%	100%	100%	100%
Engine friction reduction	42%	100%	100%	100%	100%
Cylinder deactivation	8%	56%	56%	56%	56%
Variable valve timing	0%	56%	56%	56%	56%
Gasoline direct injection	0%	0%	0%	0%	0%
8 speed transmission	44%	86%	100%	100%	100%
Low rolling resistance tires	0%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	42%	100%	100%	100%
Mass reduction and materials	0%	42%	56%	100%	100%
Electric power steering	42%	86%	100%	100%	100%
Improved accessories	41%	41%	86%	86%	92%
Stop/start engine systems	0%	0%	0%	20%	7%
Mild hybrid	0%	0%	0%	18%	20%
Strong hybrid	0%	1%	25%	48%	66%

Table 11-65 Technology Penetration Rates for Gasoline Vans using Method B

	ALTERNATIVE 1A (0% PER YEAR)	ALTERNATIVE 2 2% PER YEAR	ALTERNATIVE 3 (2.5% PER YEAR)	ALTERNATIVE 4 (3.5% PER YEAR)	ALTERNATIVE 5 (4% PER YEAR)
Low friction lubricants	45%	100%	100%	100%	100%
Engine friction reduction	45%	100%	100%	100%	100%
Cylinder deactivation	23%	23%	23%	23%	23%
Variable valve timing	40%	40%	40%	40%	40%
Gasoline direct injection	42%	52%	77%	97%	100%
8 speed transmission	0%	95%	97%	97%	97%
Low rolling resistance tires	8%	60%	100%	60%	100%
Aerodynamic drag reduction	0%	40%	53%	53%	53%
Mass reduction and materials	0%	0%	8%	13%	13%
Electric power steering	3%	41%	55%	53%	53%
Improved accessories	0%	20%	7%	20%	42%
Stop/start engine systems	0%	0%	0%	2%	0%
Mild hybrid	0%	0%	0%	18%	38%
Strong hybrid	0%	0%	7%	0%	4%

Table 11-66 Technology Penetration Rates for Diesel Pickups using Method B

	ALTERNATIVE 1A (0% PER YEAR)	ALTERNATIVE 2 2% PER YEAR	ALTERNATIVE 3 (2.5% PER YEAR)	ALTERNATIVE 4 (3.5% PER YEAR)	ALTERNATIVE 5 (4% PER YEAR)
Low friction lubricants	0%	0%	0%	0%	0%
Engine friction reduction	0%	0%	0%	0%	0%
Turbo machinery improvements	75%	100%	100%	100%	100%
8 speed transmission	61%	97%	97%	97%	97%
Low rolling resistance tires	0%	100%	100%	100%	100%
Aerodynamic drag reduction	0%	35%	100%	100%	100%
Mass reduction and materials	0%	35%	58%	100%	100%
Electric power steering	35%	53%	100%	100%	100%
Improved accessories	33%	35%	100%	100%	100%
Stop/start engine systems	0%	0%	0%	11%	31%
Mild hybrid	0%	0%	0%	36%	47%
Strong hybrid	0%	0%	0%	0%	0%

Table 11-67 Technology Penetration Rates for Diesel Vans using Method B

	ALTERNATIVE 1A (0% PER YEAR)	ALTERNATIVE 2 2% PER YEAR	ALTERNATIVE 3 (2.5% PER YEAR)	ALTERNATIVE 4 (3.5% PER YEAR)	ALTERNATIVE 5 (4% PER YEAR)
Low friction lubricants	0%	0%	0%	0%	0%
Engine friction reduction	0%	0%	0%	0%	0%
Turbo machinery improvements	0%	20%	20%	20%	20%
8 speed transmission	0%	47%	67%	67%	93%
Low rolling resistance tires	7%	80%	54%	54%	100%
Aerodynamic drag reduction	0%	0%	7%	7%	7%
Mass reduction and materials	0%	0%	7%	7%	7%
Electric power steering	0%	11%	21%	12%	12%
Improved accessories	0%	0%	7%	7%	7%
Stop/start engine systems	0%	0%	0%	0%	0%
Mild hybrid	0%	0%	0%	0%	0%
Strong hybrid	0%	0%	0%	0%	0%

11.4 Numerical Standards Corresponding to Alternative Technology Scenarios

This section summarizes alternative EPA GHG and NHTSA fuel consumption standards corresponding to Alternatives 2, 4, and 5, including coefficients for the HD Pickup and Van alternative target curves. Note that the proposed standards correspond to Alternative 3.

11.4.1 Alternative 2 Vehicle Standards

Potential EPA GHG and NHTSA fuel consumption standards are shown for Alternative 2 in Table 11-68 to Table 11-71 and the coefficients for the HD Pickup and Van target curves for Alternative 2 are shown in Table 11-72.

Table 11-68 Alternative 2 Phase 2 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	305	194	205
Multi-Purpose	314	196	207
Regional	328	192	195
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	29.9468	19.0615	20.0969
Multi-Purpose	30.8574	19.2642	20.2999
Regional	32.1726	18.8587	19.1834
2024 and Later Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	296	187	198
Multi-Purpose	304	189	200
Regional	317	185	190
2024 and Later Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	29.0602	18.3233	19.4746
Multi-Purpose	29.8789	18.5280	19.6796
Regional	31.1068	18.2209	18.6547

Table 11-69 Alternative 2 Phase 2 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	330	210	221
Multi-Purpose	339	212	223
Regional	353	207	211
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	37.0853	23.5770	24.8811
Multi-Purpose	38.1283	23.8092	25.1137
Regional	39.7508	23.3446	23.7185
2024–2026 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	325	205	217
Multi-Purpose	334	207	219
Regional	348	204	208
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	36.5703	23.0998	24.4215
Multi-Purpose	37.6252	23.3344	24.6563
Regional	39.1490	22.9826	23.3648

Table 11-70 Alternative 2 Tractor Standards

2021 MODEL YEAR CO_2 GRAMS PER TON-MILE			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	102	82	73
Mid Roof	112	88	81
High Roof	114	90	80
2021 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	10.0196	8.055	7.1709
Mid Roof	11.0020	8.6444	7.9568
High Roof	11.1984	8.8409	7.8585
2024 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	97	77	68
Mid Roof	107	84	76
High Roof	109	85	74
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	9.5285	7.5639	6.6798
Mid Roof	10.5108	8.2515	7.4656
High Roof	10.7073	8.3497	7.2692

Table 11-71 Alternative 2 Trailer Standards

MODEL YEAR	SUBCATEGORY	DRY VAN		REFRIGERATED VAN	
	LENGTH	LONG	SHORT	LONG	SHORT
2018 – 2020	EPA Standard (CO_2 Grams per Ton-Mile)	83	147	84	151
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.1532	14.4401	8.2515	14.8330
2021 – 2023	EPA Standard (CO_2 Grams per Ton-Mile)	82	147	84	151
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.0550	14.4401	8.2515	14.8330
2024 – 2026	EPA Standard (CO_2 Grams per Ton-Mile)	81	147	83	151
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.9568	14.4401	8.1532	14.8330

Table 11-72 Alternative 2 HD Pickup and Van Standard Target Curve Coefficients

Diesel Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0416	320	0.0004086	3.143
2021	0.0408	313	0.0004008	3.075
2022	0.0400	307	0.0003929	3.016
2023	0.0392	301	0.0003851	2.957
2024	0.0384	295	0.0003772	2.898
2025 and later	0.0376	289	0.0003694	2.839
Gasoline Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0440	339	0.0004951	3.815
2021	0.0431	332	0.0004850	3.736
2022	0.0422	325	0.0004749	3.657
2023	0.0414	319	0.0004658	3.590
2024	0.0406	312	0.0004568	3.511
2025 and later	0.0398	306	0.0004478	3.443

Note:
[a] Phase 1 primary phase-in coefficients. Alternative phase-in coefficients are different in MY2018 only.

11.4.2 Alternative 4 Vehicle Standards

Potential EPA GHG and NHTSA fuel consumption standards are shown for Alternative 4 in Table 11-73 to Table 11-76 and the coefficients for the HD Pickup and Van target curves for Alternative 4 are shown in Table 11-77.

Table 11-73 Alternative 4 Phase 2 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	288	183	193
Multi-Purpose	297	185	196
Regional	309	181	185
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	28.3890	17.9764	18.8605
Multi-Purpose	29.0766	18.0747	18.9587
Regional	30.1572	17.6817	17.9764
2024 and Later Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	272	172	182
Multi-Purpose	280	174	183
Regional	292	170	174
2024 and Later Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	26.7191	16.8959	17.8782
Multi-Purpose	27.5049	17.0923	17.9764
Regional	28.6837	16.6994	17.0923

Table 11-74 Alternative 4 Phase 2 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	313	199	210
Multi-Purpose	323	201	212
Regional	336	197	201
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	35.2200	22.3923	23.6300
Multi-Purpose	36.3452	22.6173	23.8551
Regional	37.8080	22.1672	22.6173
2024 and Later Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	299	189	196
Multi-Purpose	308	191	198
Regional	321	187	188
2024 and Later Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	33.6446	21.2670	22.0547
Multi-Purpose	34.6574	21.4921	22.2797
Regional	36.1202	21.0420	21.1545

Table 11-75 Alternative 4 Tractor Standards

	DAY CAB		SLEEPER CAB
	Class 7	Class 8	Class 8
Low Roof	94	76	68
Mid Roof	104	82	76
High Roof	106	84	75
2021 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	9.2338	7.4656	6.6798
Mid Roof	10.2161	8.055	7.4656
High Roof	10.4126	8.2515	7.3674
2024 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	87	70	62
Mid Roof	96	76	69
High Roof	96	76	67
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.5462	6.8762	6.0904
Mid Roof	9.4303	7.4656	6.7780
High Roof	9.4303	7.4656	6.5815

Table 11-76 Alternative 4 Trailer Standards

MODEL YEAR	**SUBCATEGORY**	**DRY VAN**		**REFRIGERATED VAN**	
	LENGTH	**LONG**	**SHORT**	**LONG**	**SHORT**
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	83	144	84	147
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.1532	14.1454	8.2515	14.4401
2021 - 2023	EPA Standard (CO_2 Grams per Ton-Mile)	80	142	81	145
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.8585	13.9489	7.9568	14.2436
2024 - 2026	EPA Standard (CO_2 Grams per Ton-Mile)	77	140	80	144
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.5639	13.7525	7.8585	14.1454

Table 11-77 Alternative 4 HD Pickup and Van Standard Target Curve Coefficients

Diesel Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0416	320	0.0004086	3.143
2021	0.0402	308	0.0003949	3.026
2022	0.0388	298	0.0003811	2.927
2023	0.0374	287	0.0003674	2.819
2024	0.0361	277	0.0003546	2.721
2025 and later	0.0348	267	0.0003418	2.623
Gasoline Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0440	339	0.0004951	3.815
2021	0.0425	327	0.0004782	3.680
2022	0.0410	315	0.0004613	3.545
2023	0.0395	304	0.0004445	3.421
2024	0.0381	294	0.0004287	3.308
2025 and later	0.0368	283	0.0004141	3.184

Note:
[a] Phase 1 primary phase-in coefficients. Alternative phase-in coefficients are different in MY2018 only.

11.4.3 Alternative 5 Vehicle Standards

Potential EPA GHG and NHTSA fuel consumption standards are shown for Alternative 4 in Table 11-78 to Table 11-81 and the coefficients for the HD Pickup and Van target curves for Alternative 5 are shown in Table 11-82.

Table 11-78 Alternative 5 Phase 2 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	292	185	194
Multi-Purpose	300	186	196
Regional	313	183	185
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	32.8863	20.7809	21.8523
Multi-Purpose	33.8112	20.9856	22.0566
Regional	35.2499	20.5761	20.8312
2024 and Later Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	278	175	185
Multi-Purpose	286	177	186
Regional	298	174	177
2024 and Later Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	31.2817	19.7042	20.7621
Multi-Purpose	32.1840	19.9043	20.9617
Regional	33.4874	19.6042	19.8637

Table 11-79 Alternative 5 Phase 2 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	292	185	194
Multi-Purpose	300	186	196
Regional	313	183	185
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	32.8863	20.7809	21.8523
Multi-Purpose	33.8112	20.9856	22.0566
Regional	35.2499	20.5761	20.8312
2024 and Later Model Year CO_2 Grams per Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	278	175	185
Multi-Purpose	286	177	186
Regional	298	174	177
2024 and Later Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Class 2b-5)	**MHD (Class 6-7)**	**HHD (Class 8)**
Urban	31.2817	19.7042	20.7621
Multi-Purpose	32.1840	19.9043	20.9617
Regional	33.4874	19.6042	19.8637

Table 11-80 Alternative 5 Tractor Standards

	DAY CAB		SLEEPER CAB
	Class 7	Class 8	Class 8
Low Roof	87	70	63
Mid Roof	96	75	71
High Roof	98	77	70
2021 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.5462	6.8762	6.1886
Mid Roof	9.4303	7.3674	6.9745
High Roof	9.6267	7.5639	6.8762
2024 Model Year CO_2 Grams per Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	82	65	58
Mid Roof	91	71	64
High Roof	92	72	63
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	Day Cab		Sleeper Cab
	Class 7	Class 8	Class 8
Low Roof	8.0550	6.3851	5.6974
Mid Roof	8.9391	6.9745	6.2868
High Roof	9.0373	7.0727	6.1886

Table 11-81 Alternative 5 Trailer Standards

MODEL YEAR	SUBCATEGORY	DRY VAN		REFRIGERATED VAN	
	LENGTH	LONG	SHORT	LONG	SHORT
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	82	144	83	147
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	8.0550	14.1454	8.1532	14.4401
2021 - 2023	EPA Standard (CO_2 Grams per Ton-Mile)	79	142	81	145
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.7603	13.9489	7.9568	14.2436
2024 - 2026	EPA Standard (CO_2 Grams per Ton-Mile)	76	140	80	143
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.4656	13.7525	7.8585	14.0472

Table 11-82 Alternative 5 HD Pickup and Van Standard Target Curve Coefficients

Diesel Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0416	320	0.0004086	3.143
2021	0.0400	307	0.0003929	3.016
2022	0.0384	295	0.0003772	2.898
2023	0.0368	283	0.0003615	2.780
2024	0.0354	271	0.0003477	2.662
2025 and later	0.0339	261	0.0003330	2.564
Gasoline Vehicles				
Model Year	a	b	c	d
2018-2020 [a]	0.0440	339	0.0004951	3.815
2021	0.0422	325	0.0004749	3.657
2022	0.0405	312	0.0004557	3.511
2023	0.0389	300	0.0004377	3.376
2024	0.0374	288	0.0004208	3.241
2025 and later	0.0359	276	0.0004040	3.106

Note:
[a] Phase 1 primary phase-in coefficients. Alternative phase-in coefficients are different in MY2018 only.

11.4.4 Alternative Engine Standards

The alternative standards the agencies considered for heavy-duty tractor engines are provided in Table 11-83.

Table 11-83 Alternative Heavy-Duty Tractor Engine Standards over the SET Cycle

MODEL YEAR	STANDARDS	ALTERNATIVE 2		ALTERNATIVE 4		ALTERNATIVE 5	
		MHD	HHD	MHD	HHD	MHD	HHD
2021 – 2023	EPA Standard (CO_2 Grams per Ton-Mile)	481	455	477	451	474	448
	NHTSA Standard (Gallons per 100 Ton-Mile)	4.7250	4.4695	4.6857	4.4303	4.6562	4.4008
2024 and Later	EPA Standard (CO_2 Grams per Ton-Mile)	471	445	466	441	464	438
	NHTSA Standard (Gallons per 100 Ton-Mile)	4.6267	4.3713	4.5776	4.3320	4.5580	4.3026

Table 11-84 presents the alternative CO_2 and fuel consumption standards the agencies considered for compression-ignition engines to be installed in vocational vehicles. As with the proposed standards, the first set of alternative standards would take effect with MY 2021, and the second set would take effect with MY 2024.

Table 11-84 Alternative Vocational Diesel Engine Standards over the Heavy-Duty FTP Cycle

MODEL YEAR	STANDARD	LIGHT HEAVY-DUTY DIESEL	MEDIUM HEAVY-DUTY DIESEL	HEAVY HEAVY-DUTY DIESEL
Alternative 2				
2021-2023	CO_2 Standard (g/bhp-hr)	571	571	550
	Fuel Consumption Standard (gallon/100 bhp-hr)	5.6090	5.6090	5.4028
2024 and Later	CO_2 Standard (g/bhp-hr)	559	559	539
	Fuel Consumption (gallon/100 bhp-hr)	5.4912	5.4912	5.2947
Alternative 4				
2021-2023	CO_2 Standard (g/bhp-hr)	562	562	541
	Fuel Consumption Standard (gallon/100 bhp-hr)	5.5206	5.5206	5.3143
2024 and Later	CO_2 Standard (g/bhp-hr)	553	553	533
	Fuel Consumption (gallon/100 bhp-hr)	5.4322	5.4322	5.2358
Alternative 5				
2021-2023	CO_2 Standard (g/bhp-hr)	559	559	538
	Fuel Consumption Standard (gallon/100 bhp-hr)	5.4912	5.4912	5.2849
2024 and Later	CO_2 Standard (g/bhp-hr)	550	550	530
	Fuel Consumption (gallon/100 bhp-hr)	5.4028	5.4028	5.2063

References

[1] OMB Circular A-4, September 17, 2003. Available at http://www.whitehouse.gov/omb/circulars_a004_a-4.
[2] NEPA requires agencies to consider a "no action" alternative in their NEPA analyses and to compare the effects of not taking action with the effects of the reasonable action alternatives to demonstrate the different environmental effects of the action alternatives. *See* 40 CFR 1502.2(e), 1502.14(d).CEQ has explained that "[T]he regulations require the analysis of the no action alternative even if the agency is under a court order or legislative command to act. This analysis provides a benchmark, enabling decision makers to compare the magnitude of environmental effects of the action alternatives. [*See* 40 CFR 1502.14(c).] * * * Inclusion of such an analysis in the EIS is necessary to inform Congress, the public, and the President as intended by NEPA. [*See* 40 CFR 1500.1(a).]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026 (1981) (emphasis added).
[3] http://energy.gov/eere/vehicles/vehicle-technologies-office-21st-century-truck
[4] http://www.epa.gov/smartway/
[5] State of California Global Warming Solutions Act of 2006 (Assembly Bill 32, or AB32)
[6] Confidence Report: Idle-Reduction Solutions, North American Council for Freight Efficiency, Lee, Tessa, 2014, p. 13.
[7] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," (hereafter, "NAS 2010"). Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (last accessed September 10, 2010).
[8] Note that the "CO_2 emission rates" for tractors and vocational vehicles reflect changes in CO_2 emissions not represented by tire rolling resistance, aerodynamic drag, or vehicle weight.
[9] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).
[10] Vocational tractors are included in the short-haul tractor segment.
[11] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles under 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).
[12] Vocational tractors are included in the short-haul tractor segment.
[13] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).
[14] Vocational tractors are included in the short-haul tractor segment.
[15] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).
[16] Vocational tractors are included in the short-haul tractor segment.

[17] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles under 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

[18] Vocational tractors are included in the short-haul tractor segment.

Chapter 12: Initial Regulatory Flexibility Analysis

This chapter discusses the agencies' Initial Regulatory Flexibility Analysis (IRFA) that evaluates the potential impacts of the proposed standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Pursuant to this requirement, we have prepared an IRFA for the proposed rule. Throughout the process of developing the IRFA, EPA conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking to gain feedback, including recommendations, on how to reduce the impact of the rule on these entities. The small business recommendations stated here reflect the comments of the small entity representatives (SERs) and members of the Small Business Advocacy Review Panel (SBAR Panel, or 'the Panel'). NHTSA maintains obligations to evaluate small business impacts under the Regulatory Flexibility Act, but is not required to convene a SBAR Panel. As a joint rulemaking, EPA and NHTSA have coordinated formulation of standards, including flexibilities for small businesses.

12.1 Overview of the Regulatory Flexibility Act

In accordance with Section 609(b) of the Regulatory Flexibility Act (RFA), EPA convened an SBAR Panel before conducting the IRFA. A summary of the Panel's recommendations is presented in the preamble of this proposed rulemaking. Further detailed discussion of the Panel's outreach, advice and recommendations is found in the Final Panel Report contained in the docket for this proposed rulemaking.[1]

Section 609(b) of the RFA directs the Panel to report on the comments of small entity representatives and make findings on issues related to elements of an IRFA under Section 603 of the RFA. Those elements of an IRFA are:

- A description of, and where feasible, an estimate of the number of small entities to which the proposed rule will apply;
- A description of projected reporting, record keeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record;
- An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the proposed rule;
- A description of any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the proposed rule on small entities.

The RFA was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although EPA is not required by the Clean Air Act to provide special treatment to small businesses, the RFA requires EPA and NHTSA to carefully consider the economic impact that our rules will have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with the Clean Air Act requirements.

12.2 Need for Rulemaking and Rulemaking Objectives

Heavy-duty vehicles are classified as those with gross vehicle weight ratings (GVWR) of greater than 8,500 lb. Section 202(a) of the Clean Air Act (CAA) requires EPA to promulgate emission standards for pollutant emissions from new motor vehicles and engines which emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. In 2009, EPA found that six greenhouse gases (GHGs) were anticipated to endanger public health or welfare, and that new motor vehicles and new motor vehicle engines contribute to that pollution which endangers. As explained in preamble section I, the D.C. Circuit upheld this endangerment finding, and further held that EPA had a mandatory duty to promulgate standards for emissions of the pollutant which contributes to the endangerment: GHGs from new motor vehicles and engines.

The Energy and Security Independence Act of 2007 (EISA) directs NHTSA to develop regulations to increase fuel efficiency for commercial medium-duty and heavy-duty on-highway vehicles and work trucks. Fundamentally, EISA seeks energy conservation. In 2010, total fuel consumption and GHG emissions from medium- and heavy-duty vehicles accounted for 23 percent of total U.S. transportation-related GHG emissions.

EPA and NHTSA's Phase 1 Heavy-Duty Engines and Vehicles Program, which was finalized in September 2011 (76 FR 57106), marked the first greenhouse gas emissions and fuel efficiency standards for heavy-duty vehicles and engines. The program addressed medium- and heavy-duty GHG emissions and fuel efficiency through the adoption of performance-based standards that allow manufacturers to determine the optimal mix of technologies to achieve the necessary reductions for their vehicle fleets and engines.

Building on the Phase 1 rule, this proposed Phase 2 rule would reduce GHG emissions and fuel consumption associated with the transportation of goods across the United States post-2017. The proposed Phase 2 rulemaking considers changes to existing engine, GHG, and fuel efficiency standards, as well as regulatory standards and certification requirements for previously-unregulated new trailers pulled by semi-tractors. If such a rule is adopted, manufacturers of heavy-duty engines, chassis, vehicles and trailers could be required to incorporate GHG-reducing and fuel-saving technologies in order to comply with the agencies' performance-based standards.

12.3 Definition and Description of Small Businesses

The RFA defines small entities as including "small businesses," "small governments," and "small organizations" (5 USC 601) and references the Small Business Act for the definition of "small businesses" using size standards based on the North American Industry Classification System (NAICS) (13 CFR 121.201). The standards being considered by EPA for this rulemaking are expected to affect a variety of small businesses. A listing of the NAICS codes identified as relevant to the potential rulemaking, along with their respective SBA size thresholds, is located in Table 12-1, below.

The agencies expect that the same industries affected by the Phase 1 rulemaking will also be affected by the proposed Phase 2 rulemaking. In addition, small businesses and trailer manufacturers are also included in the proposed Phase 2 rule. EPA and NHTSA used the criteria for small entities developed by the Small Business Administration (SBA) as a guide to identifying Small Entity Representatives (SERs) for this proposed rulemaking. Table 12-1 lists industries potentially directly affected by the regulation. The NAICS Code and size threshold are shown as well.

Table 12-1 Industry Sectors Potentially Affected by the Agencies' Planned Action

INDUSTRY EXPECTED IN RULEMAKING	NAICS CODE	NAICS DESCRIPTION	SBA SIZE THRESHOLD
Alternative Fuel Engine Converters	333999	Misc. General Purpose Machinery	500 employees
	811198	All Other Auto Repair & Maintenance	$7.0M (annual receipts)
HD Pick-up Trucks & Vans	336111	Automobile Manufacturing	1,000 employees
Vocational Chassis, Class 7 & 8 Tractors	336120	Heavy-Duty Truck Manufacturing	1,000 employees
Trailers	336212	Truck Trailer Manufacturing	500 employees
	333924	Ind. Truck, Trailer & Stacker Machinery	750 employees
HD Engines	336310	Motor Vehicle Gasoline Engine & Engine Parts	750 employees

12.4 Summary of Small Entities to which the Rulemaking will Apply

Using the information from Table 12-1, with the agencies' certification data and employment information from the Hoover's online business information database, EPA and NHTSA determined that only three of these affected industries contained small businesses: vocational chassis manufacturers, alternative fuel engine converters, and trailer manufacturers, as described below. The agencies believe there are about 115 trailer manufacturers and 100 of these manufacturers qualify as small entities with 500 employees or less. EPA and NHTSA identified 21 alternative fuel engine converters from previous certification data and 18 of these converters are considered small entities. Currently, 20 manufacturers that make chassis for vocational vehicles certify with EPA under the Phase 1 program. Three vocational chassis manufacturers contacted EPA and NHTSA to request an exemption from Phase 1 based on their small entity status. Gliders are a subset of vehicles being considered for regulation under the proposed Phase 2 rulemaking (including for regulation of criteria pollution emissions). Glider manufacturers traditionally manufacture new vehicle bodies (vocational vehicles or Class 7 and 8 tractors) for use with older powertrains. The agencies are aware of four glider manufacturers and three are small entities.

12.5 Related Federal Rules

The Phase 1 rulemaking continues to be in effect in the absence of this proposed rule. The Panel noted that it was aware that the proposed Phase 2 rule would be a joint action by EPA and Department of Transportation (DOT), through NHTSA, as was done in the Phase 1 rulemaking. The Panel is also aware of several other state and Federal rules related to heavy-duty vehicles and to the proposed Phase 2 rule under consideration. NHTSA has safety requirements for medium- and heavy-duty vehicles located at 49 CFR 571. California adopted its own greenhouse gas initiative, which places aerodynamic requirements on trailers used in long-haul applications. None of these existing regulations were found to conflict with the proposed rulemaking.

12.6 Projected Reporting, Recordkeeping, and Other Compliance Requirements

For any emission control program, EPA must have assurances that the regulated products will meet the standards. The program that EPA and NHTSA are considering for manufacturers subject to this proposal will include testing, reporting, and recordkeeping requirements. Testing requirements for these manufacturers could include use of EPA's Greenhouse gas Emissions Model (GEM) vehicle simulation tool to obtain the overall CO_2 emissions rate for certification of vocational chassis and trailers, aerodynamic testing to obtain aerodynamic inputs to GEM for some trailer manufacturers, and engine dynamometer testing for alternative fuel engine converters to ensure their conversions meet the proposed CO_2, CH_4 and N_2O engine standards. Reporting requirements would likely include emissions test data or model inputs and results, technical data related to the vehicles, and end-of-year sales information. Manufacturers would have to keep records of this information.

12.7 Regulatory Flexibilities

The Panel developed a range of regulatory flexibilities intended to mitigate the impacts of the proposed rulemaking on small businesses, and recommended that EPA propose and seek comment on the flexibilities. The Panel's findings and discussions are based on the information that was available during the term of the Panel and issues that were raised by the SERs during the outreach meetings and in their written comments. It was agreed that EPA should consider the issues raised by the SERs (and issues raised in the course of the Panel) and that EPA should consider the comments on flexibility alternatives that would help to mitigate any negative impacts on small businesses.

Alternatives discussed throughout the Panel process include those offered in the development of the upcoming rule. Though some of the recommended flexibilities may be appropriate to apply to all entities affected by the rulemaking, the Panel's discussions and recommendations are focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations, along with those provisions that we are actually proposing in this action, are detailed below. A full discussion of the regulatory alternatives and hardship provisions discussed and recommended by the Panel, all written comments received from SERs, and summaries of the two outreach meetings that were held with the SERs can be found in the SBREFA Final Panel Report.[2] In addition, all of the flexibilities that are being proposed in the rulemaking for small businesses, as well as those for all entities that may be affected by the rulemaking, are described in the preamble to the proposed rule.

12.7.1 **Alternative Fuel Engine Converter Flexibilities**

12.7.1.1 SBAR Panel Recommendations

To reduce the compliance burden of small business engine converters who convert engines in previously-certified complete vehicles, the Panel recommended allowing engine compliance to be sufficient for certification. This would mean the converted vehicle would not need to be recertified *as a vehicle.* This flexibility would eliminate the need for these small manufacturers to gather all of the additional component-level information (e.g., transmission data, aerodynamic performance, tire rolling resistance) in addition to the engine CO_2 performance necessary to properly certify a vehicle with GEM. In addition, the Panel recommended that small engine converters be able to submit an engineering analysis, in lieu of measurement, to show that their converted engines do not increase N_2O emissions. Many of the small engine converters are converting SI-engines, and the catalysts in these engines are not expected to substantially impact N_2O production. Small engine converters that convert CI-engines could likely certify by ensuring that their controls require changes to the SCR dosing strategies.

Based on the comments received from SERs, the Panel recommended not having separate standards for small business natural gas engine manufacturers. The Panel believed this would discourage entrance into this emerging market by adding unnecessary costs to a technology that has the potential to reduce CO_2 tailpipe emissions. In addition, the Panel stated that it believes additional leakage requirements beyond a sealed crankcase for small business natural gas-fueled CI engines and requirements to follow industry standards for leakage could be waived for small businesses with minimal impact on overall GHG emissions.

Finally, the Panel recommended that small engine converters receive a one-year delay in implementation for each increase in stringency throughout the proposed rule. This flexibility would provide small converters additional lead time to obtain the necessary equipment and perform calibration testing if needed.

12.7.1.2 The Agencies' Proposed Regulatory Flexibility Options

The agencies have chosen to propose the Panel's recommended regulatory flexibility provisions for alternative fuel engine converters. EPA and NHTSA are proposing to offer small business engine converters a one year delay in implementation for each increase in stringency throughout the proposed rule. In addition, small businesses that convert complete vehicles will be able to use an engine-only certification of their final vehicles. Finally, the agencies are proposing to allow small business engine converters to use an engineering analysis approach to show that their converted engines do not impact N_2O production.

12.7.2 **Vocational Vehicle Chassis Manufacturer Flexibilities**

12.7.2.1 SBAR Panel Recommendations

The Panel recommended proposing less stringent standards for emergency vehicle chassis manufactured by small businesses. The Panel stated that it believes it is feasible for small manufacturers to install a Phase 2-compliant engine, but recommended that the rulemaking request comment on whether the use of LLR tires will provide enough CO_2 benefits to justify requiring small business emergency chassis manufacturers to adopt them. In addition, the Panel recommended a simplified certification approach for small manufacturers who make chassis for emergency vehicles that reduces the number of inputs these manufacturers would need to obtain for GEM.

The Panel recommended proposing a low volume exemption for small business custom chassis manufacturers based on the volume of sales. Similar to the recommendation for emergency vehicle chassis manufacturers, the Panel stated it believes it is feasible to require installation of a Phase 2-compliant engine and recommended that EPA request comment on the benefits of LRR tires in this market segment. The Panel also recommended that the rulemaking request comment on how to design a small business exemption by means of a volume exemption and what sales volume would be an appropriate threshold.

The Panel stated that it believes that the number of vehicles produced by small business glider manufacturers is too small to have a substantial impact on the total heavy-duty inventory. The Panel also stated that there should be an allowance to produce some number of glider kits for legitimate purposes, such as for newer vehicles badly damaged in crashes. The Panel therefore recommended proposing an explicit allowance for existing small businesses to continue assembling glider vehicles without having to comply with the GHG requirements. The Panel also recommended that any regulations for glider production be flexible enough to allow sales levels as high as the peak levels in the 2010-2012 timeframe.

12.7.2.2 EPA and NHTSA's Proposed Regulatory Flexibility Options

EPA and NHTSA are proposing a flexibility for all emergency vehicles that includes fewer technology requirements and a simplified certification approach. The agencies are also requesting comment on an appropriate low volume threshold for custom chassis manufacturers that would allow them to opt into a standard that has fewer technology requirements. The exemption that the agencies are proposing for glider manufacturers is expected to encompass small glider manufacturers. See Section XIV of the NPRM preamble for additional details.

12.7.3 **Trailer Manufacturer Flexibilities**

12.7.3.1 SBAR Panel Recommendations

Box Trailers

Box trailer manufacturers have the benefit of relying on the aerodynamic technology development initiated through EPA's voluntary SmartWay program. The Panel acknowledged EPA's plan to propose a simplified compliance program for all manufacturers, in which aerodynamic device manufacturers have the opportunity to test and register their devices with EPA as technologies that can be used by trailer manufacturers in their trailer certification. This pre-approved technology strategy is intended to provide all trailer manufactures a means of complying with the standards without testing. Upon the completion of the SBREFA Panel process, it was unclear if this strategy would be available indefinitely, or if it would be an interim flexibility to allow manufacturers to ease into a testing-only compliance program. The Panel recommended that, in the event that this strategy is limited to the early years of the trailer program for all manufacturers, small manufacturers should continue to be given the option to use pre-approved devices in lieu of testing.

The Panel stated its belief that, in the event that small trailer manufacturers adopt pre-approved aerodynamic technologies and the appropriate tire technologies for compliance, it would not be necessary to require the use of a vehicle emissions model, such as GEM, for certification. Instead, the Panel stated that it could be possible for manufacturers to simply report to EPA that all of their trailers include approved technologies.

Non-Box Trailers

The Panel recommended that EPA not base a standard for non-box trailers on performance of aerodynamic devices. Some of the non-box trailer manufacturer SERs have seen prototype-level demonstrations of aerodynamic devices on non-box trailers. However, most non-box trailer SERs identified unique operations in which their trailers are used that preclude the use of those technologies.

Some non-box trailer manufacturers have experience with LRR tires and ATI systems. However, the non-box trailer manufacturer SERs indicated that LRR tires are not currently available for some of their trailer types. The SERs noted that tire manufacturers are currently focused on box trailer applications and that there are only a few LRR tire models that meet the needs of their customers. The Panel stated that it believes EPA should ensure appropriate availability of these tires in order for it to be deemed a feasible means of achieving these standards and recommends a streamlined compliance process based on the availability of technologies. The Panel suggested that the best compliance option from a small business perspective would be for the agencies to pre-approve tires once they are available in sufficient quantities on the market, similar to the approach being proposed for aerodynamic technologies, and to maintain a list that could be used to exempt small businesses when no suitable tires are available. However, the Panel stated that it recognizes the difficulties of maintaining an up-to-date list of certified technologies. The Panel recommended that, if the rulemaking does not adopt the list-based approach, the agency consider a simplified letter-based compliance option that allows manufacturers to petition the agencies for an exemption if they are unable to identify tires that meet the LRR performance requirements on a trailer family basis.

Trailers with Unique Use Patterns

The Panel recommended excluding all trailers that spend a significant amount of time in off-road applications. These trailers may not spend much time at highway speeds and aerodynamic devices may interfere with the vehicle's intended purpose. Additionally, tires with lower rolling resistance may not provide the type of traction needed in off-road applications.

General Flexibilities for All Small Trailer Manufacturers

The Panel stated that it recognizes that some manufacturers, who have diverse product lines and high sales volumes, may benefit from an emissions averaging, banking and trading (ABT) strategy. However, due to the custom-order nature of the trailer industry, SERs have expressed their concern that ABT may provide an opportunity for historically loyal customers or customers with large fractions of a manufacturer's business to bargain for the portion of a manufacturer's sales that have minimal requirements. Based on the low volume of sales and niche market of many small business trailer manufacturers, small businesses in particular may have little leverage in this situation and risk losing their customers to larger manufacturers who have credits to spare. In addition, the accounting and reporting burdens of ABT may preclude small businesses from participating in the flexibility.

Due to the potential for reducing a small business's competitiveness compared to the larger manufacturers, as well as the ABT recordkeeping burden, the Panel recommended EPA consider small business flexibilities to allow small entities to opt out of ABT without placing themselves at a competitive disadvantage to larger firms that adopt ABT, such as a low volume exemption or requiring only LRR where appropriate. The Panel recommended that EPA should also consider flexibilities for small businesses that would ease and incentivize their participation in ABT, such as streamlined the tracking requirements for small businesses. In addition, the Panel recommended that the rulemaking request comment on the feasibility and consequences of ABT for the trailer program and additional flexibilities that would promote small business participation.

In addition, for all trailer types that will be included in the proposal, the Panel recommended a 1-year delay in implementation for small trailer manufacturers at the start of the proposed rulemaking to allow them additional lead time to make the proper staffing adjustments and process changes and possibly add new infrastructure to meet these requirements. In the event that the agencies are unable to provide pre-approved technologies for manufacturers to choose for compliance, the Panel recommended that the standards provide small business trailer manufacturers an additional 1-year delay for each subsequent increase in stringency. This additional lead time would allow these small businesses to research and market the technologies required by the new standards.

12.7.3.2 The Agencies' Proposed Regulatory Flexibility Options

The agencies are proposing many of the Panel's recommendations for small business trailer manufacturers, including seeking comment on the possibility of a small volume exemption. While many of the smallest trailer manufactures sell significantly fewer trailers than the largest small manufacturers, many of the smallest trailer manufacturers produce specialty trailers that are already candidates for exemption under the proposed off-highway or heavy-haul provisions described in Section IV C. (5) of the preamble to this rulemaking.

Testing requirements for small businesses are largely reduced by provisions outlined in the program for both large and small trailer manufacturers. Tire rolling resistance is measured by tire manufacturers and information needed for compliance would be presented to trailer manufacturers when they purchase their tires. The agencies are also proposing an option for pre-approved aerodynamic device data to be made available to trailer manufacturers for use in complying with aerodynamic requirements. These pre-approved devices would eliminate the requirement for trailer manufacturers to complete aerodynamic performance testing for certification. A majority of the small trailer manufacturers produce non-box trailers, the proposed standards for which are not predicated on use of aerodynamic controls, which reduces the number of technologies to investigate, market, and implement. EPA and NHTSA expect the six small business box trailer manufacturers the agencies have identified will take advantage of the pre-approved aerodynamic devices for most of their trailers.

Additionally, the agencies are proposing a simplified compliance program with options to demonstrate trailer performance without requiring the trailer manufacturers to perform vehicle modeling using GEM. Instead, the agencies have developed a GEM-based equation for each box trailer subcategory that reproduces the CO_2 results of the vehicle model. The standards proposed for non-box trailer manufacturers would require the use of LRR tires and ATI systems, and these manufacturers would not need to evaluate the performance those technologies using GEM. As a result, no trailer manufacturers would use GEM for compliance in this proposal. For the small business trailer manufacturers that produce trailers that are regulated in this program, EPA is offering a one-year implementation delay at the beginning of the program what will allow small business trailer manufacturers to demonstrate compliance starting in model year 2019. This provision will allow small businesses additional lead time to make the proper staffing adjustments and process changes and possibly add new infrastructure to meet their requirements.

For the proposed standards, small business trailer manufacturers would already be required to comply with EPA standards when NHTSA's fuel efficiency standards would begin. Therefore, NHTSA does not believe that an additional year of delay to comply with its fuel efficiency standards would provide beneficial flexibility.

12.8 Projected Economic Effects of the Proposed Rulemaking

This section summarizes the economic impact on small businesses of the proposed Phase 2 rulemaking. To gauge the impact of the proposed standards on small businesses, the agencies employed a cost-to-sales ratio test to if small businesses would be impacted by less than one percent, between one and three percent, and above three percent of their sales. The costs used in this analysis for the proposed requirements are based on the cost estimates developed in Chapter 7 of this Draft RIA.

Based on our current analysis, EPA and NHTSA believe that small business trailer sales range from 1 to 63 million dollars. As presented in Chapter 7 of this Draft RIA, costs for trailer manufacturers range between 95 and 340 thousand dollars, which is greater than a one percent impact for most of the small trailer manufacturers. However, these projected costs do not account for the small business flexibilities, which we believe will reduce costs for a majority of the small trailer manufacturers to less than three percent of their sales. Additionally, many of the smallest manufacturers who see revenues below two million dollars produce specialty trailers that meet the criteria for exemption from the proposed standards.

We believe that small businesses in the alternative fuel engine converter sector will be able to comply with the agencies' proposed regulations with minimal incremental cost compared to their current costs for compliance with EPA's criteria pollutant programs. As such, at this time, we believe they will be impacted at less than one percent of their current annual sales. All of the vocational vehicle chassis manufacturers that EPA and NHTSA are aware of at this time are eligible for exemptions outlined in Section V B. (4), and the agencies believe they would be impacted at less than one percent of their sales.

For a complete discussion of the economic impacts of the proposed rulemaking, see Chapter 8 of this Draft Regulatory Impact Analysis.

References

[1] Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 2. Signed on January 15, 2015. Available in docket at: EPA–HQ–OAR–2014–0827

[2] Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 2. Signed on January 15, 2015. Available in docket at: EPA–HQ–OAR–2014–0827

Chapter 13: Natural Gas Vehicles and Engines

13.1 Detailed Life-Cycle Analysis

We conducted a review to assess the lifecycle impacts of natural gas used by the heavy-duty truck sector. We also present the results of an analysis by the Energy Information Administration projecting the future use of natural gas by heavy-duty trucks. Finally, we list a number of potential technologies which could help to reduce the methane emissions from natural gas trucks.

13.1.1 **Upstream Emissions**

Upstream methane emissions, occurring in the natural gas production, natural gas processing, transmission, storage and distribution sectors, are estimated and summarized in an annual report “Inventory of U.S. Greenhouse Gas Emissions and Sinks” (GHG Inventory) for the United Nations Framework Convention on Climate Change (UNFCCC).[1] As a basis for estimating the life-cycle impact of natural gas use by heavy-duty trucks, we used the year 2012 methane emission estimates in the most recent GHG Inventory, published in 2014. The GHG Inventory also includes the quantity of carbon dioxide which is co-produced with methane throughout the natural gas system and emitted to the atmosphere through venting, flaring, and as fugitive emissions.

The GHG Inventory is updated annually to account for new emission sources (e.g., new natural gas wells), updated data, emission factors and/or methodologies, and to account for changes in emissions due to changes in policy, regulations and industry practices. The GHG Inventory reflects emission reductions due to existing state regulations, National Emission Standards for Hazardous Air Pollutants (NESHAP) promulgated by EPA in 1999, the New Source Performance Standards (NSPS) promulgated by EPA in 2012, and Natural Gas Star (a flexible, voluntary partnership that encourages oil and natural gas companies to adopt proven, cost-effective technologies and practices that improve operational efficiency and reduce methane emissions)

Emission estimates in the GHG Inventory are generally bottom-up estimates which are per-unit (compressor, pneumatic valve, etc.) emission estimates based on measured or calculated emission rates from such emission sources.

In addition to the national-level data available through the GHG Inventory, facility-level petroleum and natural gas systems data is also available through EPA’s Greenhouse Gas Reporting Program (GHGRP). These data represent a significant step forward in understanding GHG emissions from this sector and EPA expects that this data will be an important tool for the Agency and the public to analyze emissions, and understand emission trends. For some sources, EPA has already used GHGRP data to update emission estimates in the GHG inventory, and EPA plans to continue to leverage GHGRP data to update future GHG Inventories.

The natural gas which comprises CNG is expected to be off-loaded from the natural gas system where the vehicles using CNG are refueled. This is because the natural gas used as CNG is compressed at the retail stations and fleet facilities which fuel the CNG vehicles. To get the natural gas to the CNG retail facilities, the natural gas must be shipped through the distribution system downstream of the natural gas transmission system. When the natural gas is transmitted through the distribution system, the methane emissions are higher because the methane emissions from the distribution system are added to the rest of the upstream methane emissions.

Because LNG plants are located separate from the retail facilities, they can be located to access the lowest cost feedstock. This means the natural gas for LNG can be sourced from the larger natural gas transmission pipelines which are upstream of the distribution pipelines. This provides two advantages for LNG: 1) by avoiding the natural gas distribution system, the natural gas is priced lower, and 2) avoiding the natural gas distribution system avoids the methane emissions which occur from the distribution system. Table 13-1 contains the 2012 methane emissions estimate for the UNFCCC document.

Table 13-1 Methane Emissions from the Natural Gas System in 2012

EMISSION POINT FROM NG FACILITIES	METHANE EMISSIONS (GIGAGRAMS)
Field Production	1858
NG Processing	892
Transmission and Storage	2071
Subtotal without Distribution	4821
Distribution	1231
Total with Distribution	6052

The GHG Inventory also includes the quantity of carbon dioxide which is co-produced with methane throughout the natural gas system and emitted to the atmosphere through venting, flaring, and as fugitive emissions. This quantity is summarized in Table 13-2.

Table 13-2 Carbon Dioxide Emissions from the Natural Gas System in 2012

EMISSION POINT FROM NG FACILITIES	CARBON DIOXIDE EMISSIONS (GIGAGRAMS)
Production	13,659
NG Processing	21,469
Transportation and Storage	63
Distribution	37
Total	35,228

In the GHG Inventory, EPA assessed the amount of uncertainty with its emission estimates and provided a lower and upper bound estimate for its emission estimates. The lower bound emission estimate is 19 percent lower than the best case estimate in Table 13-1 and the upper bound estimate is 30 percent higher than the best case estimate.

In the Climate Action Plan, EPA projects that methane emissions will increase in the future due to increases in natural gas production.[2] Table 13-3 summarizes the projected increase in US methane emissions from the Climate Action Plan and the projected increase in natural gas production referenced from the proposed power plant rulemaking,[3] which is likely the most consistent natural gas production estimate with the projections made in the Climate Action Plan.

Table 13-3 Projected Natural Gas Production Volume and Methane Emissions (g/million BTU)

YEAR	2012	2020	2025
Methane Emissions Teregram CO_2eq.	145	140	151
Natural Gas Production (dry) trillion cubic ft	24.1	26.6	29.3

As Table 13-3 shows, methane emissions from natural gas facilities are expected to increase from 145 teregram CO_2eq. in 2012 to 151 teregram CO_2 eq. in 2025, about a 4 percent increase. At the same time, natural gas production of dry natural gas is expected to increase from 24.1 trillion cubic feet in 2012 to 29.3 trillion cubic feet in 2025, about a 22 percent increase. When estimating the methane emissions on the same natural gas production basis, the methane emissions are projected to be 14 percent lower in 2025 than 2012.[A]

In the GHG Inventory, emissions associated with powering the units or equipment (i.e., compressors, pumps) used in natural gas production, processing, transmission and distribution are aggregated with all the other fossil fuel combustion activities. Rather than attempt to disaggregate those specific GHG emissions from the rest of the process emissions in the GHG Inventory, we instead used the estimated emissions for these sources provided by GREET.[4] Table 13-4 summarizes the process energy consumed to produce and process natural gas.

[A] The 14% reduction figure is calculated by multiplying the methane emissions estimate in 2025 by the ratio of 2012 natural gas production over the 2025 natural gas production (151x24.1/29.3) and the resulting value is 115, which is 85.5% of 145, or 14% less.

Table 13-4 Process Energy Demand by the Natural Gas System (BTU/million BTU)

FUEL TYPE	PRODUCTION			NATURAL GAS PROCESSING	TRANSMISSION/ DISTRIBUTION	TOTAL
	Conv Wells	Shale Wells	Weighted Avg			
Natural Gas	22,016	20,955	21,307	26,123	0	47,430
Diesel	2816	2680	2725	272	0	2997
Electricity	256	244	248	816	0	1064
Gasoline	256	244	248	0	0	248
Resid	256	244	248	0	0	248
Totals	25,600	24,367	24,777	27,211	0	51,988

Table 13-5 contains the factors we used to convert the GREET process energy demands used to operate the equipment used to produce, process and distribute natural gas to carbon dioxide emissions for those process fuels.[5]

Table 13-5 Carbon Dioxide Emission Factors for Process Fuel Consumption

PROCESS FUEL	GCO2/BTU
Natural Gas	0.0398
Diesel	0.0555
Electricity	0.1549
Gasoline	0.0535
Resid	0.0563

Table 13-6 summarizes the total estimated methane and carbon dioxide emissions emitted by the upstream natural gas system. Two estimates are provided, one of which includes the emissions from the distribution system representing the upstream emissions for CNG. The second estimate summarizes the emissions excluding the emissions from the distribution system representing the upstream emissions for LNG, since it is expected to access the natural gas from the transmission portion of the natural gas system.

Table 13-6 Summary of Year 2025 Emissions from the Natural Gas System (grams/million BTU)

	METHANE EMISSIONS	CARBON DIOXIDE
CNG Analysis (includes CH_4 emissions from the distribution system)	242	3881
LNG Analysis (does not include CH_4 emissions from the distribution system)	192	3881

13.1.2 **Downstream Emissions**

The GHG Inventory does not estimate the methane emissions for natural gas once the natural gas is diverted for use by the transportation sector, thus, we obtained information from other sources. Natural gas can be used by vehicles either as a compressed gas (CNG) or as liquefied natural gas (LNG). We discuss the emissions of both.

13.1.2.1 Compressed Natural Gas (CNG)

To make CNG available to trucks, the natural gas must be compressed from the pressure that it is available from the distribution pipelines to a pressure over 3600 psi to enable filling the truck CNG storage tanks. We used the compression energy available from GREET for this step which reflects national-average emissions for electricity generation.[6] The emissions associated with natural gas compression for CNG are summarized in Table 13-7.

Table 13-7 Estimated Emissions for Electricity Generated to Power CNG Compressors (g/million BTU)

	METHANE	CARBON DIOXIDE	NITROUS OXIDE
Emissions	6.9	3988	0.06

An important advantage that CNG has over LNG is that only a single facility, the retail outlet, is required for distributing CNG, while LNG requires both a liquefaction plant and a retail outlet. The simplified logistics of providing CNG also provides fewer opportunities for emissions and leakage to the environment.

We are aware of the following two types of emissions for CNG which are not estimated in the lifecycle analysis due to lack of quantifiable data. The first is CNG refueling emissions. CNG trucks are refueled at the retail stations providing CNG. When the refueling hose is disconnected from the connection fitting on the vehicle, a small amount of natural gas is released to the atmosphere. This CNG refueling vented gas has not been estimated and therefore not included in the lifecycle analysis.

The second is fugitive emissions from small leaks in the CNG fuel storage system. While CNG has an advantage over LNG because it is contained in a sealed system, the very high pressure at which CNG is stored dramatically increases fugitive emissions if a fitting pipe were to develop a leak. The level of fugitive emissions for a certain sized hole is directly proportional to the pressure. We do not have any data on the fugitive emissions from CNG trucks, therefore, in our lifecycle analysis, we assume that CNG fugitive emissions are zero which likely underestimates the methane emissions from CNG trucks.

13.1.2.2 Liquefied Natural Gas (LNG)

The first step in making LNG available to trucks is the liquefaction step. As discussed above, the liquefaction plant is likely to be constructed near natural gas transmission pipelines to access the natural gas at the lowest price point. The liquefaction step involves the removal of heat from the natural gas until it undergoes a phase change from a gas to a liquid at a low pressure. Once the natural gas is liquefied, it is stored in an insulated storage tank to keep the LNG liquefied.

LNG plants are configured depending on their ultimate capacity. World class LNG plants produce 5 million metric tons, or more, per year of LNG and the economy of scale of these large plants support the significant addition of capital to reduce their operating costs. An LNG plant solely producing LNG for truck fuel is expected to be significantly smaller than the world class LNG export plants and so the capital invested is expected to be much lower, thus, their operating costs would be expected to be much higher, and their energy efficiency much lower on a percentage basis. The California Air Resources Board estimates the liquefaction plants used for producing truck LNG fuel are 80 percent efficient, compared to 90 percent efficient for world class LNG plants.[7] In our lifecycle analysis of LNG as a truck fuel, we also assumed that LNG plants are 80 percent efficient. For our GHG analysis, we estimate the carbon dioxide emitted when 20 percent of the natural gas is combusted to provide the energy required to liquefy the natural gas to LNG. The upstream emissions associated with the natural gas used in the liquefaction process must be accounted for and added onto the LNG produced by the plant. These emissions are included as indirect emissions. Table 13-8 summarizes the GHG emissions attributed to the liquefaction plant.

Table 13-8 LNG Liquefaction Plant Emissions (g/million BTU)

	METHANE	CARBON DIOXIDE
Direct Emissions	0	15,175
Indirect Emissions	48	970
Total Emissions	48	16,145

To transport the LNG to the retail station, the LNG is loaded into an insulated horizontal trailer designed specifically for transporting LNG. If the LNG in the trailer were to warm sufficiently to cause the LNG to reach the pressure relief valve venting pressure, there would be boil-off emissions from the trailer. However, since the LNG is super cooled, boil off events are likely to be rare. We used a CARB estimate of boil-off emissions for LNG transportation between the LNG plant and retail outlets.[8] Table 13-9 contains the estimate of boil off emissions and the emissions from the vehicle transporting the LNG to retail.

Table 13-9 Boil-Off Emissions Estimate for LNG Transportation to Retail (g/million BTU)

	METHANE	CARBON DIOXIDE	NITROUS OXIDE
Fuel Use (Diesel Fuel)	0.45	378	0.009
Methane Boil Off Emissions	0.43	0	0
Total	0.88	378	0.009

LNG is stored in the insulated storage tank at the retail facility. Heat gain in the storage tank could eventually lead to boil-off emissions. Service stations with little LNG demand are at a higher risk of boil-off emissions compared to service stations which have a significant throughput volume. LNG stations could be configured to avoid boil-off events to the atmosphere, such as venting to a co-located CNG facility, or venting to a nearby natural gas pipeline. We used a CARB emission estimate to provide an estimate of the boil-off emissions from LNG retail facilities.[9] Table 13-10 summarizes the estimated boil off emissions for LNG retail facilities.

Table 13-10 Boil-Off Emissions Estimate for LNG Retail Facilities (g/million BTU)

	METHANE EMISSIONS
LNG Retail Boil-Off Emissions	11.1

The total well to tank emissions for CNG and LNG are summarized in Table 13-12. These emissions represent the total of upstream and downstream emissions which includes delivering the fuel to the truck fuel storage tank.

Table 13-11 Total Well to Tank Emissions Estimate for CNG and LNG (g/million BTU)

	METHANE	CARBON DIOXIDE	NITROUS OXIDE
CNG	249	7869	0.07
LNG	251	20,405	0.009

13.1.3 **Vehicle Emissions**

13.1.3.1 Vehicle Configurations

There are several different ways that diesel heavy duty engines can be configured to use natural gas as a fuel. The first is a spark ignition natural gas (SING), Otto cycle SING heavy duty engine burns the fuel stoichiometrically and uses a three-way catalyst and some also add an oxidation catalyst to provide the greatest emissions reduction. Stoichiometric combustion is used in most light-duty SING engines. Problems with thermal stress and low power density have favored the use of the lean-burn combustion system in heavy duty engines. The use of cooled EGR provides further potential to increase the engine output and, at the same time, decreases NO_X emissions. In this case the engine compression ratio is reduced similar to that of a gasoline engine, about 12 to 1 or more, and thus its thermal efficiency is lower than a diesel-like engine by about 10 - 15 percent, depending on the driver.

The second is a direct injection natural gas (DING), diesel cycle. The DING engine uses a small quantity of diesel fuel (pilot injection) or a glow plug as ignition sources. As the injection system for the diesel fuel does not have the capability of greater injection quantities, this option has no dual-fuel properties. On the other hand, an optimization of the pilot injection can be made to achieve lower emissions. An advanced high pressure direct injection (HPDI) fuel system combining the injection of both diesel fuel and natural gas can be used for lean burn combustion. This enables the engine to maintain the efficiency advantage of a compression ignition engine while running mainly CNG/LNG.

The third is a mixed-fuel natural gas (MFNG), diesel cycle. In a mixed-fuel engine, natural gas is mixed with intake air before induction to the cylinder and diesel fuel is used as ignition source. Mixed-fuel vehicle/engine means any vehicle/engine engineered and designed to be operated on the original fuel(s), or a mixture of two or more fuels that are combusted together. Mixed-fuel system means that a diesel engine works with two types of fuels together. In fact the engine is a diesel thermodynamic cycle and the energy is given by the diesel and the natural gas fuel. In mixed-fuel conversion the original engine is not modified in any way, a conversion system is installed in order to permit the engine to run on both fuels. The conversion of the engine is totally reversible, in fact it is possible to choose the mode how to run the engine (diesel / mixed-fuel). When the engine runs in diesel mode, the engine runs in the same way as per the original configuration. Engine results showed that the efficiency of the engine could decrease by about 2-5 percent in mixed-fuel mode compared to diesel mode and that the diesel replacement was approximately 40-60 percent efficient.

Each of these natural gas engine types has its merits. The SING engine is less costly, but is less fuel efficient and because of the lower compression ratio it has less torque than the two diesel cycle engines. The DING engine is likely the most expensive because of the special natural gas/diesel fuel injection system and large required amount of natural gas (LNG or CNG) storage since the truck must run on natural gas. However, because the truck can run almost completely on natural gas, the DING engine has the potential to more quickly pay down the higher investment cost of the natural gas truck. The MFNG engine provides the truck owner the flexibility to operate on natural gas or diesel fuel, but at the expense of a slower natural gas investment pay down rate because it can operate at most 50 percent of the time on natural gas.

An important advantage of LNG is the increased energy density compared to CNG. At present, CNG stored at its maximum storage pressure is only 25 percent of the energy density of diesel fuel, while LNG contains about 60 percent of the energy density of diesel fuel. Because of its higher energy density, LNG is favored over CNG for long-haul trucking. An adsorbent for natural gas (ANG) material technology[B] called metal organic framework (MOF) for storing CNG has been invented and is being tested for large scale use. The technology involves filling the

[B] Menon, V.C., Komarneni, S. 1998 "Porous Adsorbents for Vehicular Natural Gas Storage: A Review", Journal of Porous Materials 5, 43-58 (1998); Burchell, T "Carbon Fiber Composite Adsorbent Media for Low Pressure Natural Gas Storage" Oak Ridge National Laboratory

CNG tank with a specially designed substance which looks similar to a pelletized catalyst. The substance establishes a matrix which causes the methane molecules in natural gas to become better organized and store the same quantity of natural gas in a smaller volume at the same pressure, or store the same density of natural gas at a lower pressure. This MOF could improve the energy density of CNG which would make it a better candidate for natural gas storage for long range combination trucks, while avoiding the boil-off events that are a risk with using LNG.

13.1.3.2 Tailpipe Emissions

When assessing the methane emissions from both CNG and LNG trucks, it is important to separate those trucks built or converted before 2014 to those built or converted in 2014 and later. The trucks built before 2014 are only required to meet a nonmethane hydrocarbon (NMHC) standard, which means that the methane emissions from these trucks are unregulated. Our certification data shows that the methane tailpipe emissions from these trucks/buses ranges from 2 – 5 g/bhp-hr for both spark ignition (gasoline type) and compression ignition (diesel type) engines.

For 2014 and later OEM compression ignition natural gas trucks or natural gas conversions of 2014 and later diesel trucks, the trucks must meet a 0.1 g/bhp-hr methane emission standard in the case of a larger truck engine tested with an engine dynamometer, and a 0.05 g/mile methane emission standard in the case of smaller trucks tested on a chassis dynamometer. For spark ignition (gasoline style) engines, the standards take effect in 2016.[10] The natural gas truck manufacturers are allowed to offset methane emissions over the standard by converting the methane emission exceedances into CO_2 equivalent emissions and using CO_2 credits. For the initial natural gas engine certifications that EPA received for 2014, the truck manufactures chose to continue to emit high levels of methane (around 2 g/bhp-hr) and use carbon dioxide credits to offset those emissions. We don't know if this practice of using CO_2 credits to offset high methane emissions will continue in the future, however, for evaluating the lifecycle impacts of natural gas heavy-duty vehicles, the 2014 and later natural gas heavy-duty trucks may in fact have an emissions profile more like the pre-2014 trucks and not like the 2014 and later trucks as depicted below in the figures. Furthermore, our emissions analysis assumes that these trucks are emitting GHG emissions as designed. In cases when these trucks experience an increase in emissions due to deterioration or malfunction of the engines, fuel supplies or associated emission control devices on these trucks, the methane emissions could be higher than estimated. Table 13-12 summarizes the emission standards and the estimated methane emissions from heavy-duty trucks assumed in the analysis.

Table 13-12 Methane Emission Standards and Estimated Emissions from Heavy-Duty Trucks

		PRE-2014	2014 AND LATER
Methane Standard		None	g/bhp-hr
Estimated Emissions	g/bhp-hr	2 – 5	0.05
	g/million BTU	214 – 534	5.3

13.1.3.3 Boil-off, Venting and other Fugitive Emissions

Truck drivers requiring LNG fuel drive up to an LNG retail outlet or fleet refueling facility and fill up with LNG fuel. When the refueling nozzle is disconnected from the LNG tank nozzle, a small amount of methane is released to the environment. In addition, prior to refueling it may be necessary or advantageous, due to high pressure in the truck's LNG tank, to reduce the pressure in the truck's LNG tank to speed up the refueling process. In some cases the retail station is equipped with another hose and associated piping to vent the excess gas to the retail stations' storage tank, or perhaps to a natural gas pipeline. However, for those retail outlets without such vent lines to the storage tank, the truck driver may simply vent the truck's storage tank to atmosphere. As part of a sensitivity analysis for our lifecycle analysis, we estimate the emissions for venting an LNG tank prior to refueling.

A major GHG issue for LNG trucks is boil-off emissions from the trucks themselves. When the liquefied natural gas is pumped into the truck LNG tanks, it is "supercooled," meaning that the temperature of the LNG is well below the boil-off pressure and temperature. If the truck is driven extensively the drawdown of liquid level will cause some of the fuel to boil off and thus cool the rest of the liquid in the LNG storage tank. It is possible that the fuel would maintain its supercooled temperature or possibly even cool further below its supercooled temperature all the time until the LNG is completely consumed.

If the truck is not driven or is driven very little, the very low temperature LNG warms through ambient temperature gradient through the tank wall causing the temperature and pressure of the LNG to rise. When the pressure reaches a maximum of 230 psi there is a safety release valve on the LNG storage tank which releases the methane gas directly to the atmosphere until the pressure drops to 170 psi, the pressure at which the safety release resets. There are two industry standards used to design tanks to reduce the temperature increase, one for a 3 day hold time[C] and one for a 5 day hold time.[D] Hold time is the minimum time elapsed between when the truck's LNG tank is refueled and when it begins to vent.

If there is a boil-off event, a large amount of methane would be released. If aware of the impending boil-off such as when the truck is being maintained, the truck driver could hook up the LNG tank to a hose which would vent the natural gas emissions to a CNG system which would reuse the boil-off natural gas as CNG, or vent the natural gas emission to a natural gas pipeline. Otherwise the boil-off emission would simply vent to the atmosphere.

When an LNG fuel tank venting (refueling venting or boil-off) incident occurs, there are two separate processes which occur that contribute to methane emissions during the venting. The most obvious process is the pressure drop, from 230 to 170 psi, in the gaseous space above the liquid. The volume of gas vented is proportional to the reduction in absolute pressure in the tank. Since the drop in absolute pressure is 244 to 184 psi (14.7 psi is added to the 230 and 170 psi gauge pressure), about 25 percent of the gas in the tank is vented (184 psi is 25 percent of the way from 244 psi to zero pressure). The second process is the vaporization of liquid during the pressure reduction in the LNG tank. The boiling point of any liquid decreases as the pressure decreases. Thus, when the LNG undergoes the pressure reduction during a venting/boil-off, the

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[C] National Fire Protection Association 52, Compressed Natural Gas (CNG) Vehicular Fuel System Code, 2002 Edition

[D] SAE International (2008) SAE J2343: Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles. Warrendale, Pennsylvania.

boiling point of the methane decreases and to balance the system, some of the liquid methane must boil off to cause the cooling of the liquid. The quantity liquid methane which must boil off from the liquid is calculated from methane's heat of vaporization over the boiling point temperature change, which drops from -178 F to -189 F as the pressure drops from 230 to 170 psi.

The amount of natural gas which boils off during a venting event varies based on the quantity of liquid in the LNG storage tank. The greatest amount of natural gas which is lost during a venting/boil off event occurs when the tank is closest to being full. For a 200 gallon tank system, each boil off event has the potential to release on the order of 3-9 gallons or 5,300 – 15,800 grams of CH_4 which translates to 132 – 400K grams of CO_2-equivalent emissions, assuming methane has global warming potential (GWP) of 25 over a 100 year lifetime. If the vehicle continues to sit after boil-off events begin to occur with boil-off events each day and up to several boil-offs per day, as much as million grams of CO_2-equivalent emissions may be emitted over the twenty or so days at which point the vehicle LNG tank would be completely empty.

Table 13-13 summarizes the starting and ending conditions and the loss from the tank for venting incidents (200 gallon LNG tank decreases in pressure from 230 to 170 psi) when the LNG tank is 90 percent, 50 percent and 10 percent full. A refueling venting event is more likely to occur when the tank is mostly empty, so the 50 and 10 percent cases are the most likely cases to consider.

Table 13-13 Estimated Quantity of Boil-Off from a 200 Gallon LNG Fuel Tank for a Single Boil-Off Event

	PERCENT FULL (INITIAL)	PERCENT FULL (FINAL)	LIQUID LOSS (GALS)	TOTAL MASS LOSS (LBS)
Boil-off Scenarios	90	83.2	13.6	38.7
	50	46.2	7.6	24.8
	10	9.3	1.5	11.0

Table 13-13 shows that if a truck had 200 gallon of LNG storage capacity, the estimated quantity of liquid boil-off volume would range from 2 to 14 liquid gallons of LNG depending on the fill level of the LNG tank. When the quantity of LNG gas loss is included, the total loss ranges from 11 to 39 lbs.

The quantity of LNG tank boil-off or venting per distance driven by the truck depends on the frequency of boil-off or venting incidents. As described above, a truck's driving profile plays a key role in determining the boil-off risk from LNG trucks. Fleets which purchase LNG trucks do so with the intent of driving the LNG truck extensively to pay off the much higher purchase price of the LNG truck. For this reason, there is likely to be few boil-off incidents, except for cases when the truck is forced out of its routine. Examples of when the truck might be sidelined include times when the truck is being maintained, the immediate period after the truck is involved in an accident or perhaps when the owning company experiences a loss of workload or files for bankruptcy. We have no data which would allow us to estimate the frequency when these sorts of incidents would occur, and even if we did, we still could not estimate the frequency of boil-offs that occur in these cases.

As the truck ages, it likely would be sold by the company which originally purchased the truck to avoid having to deal with the increased maintenance that occurs with older trucks. Figure 13-1 shows the estimated vehicle miles traveled by class 8 trucks as they age (the data is from the MOVES Model.

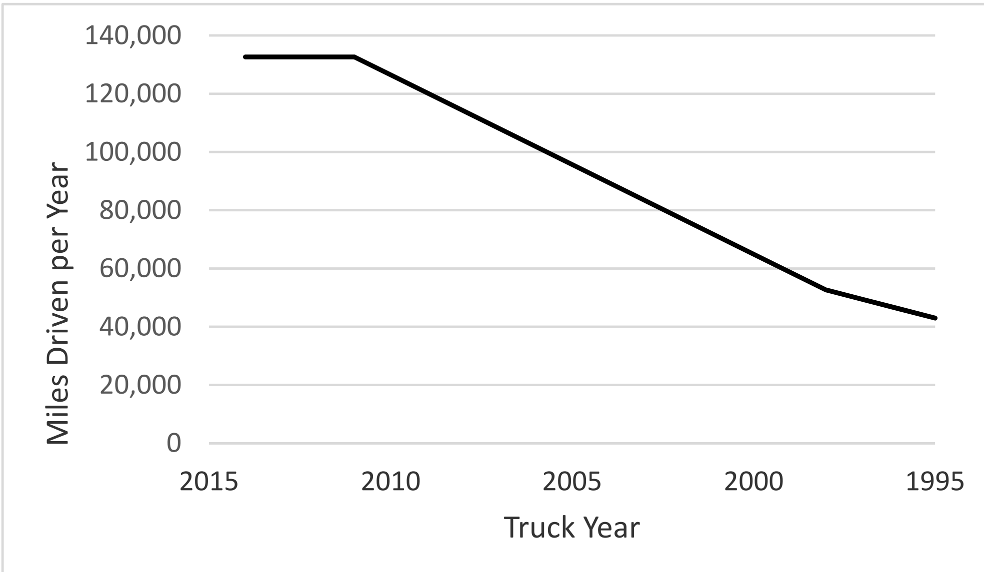

Figure 13-1 Vehicle Miles Traveled by Combination Trucks in 2014

Figure 13-1 shows that the mileage driven by combination trucks decreases as they age. By the time that a combination truck is about 17 years old, it is driven about half the number of miles per year as a new truck. It would seem that the risk of boil-off incidents increases with these older trucks.

Venting incidents during refueling can occur at any time, and there is an incentive to do so when it is time to refuel. The decision to vent an LNG tank in most cases is solely up to the truck driver who is often under pressure to complete his work in less time to maximize profits.

There is a lot of uncertainty in estimating the quantity of boil-off and venting from an LNG truck. To reflect this uncertainty, we assume two different boil-off/venting emission estimates. The low estimate assumes that 35 grams per million BTU of fuel consumed is emitted, which is from GREET. The high estimate assumes a boil-off event and a venting event each time the truck is refueled and before that tank full of LNG is used up, and this quantity is estimated to be 734 g per million BTU of fuel consumed.

The crankcase of these engines receives leakage from across the piston rings, which can contain methane. The crankcase of the spark ignition engines is normally vented into the intake of the engines, thus, any methane emissions from the crankcase which is not combusted in the engine would be accounted for in both the engine-out and tailpipe emissions. For compression ignition engines, however, the crankcase emissions are typically vented into the exhaust pipe downstream of the aftertreatment devices although they are accounted for in addition to the engine-out emissions during certification. Engine-out emissions are subjected to deterioration factors based on well-established procedure, which may make them more robust than deterioration factors for vented crankcase emissions. Moreover, deterioration of crankcase emissions may be more variable. Thus, sealed crankcases would achieve more robust control of methane emissions.

Another potential source of methane emissions from CNG and LNG trucks is leaks from the fuel piping which to the engine which is another source of fugitive emissions. Thus, either while parked or operated, the vehicle fuel and engine systems could leak methane to the environment. We do not have nor did we attempt to estimate this type of methane fugitive emissions from CNG or LNG trucks.

Table 13-14 summarize the estimated tailpipe emissions for CNG trucks, and Table 13-15 summarizes the estimated tailpipe and boil-off and venting emissions for LNG trucks.

Table 13-14 Estimated Tailpipe Emissions for CNG Trucks (g/mmbtu)

		METHANE	CARBON DIOXIDE	NITROUS OXIDE
2014 and Later	Direct	5.3	60,702	2
	Indirect	0.1	3	0
	Total	5.4	60,705	2
Pre-2014	Direct	374	60,702	2
	Indirect	6	189	0
	Total	380	60,891	2

Table 13-15 Estimated Tailpipe and Boil-Off Emissions for LNG Trucks (g/mmbtu)

		METHANE	CARBON DIOXIDE	NITROUS OXIDE
2014 and Later assuming low Venting and Boil-Off Emissions	Direct	5.3	60,702	2
	Indirect	0.07	5.5	0
	Total	40.4	60.707	2
2014 and Later Assuming High Venting and Boil-Off Emissions	Direct	5.3	60,702	2
	Indirect	0.07	5.5	0
	Total	739	60,707	2
Pre-2014 Assuming Low Venting and Boil-Off Emissions	Direct	374	60,702	2
	Indirect	4.8	386	0
	Total	413	61,088	2

13.1.3.4 Thermal Efficiency

While not an emission source per se, the thermal efficiency of the natural gas engine also plays a role in the lifecycle emissions of the truck. Thermal efficiency is defined by the amount of energy that is obtained to propel the truck compared to the energy consumed by the engine. If a fuel-engine is less thermally efficient, then it consumes more fuel, or more BTUs, to travel the same distance, thus, emitting more carbon dioxide per distance traveled, or work performed.

We estimate that SING engines can be as much as 15 percent less efficient than compressed ignition engines which operate on diesel fuel. Conversely, DING and MFNG engines which operate at a higher compression ratio, are estimated to be 5 percent less energy efficient compared to a diesel engine. In our lifecycle analysis, we provide two different sensitivities for natural gas vehicles assuming that they may be 5 percent and 15 percent less efficient.

13.1.4 **Results of Life Cycle Analysis**

To estimate the lifecycle impact of natural gas used by heavy-duty trucks, we totaled the carbon dioxide, methane and the nitrous oxide emissions for the upstream and downstream portions of the natural gas system. The methane and nitrous oxide emissions are converted to carbon dioxide-equivalent emissions using global warming potentials ((GWPs); these are a measure of the relative contribution of global warming of emissions of a given gas in comparison to that of carbon dioxide over a given time period). The GWPs EPA is currently using is from the AR4 (2007) IPCC report for 100 year timeframe, which is 25 and 298 for methane and N_2O, respectively.

To establish the impacts of natural gas use in the heavy-duty fleet, it was necessary to compare the lifecycle impacts of natural gas against its replacement, which is a diesel fueled heavy-duty truck. The lifecycle impact diesel fuel was estimated by the National Energy Technology Laboratory (NETL) for the production and use of diesel fuel in 2005. EPA used this lifecycle assessment for the Renewable Fuel Standard Rulemaking. We used this NETL diesel fuel lifecycle estimate for the baseline for comparison with the natural gas lifecycle assessment. The vehicle nitrous oxide and methane emissions are from the MOVES vehicle model developed by EPA. Table 13-16 summarizes the lifecycle emissions for diesel fuel estimated by NETL.

Table 13-16 Estimated Diesel Fuel Lifecycle Greenhouse Gas Emissions (g/million BTU)

	CARBON DIOXIDE	METHANE	NITROUS OXIDE	TOTALS CO_2EQ*
Well to Tank	15,838	98	0.3	18,377
Tank to Wheels	78,308	1	2	78,929
Well to Wheels	94,146	99	2.3	97,306

Note:
*The totals are calculated using 25 and 298 for the GWPs for methane and nitrous oxide, respectively.

NETL is in the process of updating its lifecycle analysis from the 2005 analysis year to 2009 as the analysis year. While the revised lifecycle analysis is not yet available, one of the authors of the analysis explained that the 2009 analysis appears to be quite similar to the 2005 analysis.[11]

To illustrate the relative full lifecycle impact of natural gas-fueled heavy-duty vehicles versus diesel fueled heavy-duty vehicles, we assessed a couple different scenarios. The first scenario is a conversion of a diesel engine to use CNG. Of the tens of thousands of heavy-duty natural gas trucks currently in use, over 90 percent are of this type. These are conversions of older trucks so they are not regulated by the 2014 methane standard. For future year heavy-duty trucks, we also estimated the lifecycle emissions if the trucks were meeting a 0.1 g/bhp-hr or a 0.05 g/mile methane tailpipe standard. We provide two estimates for the lower thermal efficiencies of CNG trucks, one assumes that the truck is 5 percent less thermally efficient and the second assumes that the truck is 15 percent less thermally efficient (10 percent less efficient than the 5 percent less thermally efficient case). The estimated lifecycle emissions of CNG trucks, assuming projected upstream emissions in 2025, is summarized in Table 13-17.

Table 13-17 Full Lifecycle Analysis of a CNG Truck (g/million BTU)

TRUCK TYPE	EMISSION CATEGORY	CARBON DIOXIDE	METHANE	NITROUS OXIDE	TOTAL CO_2 EQ.*	THERMAL EFFICIENCY 5% AND 15% CO_2EQ.*	TOTALS INCLUDING THERMAL EFFICIENCY IMPACT CO_2EQ. *
Pre-2014 CNG Truck	Well to Tank	7869	249	0.07	14,107	705 2116	14,812 16,223
	Tank to Wheels	60,891	380	2	70,980	3548 10647	74,528 81,627
	Well to Wheels	68,760	628	2	85087	4254 12,763	89,379 97,850
2014 or Later Truck	Well to Tank	7869	249	0.07	14,107	705 2116	14,812 16,223
	Tank to Wheels	60,704	5	2	61,436	3072 9215	64,508 70,651
	Well to Wheels	68574	254	2	75,544	3777 11,331	79,321 86,875

Note:
*The CO_2eq. totals are calculated using 25 and 298 for the GWPs for methane and nitrous oxide, respectively.

The CNG lifecycle assessment relative to a diesel truck lifecycle analysis is shown in Figure 13-2.

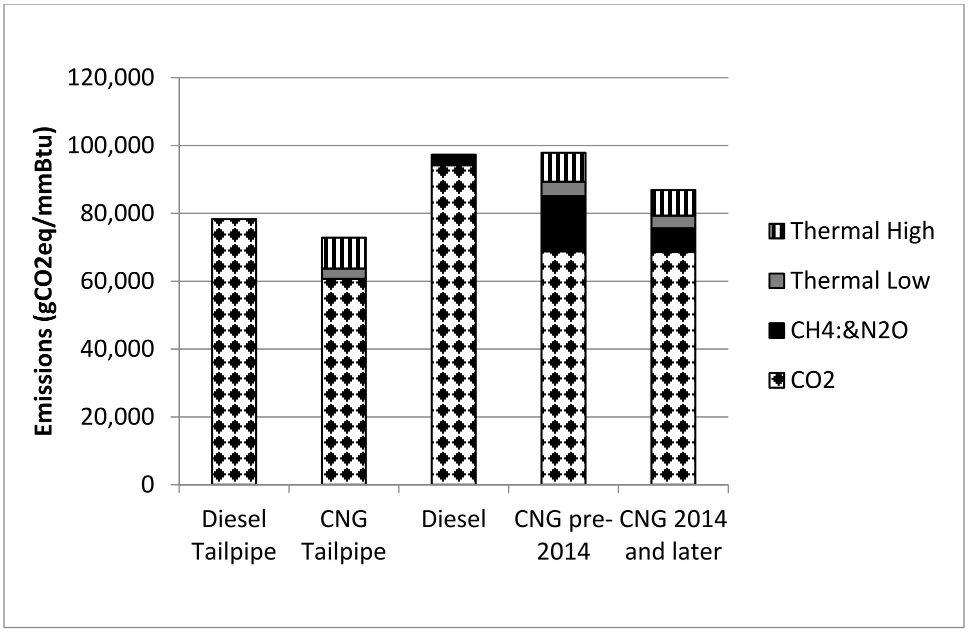

Figure 13-2 Full Lifecycle Analysis of a CNG Truck
(Projected Upstream Methane Emissions in 2025, Methane GWP of 25)

In the first two bars of Figure, it shows that based solely on tailpipe emissions (with and without thermal efficiency adjustments and assuming no increased methane emissions at the truck), natural gas trucks are estimated to emit about 20 percent less GHG emissions than diesel engines. But this advantage decreases if the natural gas engine is less thermally efficient. The three full lifecycle analyses represented by the right three bars in the figure shows that pre-2014 CNG trucks are estimated to emit about the same GHG emissions as diesel trucks, although if their thermal efficiency is much lower or if a higher GWP for methane were used, they would likely be somewhat higher emitting in GHG emissions. When such trucks are complying with the 2014 and later methane emission standards, their methane emissions are much lower and these trucks are expected to be lower emitting than diesels, even considering if they are less thermally efficient.

The second scenario is a combination truck which is assumed to be in compliance with the 2014 methane standard. Because it is high mileage truck, the truck most realistically must use LNG as a fuel to provide the necessary range for the dedicated natural gas engine. We make two different assumptions with respect to refueling and boil off emissions. In the natural gas average case, we assume a modest quantity of refueling and boil-off methane emissions which is equal to the combined boil-off emissions from the liquefaction, transportation and retail station as estimated by GREET. The second boil-off emission estimate is based on venting the LNG storage tank to the atmosphere each time the driver refills his tank, and one LNG boil-off event between each time the driver must refuel his tank. As we discussed in the discussion about refueling and truck boil-off emissions, we don’t expect this to be as common practices for newer trucks that are operated regularly. However, as the use of these trucks decreases as they age and are sold into the secondary market, the risk for refueling and boil-off emission events increases – this estimate provides a simple sensitivity emission estimate. The estimated lifecycle emissions of LNG trucks, assuming projected upstream emissions in 2025, is summarized in Table 13-18**.**

Table 13-18 Full Lifecycle Analysis of an LNG Truck (g/million BTU)

TRUCK TYPE	EMISSION CATEGORY	CARBON DIOXIDE	METHANE	NITROUS OXIDE	TOTALS* CO_2EQ.	THERMAL EFFICIENCY 5% AND 15% CO_2EQ.*	TOTALS INCLUDING THERMAL EFFICIENCY IMPACT CO_2EQ.*
Pre-2014 LNG Trucks assuming low Venting and Boil-Off Emissions	Well to Tank	20,405	251	0.01	26,693	1334 4004	28,027 30,697
	Tank to Wheels	61,088	413	2	72,896	3645 10,934	76,542 83,831
	Well to Wheels	81,494	665	2	98,732	4935 14,807	103,668 113,540
2014 and Later LNG Trucks assuming low Venting and Boil-Off Emissions	Well to Tank	20,405	251	0.01	26,693	1334 4004	28,027 30,697
	Tank to Wheels	60,707	40	2	62314	3116 9347	65,429 71,661
	Well to Wheels	81,113	291	2	89,024	4450 13,350	93.475 102,375
2014 and Later LNG Trucks with High Venting and Boil-Off Emissions	Well to Tank	20,405	251	0.01	26,693	1334 4004	28,027 30,697
	Tank to Wheels	60,707	990	2	86,037	3035 9106	89,072 95,143
	Well to Wheels	81,113	990	2	112,720	4370 13,109	117,090 125,829

Note:
*The totals are calculated using 25 and 298 for the GWPs for methane and nitrous oxide, respectively.

The LNG truck lifecycle analysis relative to a diesel truck lifecycle analysis is shown in Figure 13-3.

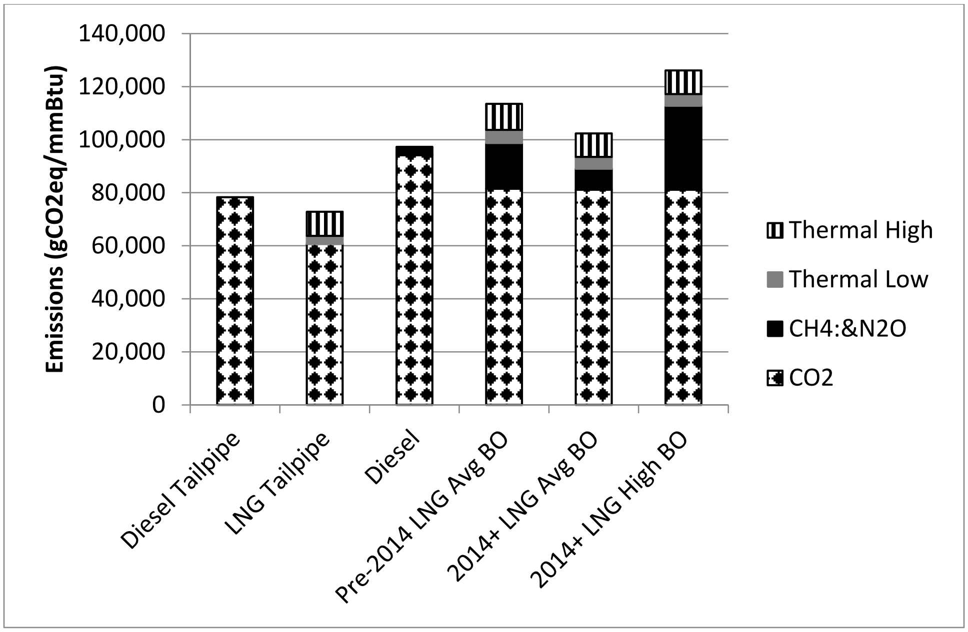

Figure 13-3 Full Lifecycle Analysis of an LNG Truck (Projected Upstream Methane Emissions in 2025, Low and High Refueling and Boil-Off Emission, Methane GWP of 25)

Figure 13-3 shows that LNG trucks have about the same greenhouse gas footprint as diesel trucks when we assume a low quantity of refueling and boil-off emissions. In comparing CNG to LNG, the LNG trucks appear higher emitting than CNG trucks because of the low thermal efficiency of the small liquefaction facilities. If these LNG trucks emit high levels of methane when refueling and by experiencing boil-off events, their GHG emissions can potentially be much greater than that from diesel trucks.

It is important to point out the uncertainties associated with the lifecycle estimates provided Figures 13-2 and 13-3. As discussed above, there is uncertainty in both the upstream and downstream methane emission estimates for natural gas facilities and equipment, and the trucks that consume natural gas. In the GHG Inventory, EPA estimates a range of natural gas emissions from the upstream natural gas production sector. The range varies from -19 percent to +30 percent relative to the principal estimate. To illustrate the impact the range has on the relative life cycle impacts of natural gas versus diesel trucks, Figure 13-4 shows the impact on the relative life cycle emissions for CNG trucks when the low and high methane emissions are compared to the best estimate case we used in the above analyses for a CNG truck complying with the methane emissions standards.

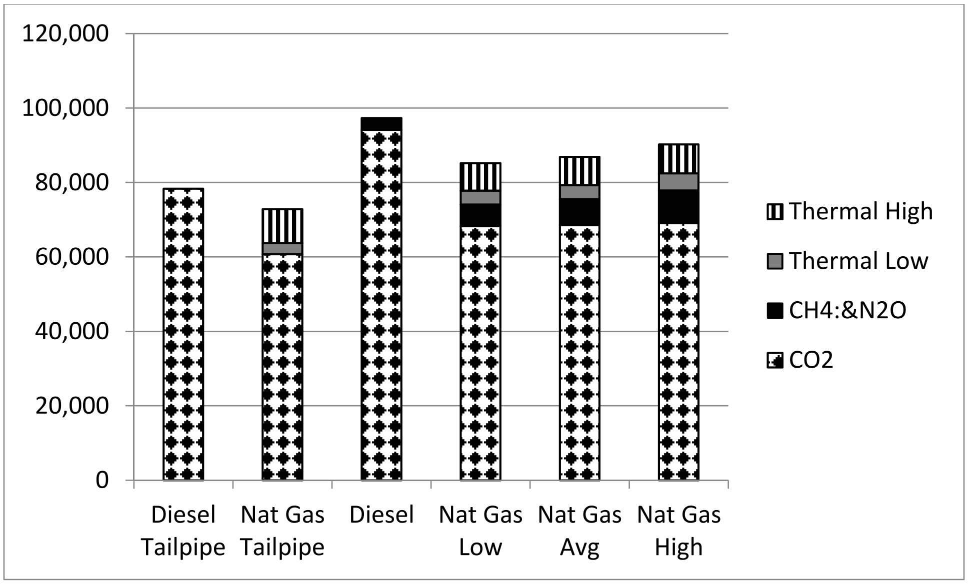

Figure 13-4 Full Lifecycle Analysis of a CNG Truck - Low, Avg and High Upstream Methane Emissions (Projected Upstream Methane Emissions in 2025, Methane GWP of 25)

Figure 13-4 shows that higher and lower upstream emissions, based on the uncertainty factors provided in the GHG Inventory, does impact the relative GHG lifecycle impact of CNG trucks, but the effect is quite modest relative to the other emissions effects depicted in the figures presented earlier.

As new methane emission information becomes available, we will update our methane emission estimates which would reduce the uncertainty. In addition to the new methane emissions information from the GHG Reporting Program, there will likely be other studies as well. For example, a number of studies are being conducted to quantify the methane emissions and life cycle impacts of natural gas by Environmental Defense Fund (EDF). The final reports for these studies have not yet been released but we will review them once they are available.

The GWPs used to assess the relative climate impacts of methane and nitrous oxide can also effect the relative life cycle impacts natural gas trucks compared to diesel trucks. The GWPs of methane and nitrous oxide vary based on the timescale assumed. To illustrate this point, we added two more sets of figures as sensitivities for comparing the life cycle impacts of CNG and LNG natural gas trucks to diesel trucks if the greenhouse gas emissions are evaluated over a different lifetime. The GWPs that we use are the two alterative GWPs reported by IPCC in its 4^{th} Assessment Report evaluated at 20 year and 500 year GHG lifetimes. Table 13-19 summarizes the GWPs at the different lifetimes along with the GWPs used in the primary analysis summarized above.

Table 13-19 Summary of GWPs

	PRIMARY ANALYSIS	SENSITIVITY ANALYSES	
	100 Year	20 Year	500 Year
Methane (CH_4)	25	72	7.6
Nitrous Oxide (N_2O)	298	289	153

It is important to point out that while there are fairly significant differences in methane emissions between the various natural gas cases being studies and compared to diesel trucks, the nitrous oxide emissions vary very little across all the cases. Therefore, when comparing the relative lifecycle impacts using different GWPs, the impact on relative lifecycle emissions is almost exclusively due to changes in the methane GWP. Figures 13-5 through 13-8 show the relative lifecycle effects of natural gas trucks compared to diesel trucks when the GWPs used are based on 20 year and 500 year lifetimes.

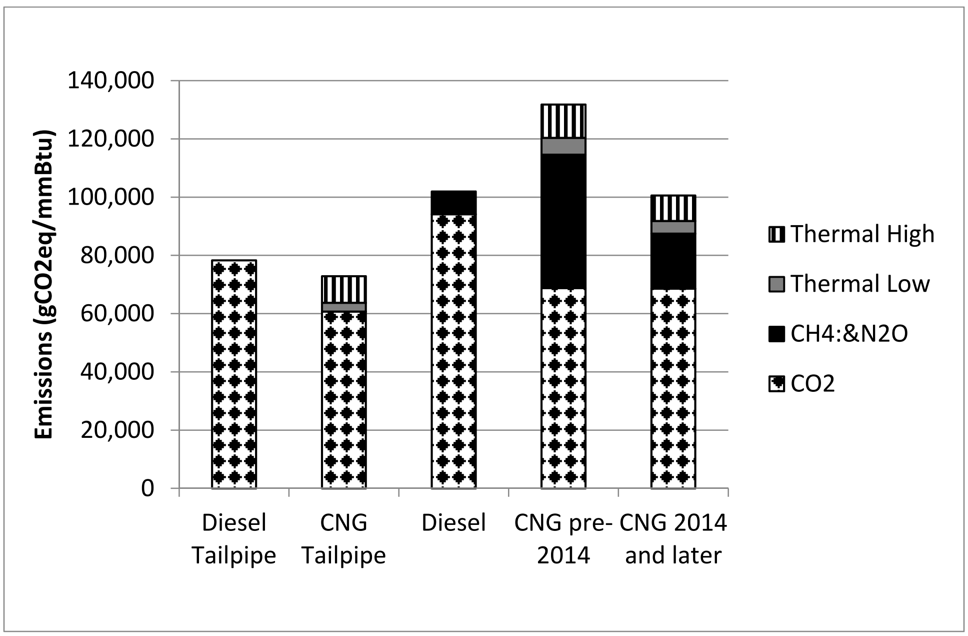

Figure 13-5 Full Lifecycle Analysis of a CNG Truck
(Projected Upstream Methane Emissions in 2025, Methane GWP of 72)

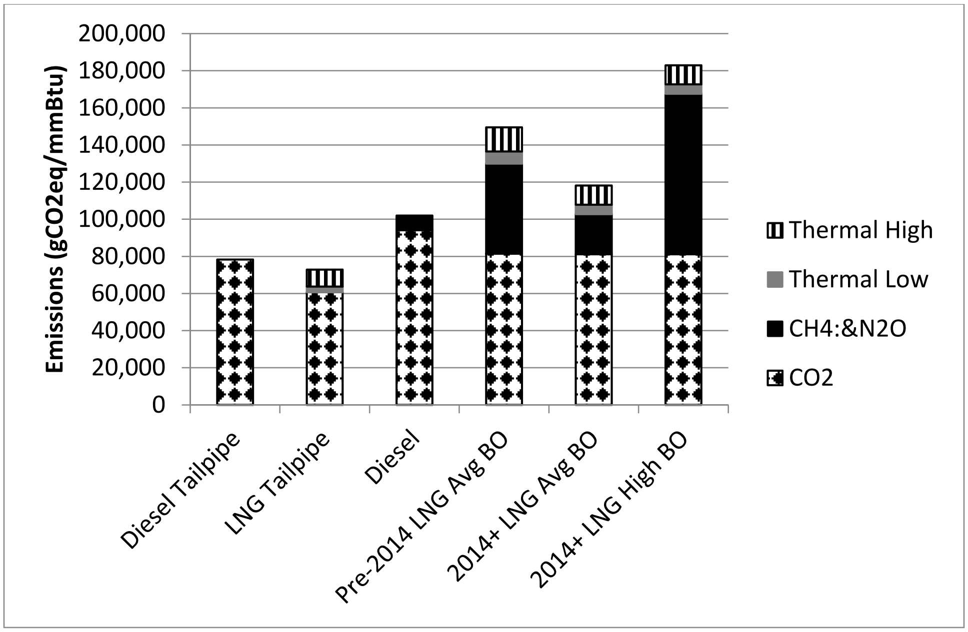

Figure 13-6 Full Lifecycle Analysis of an LNG truck
(Projected Upstream Methane Emissions in 2025,
Low and High Refueling and Boil-Off Emission, methane GWP of 72)

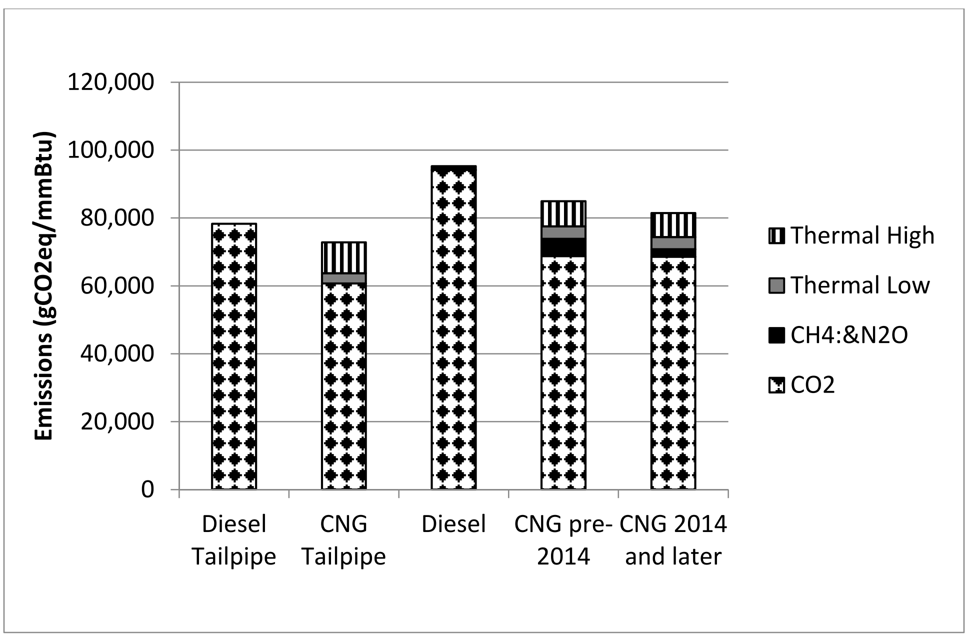

Figure 13-7 Full Lifecycle Analysis of a CNG Truck
(Projected Upstream Methane Emissions in 2025, Methane GWP of 7.6)

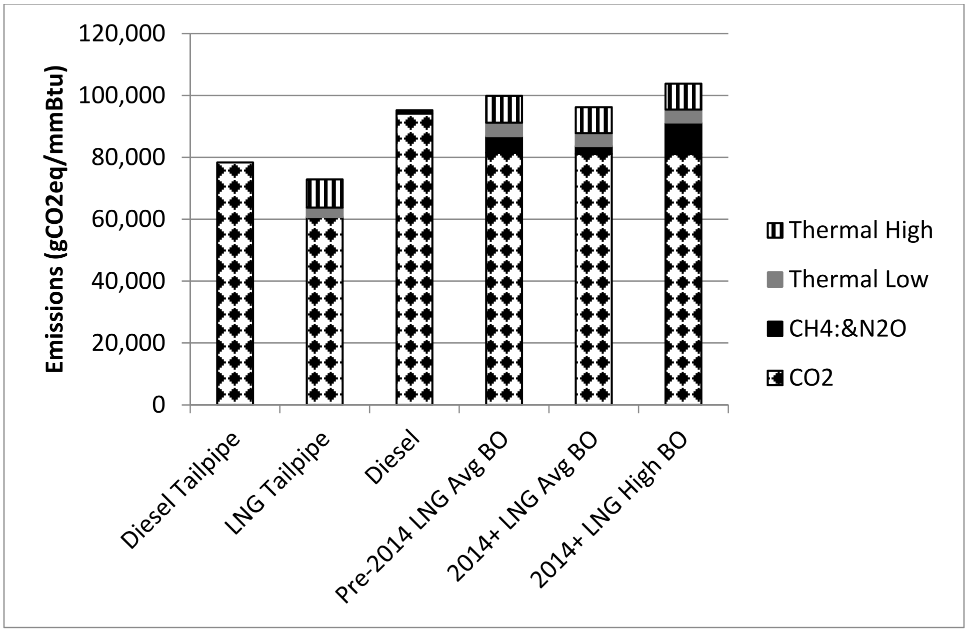

Figure 13-8 Full Lifecycle Analysis of an LNG truck
(Projected Upstream Methane Emissions in 2025,
Low and High Refueling and Boil-Off Emission, Methane GWP of 7.6)

Figures 13-5 through 13-8 show that when evaluated over a shorter timescale, the higher GWP for methane increases the relative lifecycle impact of natural gas trucks compared to diesel trucks. Conversely, when evaluated over a longer timescale, the lower GWP for methane decreases the relative lifecycle impact of natural gas trucks compared to diesel trucks.

We compared our lifecycle emission estimates for natural gas, relative to diesel fuel, with the estimates provided by the California Air Resources Board (CARB) for its Low Carbon Fuel Standard (LCFS). For our emissions estimate used in the comparison we used the carbon dioxide-equivalent (CO_2eq) emissions estimated for 2014 and later engines, which must comply with a methane tailpipe emissions standard, and assumed that the engine was 5 percent less thermally efficient than a comparable diesel engine. Both analyses used GWPs based on 100 year timescale (i.e., a GWP of 25 for methane and 298 for nitrous oxide). For the CARB emissions estimates, we used the estimates made for what it terms purposes" using the 2013 version of the CARB GREET model as published in August, 2014.[12] CARB estimates that CNG engines emit 76 percent of the CO_2eq emissions as a diesel truck, while our analysis estimates that CNG engines emit 81 percent of the CO_2eq emissions as a diesel truck. The most likely explanation for CARB's lower estimated CO_2eq emissions for CNG engines is that a much larger portion of the electricity used to compress natural gas is renewable in California than the rest of the country. CARB estimates LNG engines emit 94.5 percent of the CO_2eq emissions, as a diesel truck while our analysis estimates LNG trucks emit 96 percent of the CO_2eq emissions as a diesel truck. CARB assumes no boil-off or venting emissions from LNG trucks and for this comparison, we used our more modest boil-off and venting assumption, as described above, which is close to CARB's. Overall, our estimates are very similar to those estimated by CARB and when there are differences, the differences are as expected.[E]

A UC Davis report recently released estimated that CNG and LNG trucks using spark ignition engines (SING) emit about the same amount of CO_2-equivalent emissions, and these emissions are slightly higher than that of diesel engines.[13] The HPDI engines (DING) fueled by LNG are estimated to be the lowest emitting of the several scenarios analyzed by the study. Because the study did not discuss vehicle boil-off emissions, it is likely that the study either assumed that these emissions are zero or assumed the default vehicle boil-off emission estimates made by GREET. It is likely that the study assumed that the liquefaction plants are 90 percent efficient as this is the default assumption in GREET, which leads to lower GHG emissions by LNG trucks.

13.2 Projecting Natural Gas use in HD Trucks

EPA reviewed several information sources and projections to estimate how much natural gas is currently being used and is projected to be used by heavy-duty trucks. An obvious set of projections to review was the set of projections provided in the National Academy of Sciences (NAS) report.[14] The NAS report attached a figure, sourced from Citi Research, which provided projections by ACT, PACCAR, Frost and Sullivan and the National Petroleum Council.[15] This figure is reproduced below as Figure 13-9.

[E] Per Anthy Alexiades of CARB: CARB is planning to propose a new draft lifecycle analysis for CNG and LNG trucks at an April 2015 public meeting. While the CNG lifecycle is expected to be about the same, the LNG lifecycle analysis is expected to have lower emissions based on using a 90% efficiency for liquefaction plants instead of the 80% efficiency it was using previously. Lifecycle emissions for both CNG and LNG trucks will be adjusted to be 10% higher if using a spark ignition engine to account for their lower thermal efficiency. These estimates are solely for hypothetical analyses. LCFS credits are awarded based on GHG emissions for each specific application.

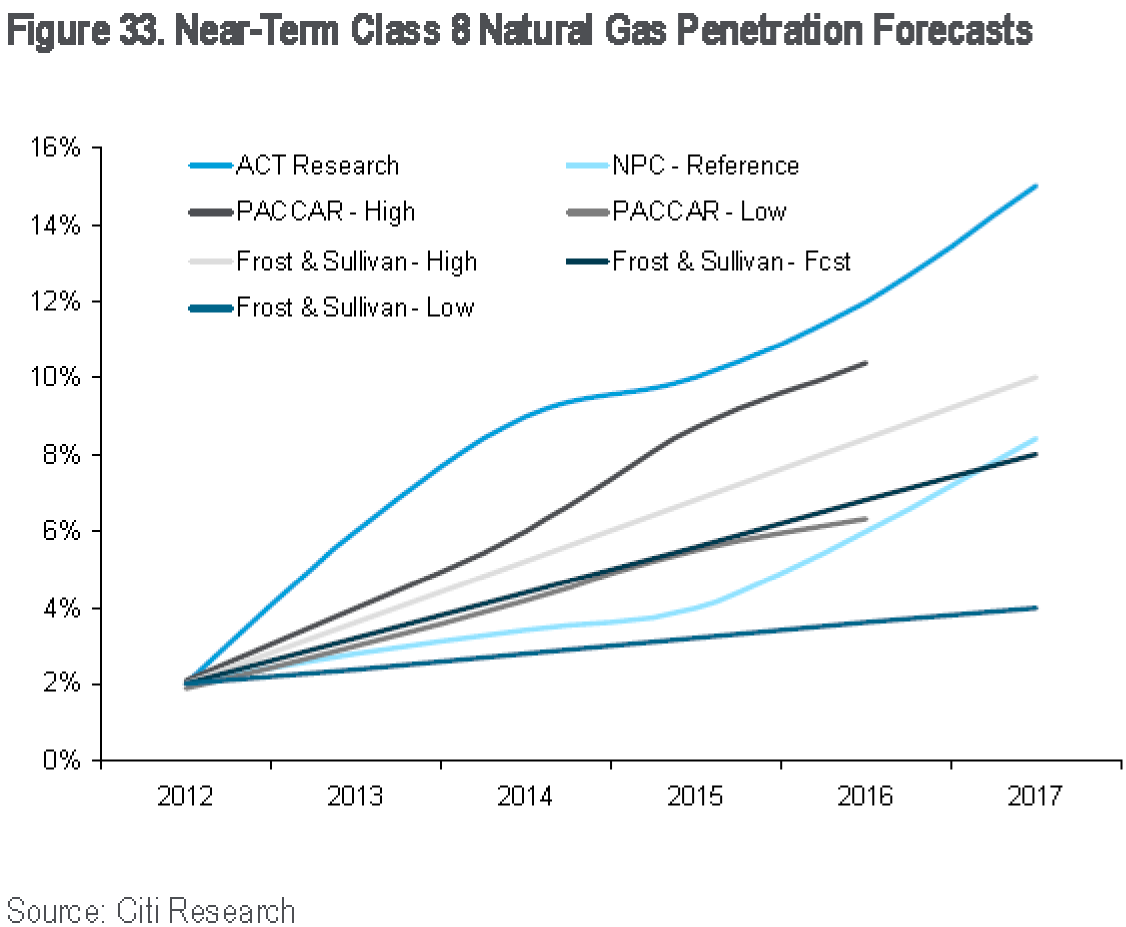

Figure 13-9 Near-Term Class 8 Natural Gas Penetration Forecasts

The first observation we can make about all these reports is that they start out assuming that natural gas use is 2 percent of the Class 8 heavy duty truck fleet in 2012. However, that level of natural gas vehicle penetration of the heavy-duty fleet is not supported by other data sources. In the Energy Information Administration's Annual Energy Outlook 2014, EIA shows natural gas use comprising about only 0.2 percent of total heavy duty fuel consumption in 2012, and natural gas use by Class 8 trucks is under 0.1 percent.[16] In 2014, AEO 2014 shows natural gas comprising about 0.4 percent of total heavy-duty fuel demand and about the same for Class 8 heavy-duty truck demand.

One estimate of the number of natural gas trucks supports this level of fuel demand made by EIA. In a meeting with the Natural Gas Vehicle for America (NGVA), NGVA presented their estimate that 62,000 heavy-duty trucks are fueled by natural gas. The MOVES data base estimates that there are 12.4 million heavy-duty trucks in 2014. Combined, the NGVA and MOVES numbers estimate that natural gas heavy-duty trucks comprise 0.5 percent of the heavy-duty truck population.

We also evaluated the growth rates for natural gas trucks, including reviewing two of the studies referenced in the NAS report. The ACT Research study shows the most aggressive growth rate for natural gas heavy-duty trucks. The ACT Research projection did not seem to consider the economics of natural gas versus diesel fuel. Instead, the ACT projection seemed to be based on a consumer acceptance profile of a new technology, presumably assuming that the technology is already economically competitive. In a recent ACT press release for a more recent report, it was acknowledged that the growth rates ACT projected earlier were too aggressive and a more modest growth rate is more likely.[17] The NPC projection shows a similar growth rate as that estimated by ACT Research, but NPC's projection for increased uptake of the natural gas technology begins in 2015 instead of 2012. In its study, NPC assumed that the increased capital cost for a natural gas truck compared to a diesel truck study decreases from $60,000 to $20,000 by 2040.[18] This cost decrease seems excessive, and it is likely an important reason why the NPC study shows such a large increase in natural gas use by heavy-duty trucks. We did not have access to core assumptions used in the PACCAR and Frost and Sullivan projections to assess their viability.

We searched for the Citigroup report on the Web and in addition to the figure provided in the NAS report, we found Citi Group's projection shown in the context of the other projections referenced by NAS from the Citi bank report in Figure 13-10.[19] Citi Group's projection is less optimistic than the ACT projection, but is more optimistic than the NPC reference case projection.

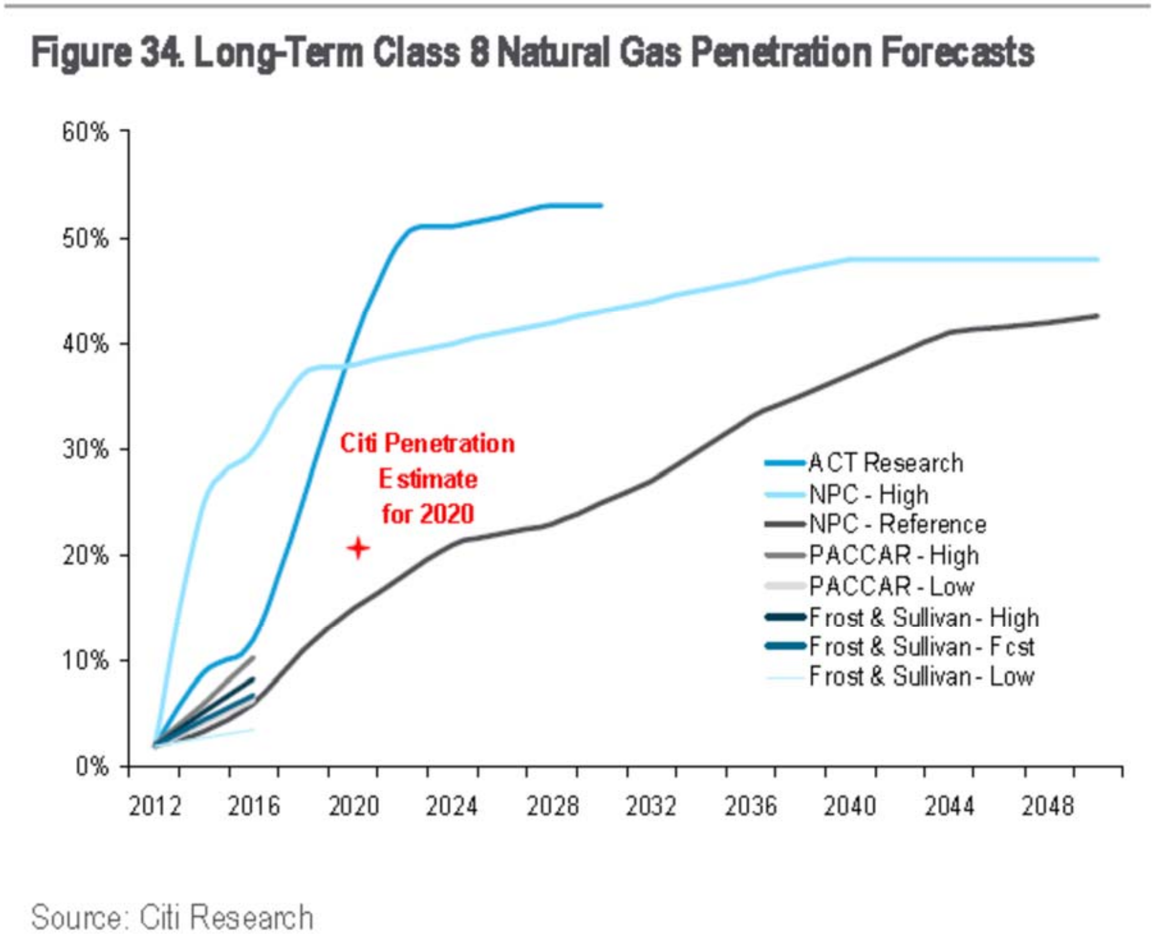

Figure 13-10 Long-Term Class 8 Natural Gas Penetration Forecasts

In its Annual Energy Outlook, EIA projects the use of different fuels by the transportation sector.[20] This projection was not referenced in the NAS report, but our review found it to be especially credible.

First, as described above, EIA estimates that natural gas fueled 0.4 percent of the energy use of heavy-duty trucks in 2014 and this estimate is consistent with the fraction of heavy-duty fleet which are fueled by natural gas.

Second, the EIA projection is based on an economic analysis which considers the increased cost of manufacturing a natural gas truck over a diesel truck, the fuel savings for using natural gas instead of diesel fuel, and whether the payback time of the fuel savings against the increased truck cost would trigger purchases of natural gas trucks. As part of this analysis, EIA assumes that lighter heavy-duty trucks would use CNG which is a lower cost technology suited for the shorter driving distances for these trucks. The long haul trucks, however, require larger stores of fuel to extend the driving range which is satisfied by storing the natural gas as a liquid. LNG has about 60 percent of the energy density of diesel fuel, compared to CNG which has only 25 percent of the energy density of diesel fuel. To satisfy the long driving range of the long haul trucks, EIA assumed that they would use LNG as a fuel. The assumptions used by EIA for conducting its economic analysis all seem reasonable.

Third, EIA is one of the several well-respected organizations in the world for collecting and analyzing today's fuel prices and projecting future fuel prices. According to the Alternative Fuels Data Center, one of the most important assumptions in projecting the future use of natural gas in the transportation sector is the relative price of natural gas to the price of diesel fuel. Figure 13-11 summarizes the total retail prices and the cost components that make up the final average year 2014 retail prices of diesel fuel, CNG and LNG, whose prices are expressed on a diesel gallon-equivalent basis.

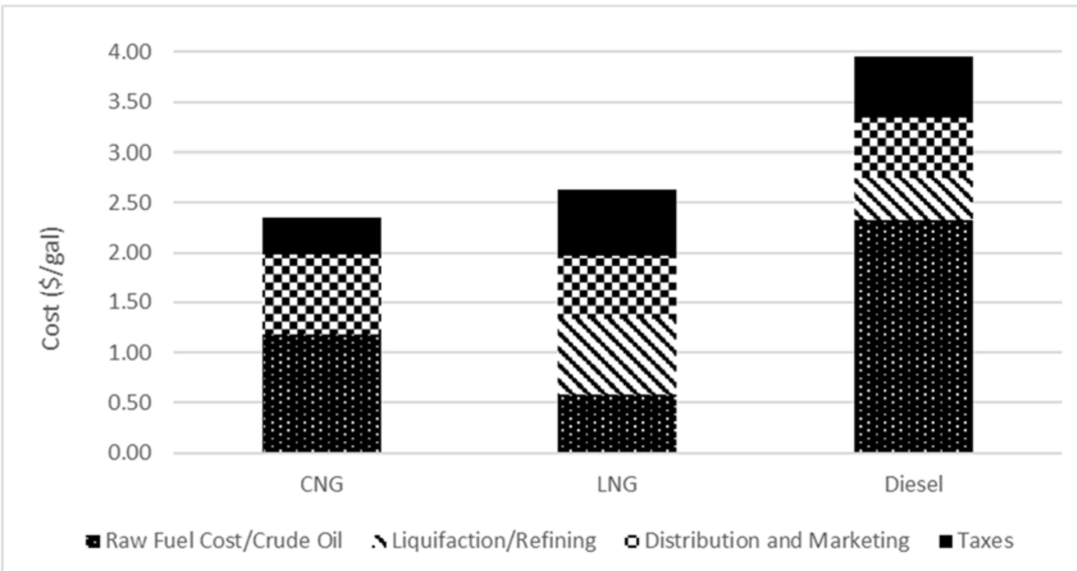

Figure 13-11 Relative Retail Cost of CNG and LNG to Diesel Fuel ($/gal dge)

In 2014, the natural gas price purchased by industrial users was about $6 per million BTU, which corresponds to $0.60 per diesel gallon equivalent. The price of crude oil has been volatile during 2014 as the Brent crude oil price started at about $110 per barrel ($2.38/gallon), but decreased to under $50 per barrel towards the end of 2014. From EIA's website, the average retail diesel fuel price in the first part of 2014 was about $3.80 cents per gallon. When comparing the natural gas spot market price on a diesel equivalent basis to the diesel fuel price, it appears that natural gas is priced about one quarter of the diesel fuel price. However, if used as compressed natural gas, the natural gas must be distributed through smaller distribution pipeline system that exists in cities, which dramatically increases the price of the natural gas to $1.15 per DGE. Then the natural gas must be compressed and stored at a retail outlet which adds another $1.30 per DGE. The estimated retail price of CNG is $2.35 on a diesel gallon equivalent basis (DGE), or about $1.45 DGE less than diesel fuel.

Similarly, if natural gas is converted to LNG, the resulting retail LNG price is much higher than the raw natural gas price. LNG liquefaction plants are assumed to be located close to large transmission pipelines away from cities, thus, they would likely pay the same low price as industrial users. However, for producing LNG, the natural gas must be liquefied which adds about $0.75 DGE. When the LNG is transported to retail outlets and marked up, the LNG is priced $60 per DGE higher. The tax applied to LNG is on a per gallon basis, thus, is much more than on a DGE basis because of LNG's lower energy density. All these steps add substantially to the price of the LNG and the estimated retail price of LNG is $2.65 DGE, or $1.15 DGE less than diesel fuel.

In its projections, EIA estimates that crude oil prices in the upcoming years will decline modestly until after 2020 when they start increasing until they reach $140/bbl in 2040. Natural gas prices are expected to only slightly increase over this period.

The fifth reason why the EIA projections seem reasonable is because the payback hurdle assumptions assumed for truck fleet owners seem reasonable. EIA projects that natural gas trucks begin to be purchased when the payback times are 4 years or less based on a survey conducted by the American Trucking Associations. The ATA survey found that 24 percent of respondents would choose natural gas trucks over diesel trucks if the payoff is 4 years, another 57 percent would choose natural gas if the payoff is 3 years, the next 15 percent would choose natural gas if the payoff is 2 years and the last 5 percent would choose natural gas if the payoff is 1 year or less.[21] This is consistent with some conversations we have had with some fleet owners. The NAS cites the pay back for the extra cost of natural gas trucks as 2 years, but other sources report a longer return closer to 4 years.[F]

The results of EIA's economic analysis and projected natural gas use in heavy duty trucks presented in the 2014 Annual Energy Outlook is presented in Figure 13-12.[22]

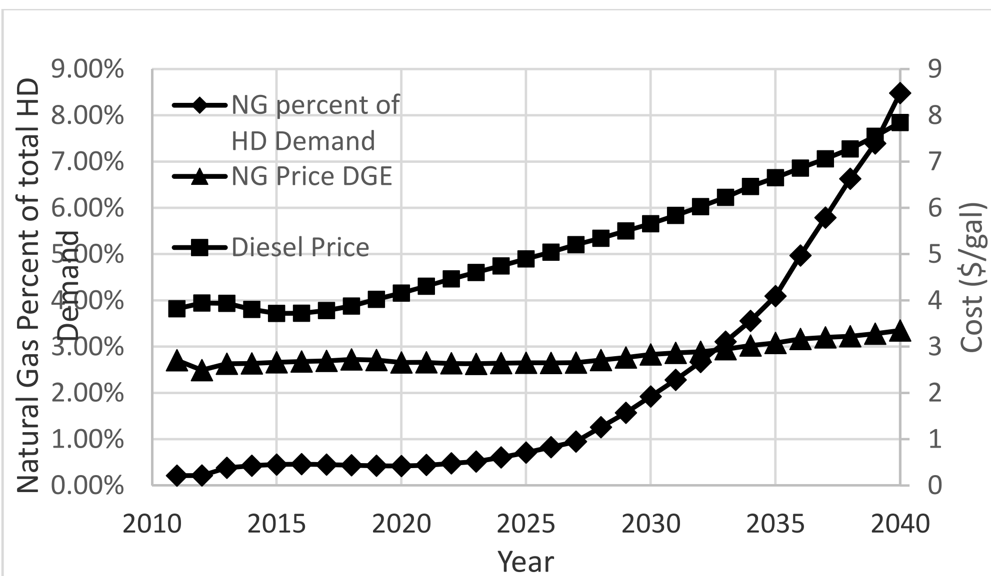

Figure 13-12 EIA Projection of Fuel Prices and Natural Gas Use by HD Engines

Figure 13-12 shows, as we discussed above, that natural gas currently supplies only about 0.5 percent of total heavy-duty truck fuel demand and it expected to continue to do so until about 2023. Starting in 2023, EIA estimates that the rising price of diesel fuel relative to that of natural

[F] Early LNG Adopters Experience Mixed Results; Truck News, October 1, 2013 gas, which begins to change about 2019, creates the economic incentive to purchase natural gas trucks. As expected, the EIA projection that the price differential between natural gas and diesel fuel continues to increase results in the effect that the uptake of natural gas use in the heavy-duty truck fleet accelerates as the price differential increases.

A very interesting conclusion of the EIA projection is the natural gas penetration differences between the different heavy-duty truck classes. Figure 13-13 summarizes the projected use of natural gas by the AEO for different truck classes.

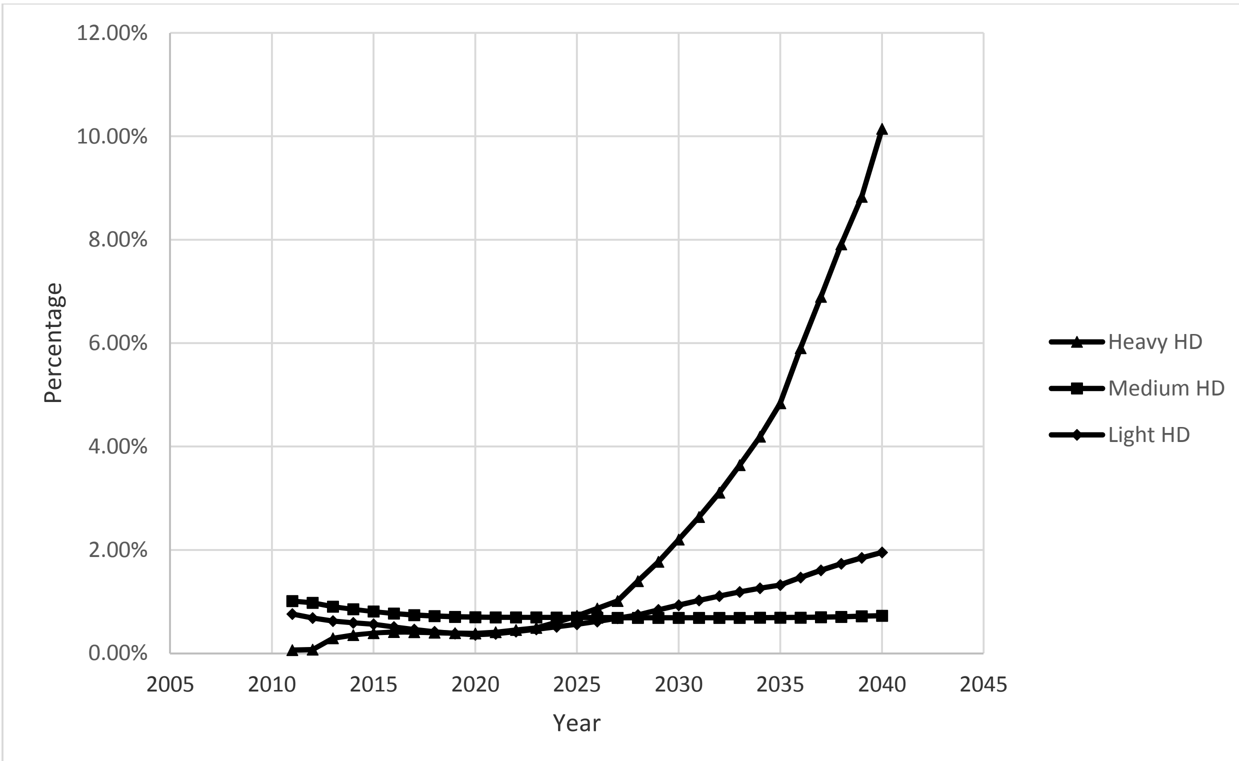

Figure 13-13 EIA Projection of NG use by Truck Weight Class

Figure 13-13 shows that the only heavy-duty sector which is projected to see a large penetration of natural gas is the heavy, heavy-duty sector which increases to 10 percent by 2040. The light and medium classes of the heavy-duty truck fleet only show modest increases in natural gas use. The likely reason EIA's analysis shows little CNG or LNG use by light and medium heavy-duty trucks is because they are driven far less and their use does not justify the higher purchase price. According to the Vehicle Inventory and Use Survey, light and medium heavy duty trucks average less than 1/3rd the annual mileage of the heaviest trucks.[23] EIA is using a distribution of VMT for new class 7 and 8 trucks as shown in Figure 13-14.

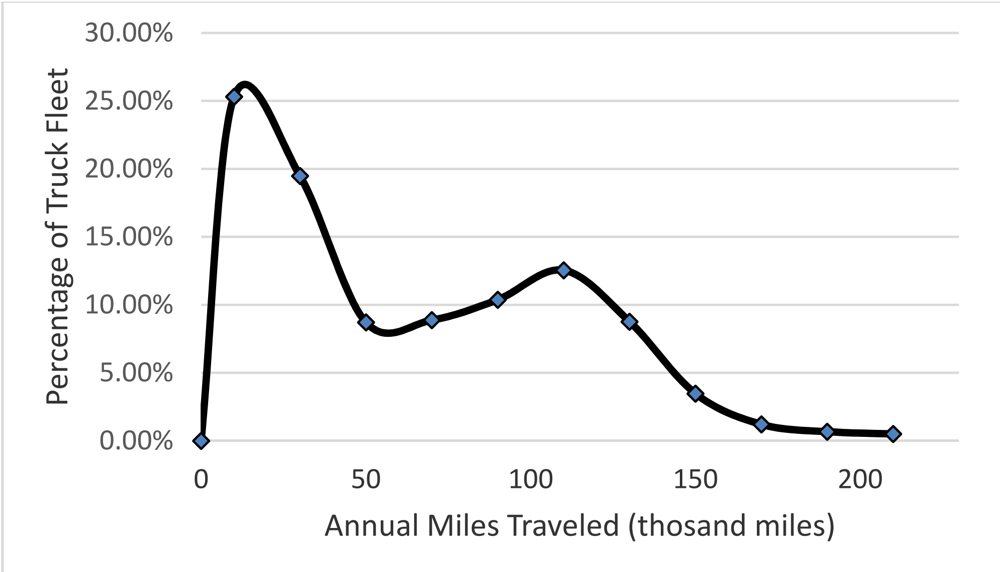

Figure 13-14 Percent of Class 7 and 8 Truck Fleet by Annual Miles Traveled

Figure 13-14 shows that although about half of class 7 and 8 trucks are driven less than 60 thousand miles per year, the other half is driven from 60 thousand to over 200 thousand miles per year. It is these high mileage long haul trucks which are prime candidates for using LNG because of their ability to pay down the high marginal natural gas truck cost.

Since EIA does not report the payback times as an output of its projections, we conducted our own analysis of sample payback times solely for illustrative purposes. We assessed the time required for the lower fuel cost of LNG to payback the incremental truck cost of using LNG assuming that a truck averages 120,000 miles per year. There were several important aspects of the payoff analysis that we conducted. First, based on the EIA analysis which found that the heavy, heavy-duty trucks sector is the only one which will see natural gas use increase dramatically, we solely studied the payback of natural gas in this truck sector. Second, as concluded by EIA, we also assume that the higher energy density of LNG will make it the most likely natural gas fuel type used by the heavy, heavy-duty trucks. Third, the higher natural gas truck cost was approximated from the analysis EIA conducted for its Annual Energy Outlook. Fourth, the analysis presents a simple payback as well as a discounted payback using a 7 percent discount factor. Fifth, we evaluated the payback in 2014, and we also assessed what the payback might be in 2020 and 2030 and assume some changes in the future years as discussed in some example evaluation cases below.

Table 13-20 Payback Analysis

	CASE 1 2014 DUEL FUELED	CASE 2 2014 HPDI	CASE 3 2020 HPDI	CASE 4 2030 HPDI
Miles per Year	120,000	120,000	120,000	120,000
Miles per Gallon	6.7	6.7	7.1	7.2
Incremental NG Truck Cost	55,000	70,000	65,000	60,000
Incremental NG Maintenance Cost per year	970	1613	1935	1935
Diesel Fuel Price ($/gal)	3.80	3.80	4.16	5.65
Natural Gas Price ($/gal DGE)	2.64	2.64	2.66	2.83
Diesel Fuel Cost per Year	68,263	56,886	70,608	94,167
Natural Gas Fuel Cost Per Year	60,062	43,978	50,614	53,810
Lower NG Efficiency (%)	5%	5%	5%	5%
Vehicle NG Use (%)	50%	95%	95%	95%
Simple Payback (years)	6.7	4.5	3.3	1.5
Discounted Payback (years)	9.1	5.5	3.7	1.6

We evaluated two different cases for 2014. Case 1 assumes an LNG fueled, heavy-duty truck which exceeds 26,000 gross vehicle weight rating and averages 120,000 miles per year. It is a mixed-fuel (MFNG) natural gas truck and is assumed to operate 50 percent on natural gas and 50 percent on diesel fuel. But because this truck can operate on diesel only, the truck can manage with a more modest storage quantity of LNG, thus reducing the cost of LNG storage. When this truck is fueled by LNG, it is estimated to be 5 percent less thermally efficient. The fuel costs are consistent with the prices during the first part of 2014. Accounting for the fuel cost savings based on the average fuel economy and also accounting for the increased maintenance cost for operating on LNG,[G] this truck only achieves a discounted payback time of 9.1 years for paying down the $55,000 increased cost for this truck.

The second case we evaluated for 2014 is a direct injection natural gas (DING) truck. Because this truck must fuel on LNG or be parked (the diesel fuel is simply used to enhance the combustion process), there must be more LNG storage capacity and the truck purchase price is estimated to be $70,000 more than a diesel truck. This case also assumes 120,000 miles accumulated per year. The discounted payback time is 5.5 years, which is less than the first case because the truck runs more of the time on natural gas.

If we used the lower diesel fuel prices that we experienced later on in 2014 and early 2015 ($2.90/gallon), the payback time would be much longer. Even on a simple payback basis, the payback time is over 20 years for both Case 1 and Case 2.

For Case 3, we assessed a 2020 case using EIA fuel price projections. Like the second case, the truck is a DING truck, but because it is six years later, we assumed a modest cost

[G] FPInnovations estimates that natural gas truck maintenance costs are $0.01/per kilometer more than diesel trucks.

reduction due to a learning curve. Due to the large price spread between diesel and natural gas, this truck's discounted payback time is 3.7 years.

For Case 4, we assessed a 2030 case using EIA fuel price projections. Like the previous two cases, the truck is a DING truck, and we assumed a further modest cost reduction due to a learning curve. This truck is also assumed to accumulate 120,000 annual miles fueled on LNG. Due to the even larger price spread between diesel and natural gas, this truck's discounted payback time is 1.6 years.

The payback time for both 2014 high mileage heavy-duty truck cases we evaluated are over 4 years. Since fleets become interested in purchasing natural gas trucks purchased when the payback times are 4 years or less, it explains the low penetration of natural gas in the heavy-duty sector.

Given the apparently poor payback times for natural gas vehicles in 2014, it suggests that existing subsidies for natural gas likely play an important role in encouraging its use. According to EIA, half the natural gas consumption by cars and trucks is in California and may be partially due to subsidies and other incentives California offers. California subsidies the purchase price of natural gas vehicles, and also offsets the cost of natural gas dispensing stations. The Low Carbon Fuel Standard (LCFS) in place in California also incentivizes natural gas use because natural gas is considered to cause less of an impact on the climate than petroleum-based gasoline and diesel fuel. The majority of the other half of the NG fleet is also in states which subsidize the natural gas truck or service station costs.

Based on the EIA projections for crude oil and natural gas prices, the payback time of LNG trucks is expected remain long (more than 4 years) until sometime around 2020 when crude oil prices are projected to begin increasing. Thus, natural gas use by heavy-duty trucks is not projected to increase above 1 percent of the heavy-duty fuel demand until after 2025. Even if the economics improve for using CNG and LNG in the heavy-duty fleet, another hurdle is fuel availability since these fuels are not already widely available. Figure 13-15 shows the number of CNG and LNG public and private service stations relative to the number of gasoline and diesel fuel service stations and truck stops, respectively.

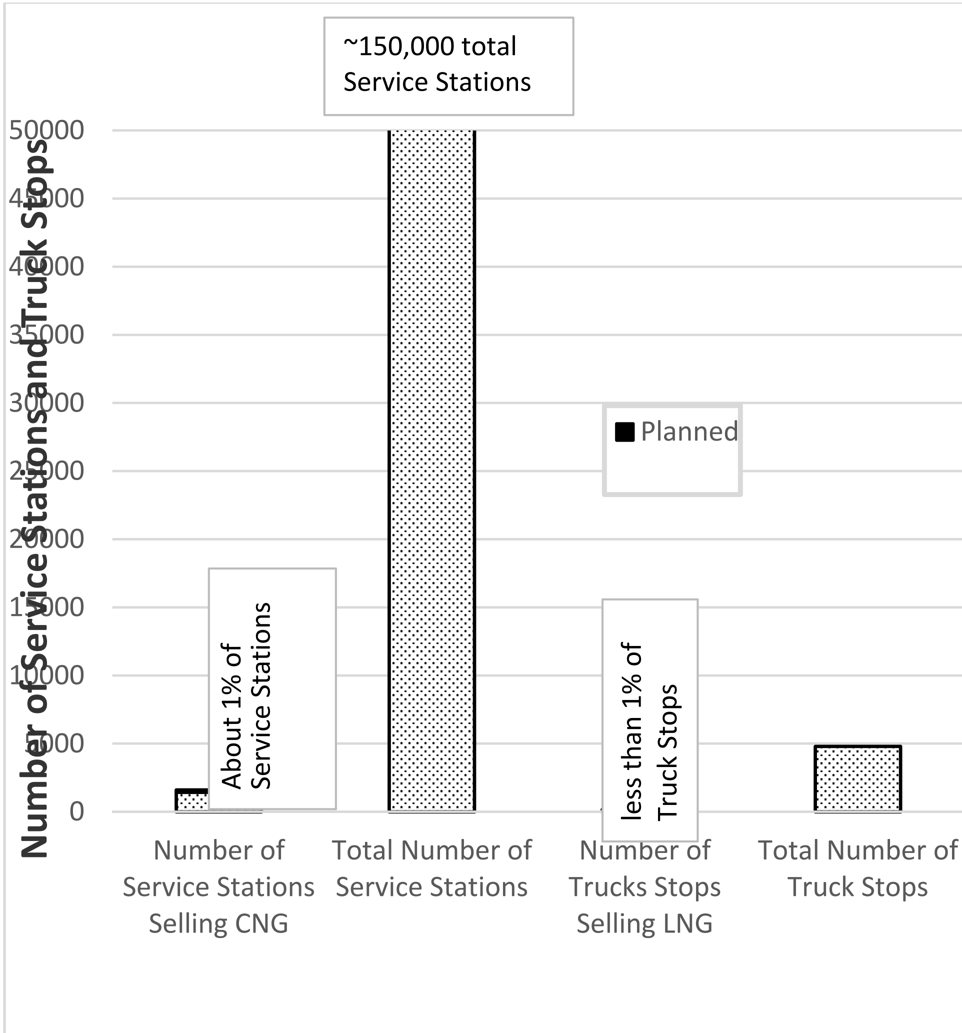

Figure 13-15 CNG and LNG Availability at Service Stations

As Figure 13-15 shows, CNG and LNG fuel availability at service stations is 1 percent or less of the availability of gasoline and diesel fuel. Even if a business owner finds the purchase of one or more new natural gas trucks an attractive investment, if the fuel is not available in the area, the business owner may have to forgo purchasing the natural gas trucks. A fleet owner might be in the position to also install a natural gas service station or establish a contract with a third party fuel provider to provide the fuel, but that may require making a large purchase of trucks to justify the installation of the service station or the establishment of the contract. If the fleet owner would need to build a CNG or LNG refueling station to enable purchasing the natural gas trucks, then the combined cost of the service station installation and the natural gas trucks purchase could make the prospect uneconomic even if the natural gas truck purchase by itself is justified. LNG availability is particularly challenging because in addition to an LNG service station, a LNG liquefaction plant would be needed as well. If the economics turn favorable for using natural gas in the truck fleet, the conversion to natural gas is likely to be slow due to the need to build out the fuel availability.

13.2.1 **Dimethyl Ether**

Although NAS focused its recommendations on natural gas, it also discussed dimethyl ether (DME), which is a potential heavy-duty truck fuel sourced from natural gas. Dimethyl ether has a high cetane number (more than 55), although its energy density is about 60 percent of that of diesel fuel. Dimethyl ether is a volatile fuel, like liquid petroleum gas, that can be stored as a liquid at normal ambient temperatures under moderate pressure. Typical DME fuel tanks would be designed to prevent any significant evaporative emissions.

A DME fueled truck is only modestly more expensive than a diesel fuel truck. The fuel tank is more expensive than a diesel fuel tank, but much less expensive than an LNG tank since it does not need to be heavily insulated. The engine modifications to enable using DME are also modest. Because DME does not have carbon-carbon bonds that form particulate particles during combustion, the particulate filter, which is normally installed on recent year diesel trucks, can be eliminated. This offsets some of the increased DME engine and fuel tank costs.

Although DME is sourced from cheap natural gas, the conversion of natural gas to DME and moving the fuel to retail outlets greatly increases the cost of the fuel. As Figure 13-16 shows, DME is more expensive than LNG, but still lower in cost than diesel fuel. Similar to Figure 13-11, the diesel fuel price used in Figure 13-16 is based on crude oil prices in early 2014.

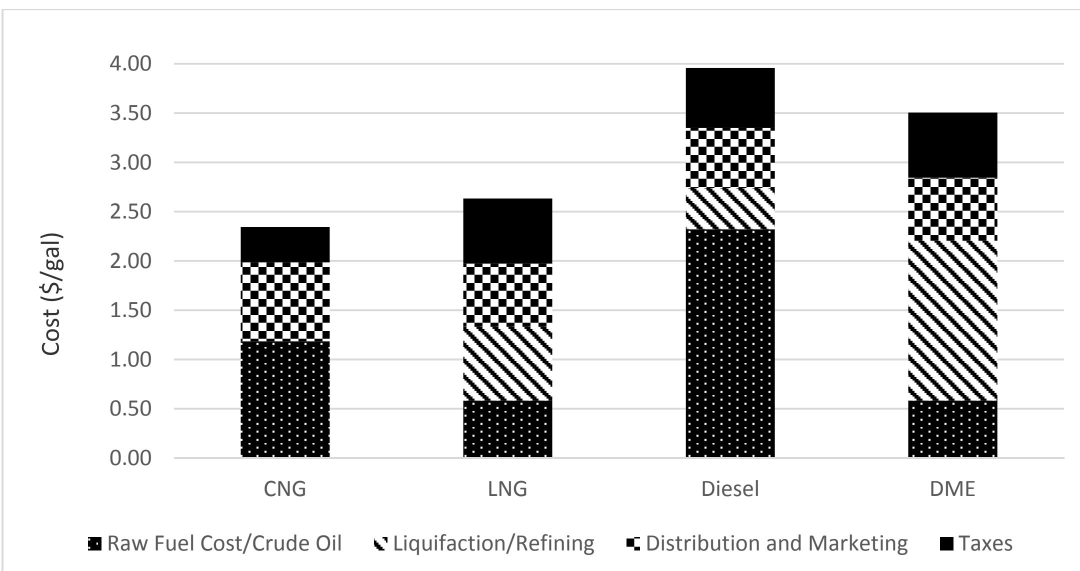

Figure 13-16 Relative Retail Cost of DME to CNG, LNG and Diesel Fuel ($/gal dge)

DME is estimated to cost $3.50/ DGE, or $0.30 DGE less than diesel fuel.

Because there is very little DME use in the US (there is only a very small fleet of DME trucks being contemplated in California), we did not conduct a lifecycle assessment of DME. We will, however, discuss a few aspects of a lifecycle analysis for DME. First, since DME is sourced from natural gas, the upstream methane emissions from the natural gas industry would still be allocated to DME. Second, there are not venting issues associated with DME as with LNG or CNG refueling. Third, but very significantly, DME's global warming potential is estimated to be 0.3 when assessed over a 100 year lifetime, which is about 1 percent of methane's GWP.[24]

13.3 Natural Gas Emission Control Measures

13.3.1 **Proposed Control Measures**

EPA is proposing some control measures to reduce potential methane emissions from natural gas vehicles. The cost discussion for each is below.

13.3.1.1 Crankcase Emissions

The proposal would require that all natural gas engines have closed crankcases, rather than continuing the provision that allows compression-ignition engines to separately measure and account for crankcase emissions that are vented to the atmosphere. This allowance has historically been in place to account for the technical limitations related to recirculating crankcase gases with high PM emissions back into the engine's air intake. Natural gas engines have inherently low PM emissions, so there is no technological limitation that would prevent manufacturers from closing the crankcase and recirculating all crankcase gases into the engine's air intake. The methane standard that was introduced in Phase 1 of this rule accounts for crankcase emissions by requiring methane in crankcase emissions be measured and included. However, there can be significant deterioration with respect to volatile crankcase emission such as methane, and it is difficult to ensure that all deterioration is fully reflected in the manufacturer's deterioration factor. When the system is sealed and emissions are routed to the engine intake, crankcase emissions are zero and deterioration ceases to be a concern. See the Preamble Section II. D. for a description of the proposed requirement.

Most (if not all) NG engines are derived from either a gasoline engine or a diesel engine. Since it is already required for gasoline engines to seal the crankcase, it is not necessary to propose any crankcase changes for gasoline-derived engines. Diesel engines are not required to seal the crankcase, but are required to include the crankcase emissions in the emissions test. Many OEMs already close the crankcase for their engines, and EPA projects the average costs to comply with this proposed requirement would be negligible.

13.3.1.2 Require 5 Day Hold Time

Boil-off emissions from LNG vehicles were not addressed nor accounted for in Phase 1 of this rule. As more testing has been done in this area since that time for this emerging issue, a minimal requirement EPA is proposing as described in the Preamble Section XII is to require manufacturers to follow current industry recommended practice, SAE J2343 for five day hold time to limit boil-off emissions from LNG vehicles. The ANSI standard for NG vehicles was adopted in 1994 when we required evaporative standards for NG vehicles (59 FR 48472 September 21, 1994). This was updated to the more recent ANSI NGV1-2006 in the Tier 3 Rule

(79 FR 23414, April 28, 2014) to the proposal would adopt the analogous requirements for LNG, found in SAE J2343 in Section 4.2.

The specifications of this safety related standard will only affect new LNG vehicles to prevent boil-off initially and does not address aging vehicles as their insulating properties diminish such as loosing vacuum over time and may eventually result in much shorter hold times. The SAE J2343 test is done at 72°F, therefore it is reasonable to assume that hold times will be shorter for very hot summer days and high solar loading.

Since the majority or all of the NG vehicles are already compliant with the NFPA 52 and SAE J2343 recommended practices for 3 and 5 day hold times, there would appear to be zero to minimal costs for the requirement for a 5 day hold time.

13.3.2 **Potential Controls**

EPA is also investigating additional controls to further reduce potential methane emissions from natural gas vehicles.

There are not well defined cost estimates for many of these options since they are ideas that will require research and development.

13.3.2.1 Update to CO_2 Credits Program

The Phase 1 Heavy-duty vehicle rulemaking establishing greenhouse gas emission standards included a compliance alternative allowing heavy-duty manufacturers and conversion companies to comply with the respective methane or nitrous oxide standards by means of over-complying with CO_2 standards (40 CFR 85.525 (ii)). The heavy-duty rules allow averaging only between vehicles or engines of the same designated type (referred to as an “averaging set” in the rules). Specifically, the Phase 1 Heavy-duty rulemaking added a CO_2 credits program which allowed heavy-duty manufacturers to average and bank pollutant emissions to comply with the methane and nitrous oxide requirements after adjusting the CO_2 emission credits (generated from the same averaging set) based on the relative GHG equivalents. To establish the GHG equivalents used by the CO_2 credits program, the Phase 1 Heavy-duty vehicle rulemaking incorporated the IPCC Fourth Assessment Report GWP values of 25 for CH_4 and 298 for N_2O, which are assessed over a 100 year lifetime.

Since the Phase 1 rule was finalized, a new IPCC report has been released (the Fifth Assessment Report), with new GWP estimates. This is prompting us to look again at the relative CO_2 equivalency of methane and to seek comment on whether the methane GWP used to establish the GHG equivalency value for the CO_2 Credit program should be updated to those established by IPCC in its Fifth Assessment Report. The Fifth Assessment Report provides four 100 year GWPs for methane ranging from 28 to 36. Therefore, we not only request comment on whether to update the GWP for methane to that of the Fifth Assessment Report, but also on which value to use from this report.

The costs for changing the GWPs used for the CO_2 Credits Program can be estimated by the cost to the manufacturer for reducing CO_2 emissions. If for example the GWP of methane is increased from 25 to 34, then the number of CO_2 credits that will be necessary to offset methane emissions above the standard can be calculated by this change. The cost involved would be the cost per ton of CO_2 for the difference in CO_2 credits. See chapter 7 for a discussion of our estimated cost per ton of CO_2 credit.

13.3.2.2 Deterioration Factors for NG Tailpipe Emissions

The current deterioration factors are based on diesel technology.

13.3.2.3 Vehicle Boil-Off Warning

A simple means to help limit boil-off emissions would be to require that natural gas truck drivers be alerted to expected near-future boil-off events. Such an alert could be in the form of a warning light and associated alarm that would indicate that the LNG storage tank is approaching a pressure which would require that the tank vent. Knowing this, the truck driver could take evasive action to prevent such a release.

A second alarm could be required when the LNG tank is venting. This would alert the truck driver to take action to avoid the potential for an explosive environment forming from the vented natural gas emissions.

To alert for a boil-off event a pressure sensor integrated with the vehicle's horn would cost on the order of $5.

13.3.2.4 Extend 5 Day Hold Time

The specifications of the proposed 5 Day Hold Time SAE 2343 safety related standard will only affect new LNG vehicles to prevent boil-off initially and does not address aging vehicles as their insulating properties diminish such as loosing vacuum over time and may eventually result in much shorter hold times. LNG tank manufacturers are further developing their technologies for improvement of hold times and reducing boil-off from LNG storage tanks on trucks. These improvements can be incorporated by requiring longer hold times. It may be possible using these improvements in technology to extend the hold times to ten days or longer.

One example of an existing technology to address boil-off emissions has shown a 10 day or more hold time depending on ambient temperatures and solar loading experienced by the vehicle. Westport Innovations, Inc. Ice Pack technology[H] is an integrated vehicle design which requires low pressure, lower temperature fuel, referred to as "blue" fuel, for the longer hold times. The system does accept the typical LNG fuel which is higher pressure and temperature, referred to as "green" fuel, at the expense of shorter hold times. Fleet owners of these innovative vehicles have installed refueling stations which service their own fleets. The Ice Pack technology used by Westport has been on the market since 2007 and has gone through several revisions to work out issues. The technology involves a pump at the bottom of the tank which

[H] Reiskin, Jonathon S. "Expensive Fuel Tanks, Systems Drive High Price of Nat-Gas Trucks", Transport Topics Special Report "Alternative Fuels" December 2013 pumps the liquid fuel to the engine. Through a series of pressure changes and pumps, vapor is fed to the engine. At the same time a purge system takes the high pressure warming vapor in the fuel tank through a series of valves and feed it to the engine using the pressure. This purge system reduces the pressure of the fuel tank which further extends the hold time.

The range of enhancements necessary to achieve extended hold time of at least 10 days will range in cost from $5000 to $20,000 per vehicle.[I] Ice Pack technology used by Westport is on the higher end of that range due to the additional vehicle pump and complicated engineering system which depressurizes the LNG for use in the engine while purging the gas during engine operation and keeping the LNG in the tank cold. Other approaches used by OEMs include increasing the vacuum size between the interior and exterior tank walls to maximize the insulation, keeping heat transfer to a minimum. The colder the LNG stays, the longer the hold time.

13.3.2.5 Capturing and/or Converting Methane Refueling or Boil-Off Emissions

A methane canister using adsorbents such as ANG (adsorbed natural gas) could be added to capture the methane which otherwise would be released to the environment during a refueling or boil-off event. Once captured, steps could be taken to route the methane to the engine intake once the vehicle is operating again, or to take steps to converting the methane to less GHG-potent CO_2. ANG has been a patented technology since the 1950's.[J] The Department of Energy (DOE) Advanced Research Projects Agency (ARPA-E) has awarded over $10 million in 2012 to four different projects to develop new sorbent materials for on-board natural gas storage. Gas Technology Institute (GTI), a research and development organization which serves energy and environmental markets has been utilizing the grant to develop lightweight, affordable, natural gas tanks for natural gas vehicles. Methane will adsorb more efficiently with high pressure such as a boil-off event onto this material.

As shown in Figure 13-17, for a 115 gallon LNG tank which would boil off completely in approximately 35 days[K] the boil-off methane emissions would be on the order of 18 lbs over two days, and close to 50 lbs in 5 days. This would require a canister of approximately 15-50 gallons of the adsorbent material for a 2-5 day hold time,[L] as show in Figure 13-18.

A methane canister using adsorbents such as ANG will need to be on the order of 15-50 gallons for 2-5 day hold time. It is still early to say what the costs for this application will be because there is so much engineering development and testing yet to do, but it is estimated that the casing and adsorbents for this size of canister will range from $1,500-$8,000.

[I] As per confidential discussions with OEM's, June 27, 2014, and November 20, 2014.
[J] Menon, V.C., Komarneni, S. "Porous Adsorbents from Vehicular natural Gas Storage: A Review", Journal of Porous Materials 5, 43-58 (1998)
[K] Powars, Charles A. "Best Practices to Avoid LNG Fueling Station Venting Losses", St. Croix Research for Brookhaven National Laboratory, 2010
[L] LNG-ANG Venting Calculations Spreadsheet, "LNG-ANG Venting Calcs.xlsx"

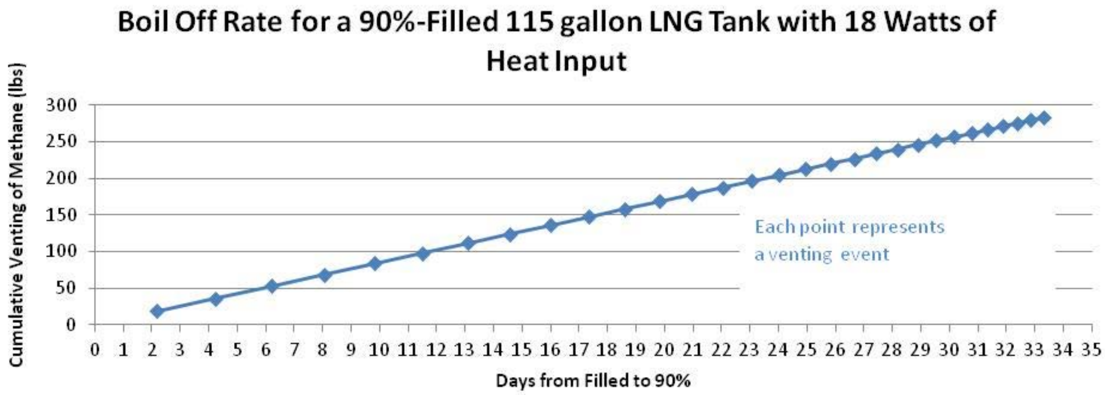

Figure 13-17 Boil Off Rate for a 90% Filled 115 gallon LNG Tank with 18 Watts of Heat Input

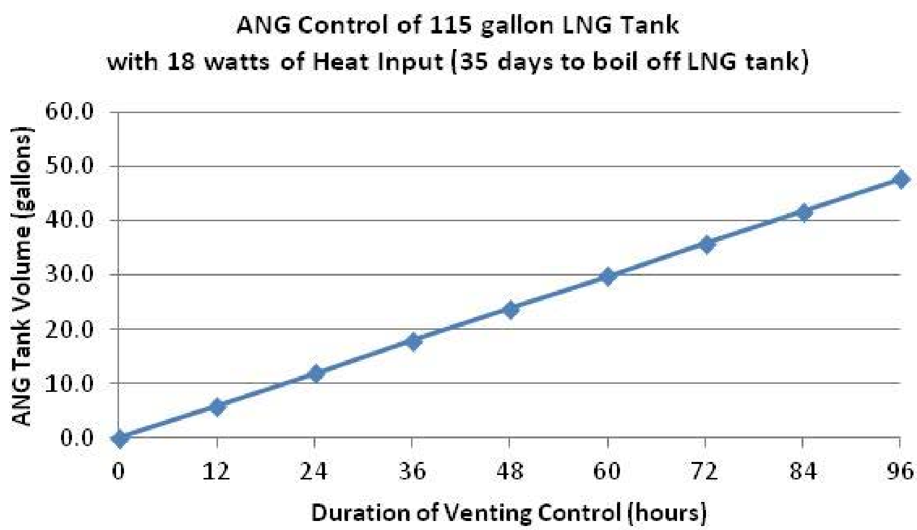

Figure 13-18 ANG Control of 115 gallon LNG Tank with 18 watts of Heat Input

If being discharged to the environment, the methane potentially could be burned to CO_2 using a burner. Another potential option would be to convert the methane captured in a canister to CO_2 over a catalyst. If a catalyst were to be developed, it would have to be designed to transform any escaping methane into carbon dioxide to reduce the global warming potential of methane down to that of carbon dioxide.

A methane catalyst for a boil-off event on a vehicle has not yet been designed. We acknowledge that this would be a challenge and expect a good deal of engineering will be required for this application which will include an external heat source to be triggered upon a boil-off event initiation, possibly a pressure sensor which notices when the pressure builds to close to 230 psi when boil-off occurs.

13.3.2.6 Reducing Refueling Emissions

In addition to the boil-off issue is the recurrence of manual venting at refueling by LNG truck operators. Under high pressure circumstances, such as when the vehicle has been sitting for some time period in warmer temperatures, it is necessary to decrease the pressure in the fuel tank before new fuel can enter the tank. The recommended practice is to transfer the extra vaporized fuel to the gas station or natural gas pipeline, but this can take extra time. In some areas it has turned into common practice to just vent to the atmosphere to keep the down time at the refueling station to a minimum. In other areas there is an incentive to reroute the gas into the station storage tank or natural gas pipeline with credit towards the fuel purchase. One option would be to require a system for rerouting back to fuel storage tank, whether it is to a CNG tank, a CNG pipeline or re-liquefying system for an LNG storage tank. There are opinions within the industry that the technology at the refueling station and the vehicles are advancing so that the newer pumps and vehicles will automatically vent any pressurized gas back through the refueling nozzle which will quickly cool with LNG in the fuel line and go back into the vehicle as a liquid which ultimately lowers the pressure with the drop in temperature. Most LNG refueling stations are already equipped with a vent line to take excess vapors back to the station storage tank before refueling with the cold liquid fuel. For the older LNG stations which are not equipped with a vent line, there would be an overhead cost of approximately $10,000-$15,000 to install a vent line system at each pump. Advancing this feature to tie into a NG pipeline for monetary credit would add another overhead of similar magnitude. The technology exists to install a very small methane liquefaction facility at a retail station which would allow the retail outlet to re-liquefy the vented gas and put it back into their storage tank.

Another option would be to control refueling emissions for LNG trucks with an on-board vapor recovery refueling system similar to light duty gasoline vehicles. This would likely involve a canister with carbon designed to adsorb methane specifically. See discussion in 13.3.2.5.4.

Onboard refueling will require research and development for an onboard canister with methane adsorbents with a canister sized to take the vapors from a refueling event. The resulting canister and therefore costs will likely be similar to the discussion in Section B4.2.4.

The recently promulgated Tier 3 rule requires use of the ANSI-NGV1-206 standard practice to meet the evaporative emissions refueling requirement. Small puffs of up to 200 cc/hr (which equates to 72 grams of methane per hour) of leakage are allowed with these tests. For CNG the current recommended practice for refueling involves a vent line taking a small amount of NG away from the operator for safety reasons, but this small amount is generally released to the atmosphere. Multiplied out for all of the refueling events of the CNG fleet this small amount can add up quickly especially with projected fleet expansion. When it is again multiplied by the methane GWP it would be worth investigating options for a system that would recompress the gas and reroute back into the CNG storage tank or pipeline.

Rerouting the vent line from a CNG refueling event will be a slightly more complex endeavor due to the mixing of air involved. In order to reroute the vent line to a NG pipeline for credit or to compress for usage will both require some engineering and development. This will be an overhead cost for the station.

13.3.2.7 OBD Requirements for Fuel System Methane Leak Detection

Onboard diagnostics (OBD) are required to detect and provide a warning for when methane leaks occur due to wear of connections and components of the CNG or LNG fuel system. Methane leaks occur due to wear of connections and components of the fuel system just as in gasoline or diesel systems. This can result in cracks, holes or structural breaks in the components. The HD OBD Rule requires comprehensive component monitoring with rationality and functionality checks for all HD vehicles including NG, by 2013. By 2019 all HD vehicles, including NG, must verify that their emissions control systems are functioning (74 FR 8310 February 24, 2009. The implementation schedule is found in 86.010-18(o)).

The requirements are already in place for methane leak detection. Therefore there would be minimal additional costs to include a pressure sensor and warning light for impending boil-off. The OBD code should already be programmed to record all associated methane leak events and keep a running record. Therefore adding accounting for boil-off venting should be minimal. There would be additional hardware and programming involved to detect whether the operator is venting high pressure gas to the refueling storage tank or to the atmosphere. Depending on the amount of engineering development required for a system of pressure and temperature sensors this approach could be relatively cost effective. The incremental costs for a vehicle with an OBD system already in place would be minimal, on the order of $5-10.

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