Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder

United States
Environmental Protection
Agency

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

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List of Acronyms

µm	Micrometers
b_{ext}	Light-Extinction Coefficient
µg	Microgram
µg/m3	Microgram per Cubic Meter
AAR	Association of American Railroads
ABT	Average Banking and Trading
ACS	American Cancer Society
AEO	Annual Energy Outlook (an EIA publication)
AESS	Automatic Engine Stop/Start System
AIM	Aerosol Inorganics Model
AIRS	Aerometric Information Retrieval System
APHEA	Air Pollution and Health: A European Approach
APU	Auxiliary Power Unit
AQ	Air Quality
AQCD	Air Quality Criteria Document
AQMTSD	Air Quality Modeling Technical Support Document
ARB	Air Resources Board (California)
ASLRRA	American Short Line and Regional Railroad Association
ASPEN	Assessment System for Population Exposure Nationwide
ATAC	Average Total Cost
avg	Average
BenMAP	Benefits Mapping and Analysis Program
bhp	Brake Horsepower
BNSF	Burlington Northern Santa Fe
BSFC	Brake Specific Fuel Consumption
BTS	Bureau of Transportation
C	Celsius
C1	Category 1
C2	Category 2
C3	Category 3
CA	California
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule (CAIR) (70 FR 25162, May 12, 2005)
CAMR	Clean Air Mercury Rule
CAND	Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004)
CARB	California Air Resources Board
CASAC	Clean Air Scientific Advisory Committee
CAVR	Clean Air Visibility Rule
CB	Chronic Bronchitis
CCV	Closed Crankcase Ventilation
CDC	Centers for Disease Control
CDPF	Catalyzed Diesel Particulate Filter
CEA	Cost Effective Analysis
CES	Constant Elasticity of Substitution
CFR	Code of Federal Regulations
CI	Compression Ignition (i.e., diesel engines)
CI	Confidence Interval
CIMT	Carotid Intima-Media Thickness
CITT	Chemical Industry Institute of Toxicology
CMAQ	Community Multiscale Air Quality
CMB	Chemical Mass Balance
CN	Canadian National Railroad
CO	Carbon Monoxide
CO_2	Carbon Dioxide

COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
CPI-U	Consumer Price Index - All Urban Consumers
C-R	Concentration Response
CSS	Coastal Sage Scrub
CUA	Cost Utility Analysis
cyl	Cylinder
D	Demand
DE	Diesel Exhaust
DEM	Domestic Engine Manufacturer
DDHS	Diesel Driven Heating System
diff	Difference
disp	Displacement
DOC	Diesel Oxidation Catalyst
DOE	Department of Energy
DOT	Department of Transportation
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
DR	Discount Rate
DRIA	Draft Regulatory Impact Analysis
DV	Design Values
EAC	Early Action Component
EC	Elemental Carbon
EDHS	Electric Driven Heating System
EF	Emission Factor
EGR	Exhaust Gas Recirculation
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EIA	Economic Impact Analysis
EIM	Economic Impact Model
EMD	Electromotive Diesel
EMS-HAP	Emissions Modeling System for Hazardous Air Pollution
EO	Executive Order
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005
ESPN	EPA speciation network
F	Fahrenheit
FEM	Foreign Engine Manufacturer
FEV	Functional Expiratory Volume
FR	Federal Register
FRA	Federal Railroad Administration
FRM	Final Rulemaking
FRP	Fiberglass-Reinforced Plastic
g	Gram
g/bhp-hr	Grams per Brake Horsepower Hour
g/kW-hr	Grams per Kilowatt Hour
gal	Gallon
GAO	Government Accountability Office
GDP	Gross Domestic Product
GEOS	Goddard Earth Observing System
GETS	General Electric Transportation Systems
GIS	Geographic Information System
H_2	Hydrogen Gas
HAD	Diesel Health Assessment Document
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HD	Heavy-Duty

HEI	Health Effects Institute
HEP	Head End Power
HES	Health Effects Subcommittee
hp	Horsepower
hp-hrs	Horsepower Hours
hrs	Hours
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
IMO	International Maritime Organization
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRIS	Integrated Risk Information System
ISCST3	Industrial Source Complex Short Term Model
ISORROPIA	Inorganic Aerosol Thermodynamic Model
JAMA	Journal of the American Medical Association
K	Kelvin
k	Thousand
km	Kilometer
kW	Kilowatt
kWH	Kilowatt Hour
L	Liter
lb	Pound
LM	Locomotive and Marine
LRS	Lower Respiratory Symptoms
LSD	Low Sulfur Diesel fuel
m3	Cubic Meters
MARAD	U.S. Maritime Administration
MARPOL	The International Convention for the Prevention of Pollution of Ships
MC	Marginal Cost
MCIP	Meteorology-Chemistry Interface Processor
MECA	Manufacturers of Emission Controls Association
mg	Milligram
MI	Myocardial Infarction
MILY	Morbidity Inclusive Life Years
min	Minute
MM	Million
MM-1	Inverse Megameter
MOBILE6	Vehicle Emission Modeling Software
MRAD	Minor Restricted Activity Days
MSAT	Mobile Source Air Toxic
MSAT1	2001 Mobile Source Air Toxics Rule
MSB	Major Shipbuilding Base
MVUS	Merchant Vessels of the U. S.
MW	Megawatt
MW-hrs	Megawatt Hours
N	Nitrogen
N_2	Nitrogen Molecule
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NATA	National Air Toxic Assessment
NBER	National Bureau of Economic Research
NCDC	National Clean Diesel Campaign
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network

NEI	National Emissions Inventory
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NH_3	Ammonia
NIOSH	National Institute of Occupational Safety and Health
NLEV	National Low Emission Vehicle
NMHC	Nonmethane Hydrocarbons
NMIM	National Mobile Inventory Model (EPA software tool)
NMIM2005	National Mobile Inventory Model Released in 2005
NMMA	National Marine Manufacturers Association
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NONROAD	EPA's Non-road Engine Emission Model
NONROAD2005	EPA's Non-road Engine Emission Model Released in 2005
NOx	Oxides of Nitrogen
NPRM	Notice of Proposed Rulemaking
NPV	Net Present Value
NRC	National Research Council
NREC	National Railway Equipment Co
NRLM	Nonroad, Locomotive and Marine diesel fuel
NRT4	Nonroad Tier 4 Rule
NSTC	National Science and Technology Council
NTE	Not To Exceed
O&M	Operating and maintenance
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OC	Organic Carbon
ºCA	Degree Crank Angle
OEHHA	Office of Environmental Health Hazard Assessment
OEM	Original Equipment Manufacturer
OMB	Office of Management and Budget
OTAQ	Office of Transportation and Air Quality
P	Price
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PGM	Platinum Metals Group
PM	Particulate Matter
PM AQCD	EPA Particulate Matter Air Quality Criteria Document
PM/NMHC	Particulate Matter to Non-Methane Hydrocarbon Ratio
PM10	Coarse Particulate Matter (diameter of 10 µm or less)
PM2.5	Fine Particulate Matter (diameter of 2.5 µm or less)
PMM	Post-Manufacturer Marinizer
PMNAAQS	Particulate Matter National Ambient Air Quality Standards
POM	Polycyclic Organic Matter
ppb	Parts per Billion
PPI	Producer Price Index
ppm	Parts per Million
psi	Pounds per Square Inch
PSR	Power Systems Research
Q	Quantity
QALY	Quality Adjusted Life Years
R&D	Research and Development
RfC	Reference Concentration
RFA	Regulatory Flexibility Analysis

RFS	Renewable Fuels Standard
RIA	Regulatory Impact Analysis
rpm	Revolutions per Minute
RPO	Regional Planning Organization
RRF	Relative Reduction Factors
RV	Revision
RVP	Reid Vapor Pressure
S	Sulfur
S	Supply
SAB	Science Advisory Board
SAB-HES	Science Advisory Board - Health Effects Subcommittee
SAE	Society of Automotive Engineers
SAPS	Sulfated-Ash, Phosphorus, and Sulfur Content
SBA	Small Business Administration
SBREFA	Small Business Regulatory Enforcement Fairness Act
SCC	Source Classification Code
SCR	Selective Catalyst Reduction
SI	Spark Ignition
SIC	Standard Industrial Classification
SiC	Silicon Carbide
SMAT	Speciated Modeled Attainment Test
SO_2	Sulfur Dioxide
SOx	Oxides of Sulfur
SOA	Secondary Organic Carbon Aerosols
SOF	Soluble Organic Fraction
STB	Surface Transportation Board
SVOC	Semi-Volatile Organic Compound
SwRI	Southwest Research Institute
TBN	Total Base Number
TCC	Total Compliance Cost
TCM	Total Carbon Mass
TDC	Top Dead Center
TFM	Transportacion Ferroviaria Mexicana
THC	Total Hydrocarbon
TSD	Technical Support Document
TVCC	Total Variable Compliance Cost
ULSD	Ultra Low Sulfur Diesel fuel
UP	Union Pacific Railroad
URS	Upper Respiratory Symptoms
USDA	United States Department of Agriculture
UV	Ultraviolet
UV-b	Ultraviolet-b
VOC	Volatile Organic Compound
VOF	Volatile Organic Fraction
VSL	Value of Statistical Life
WLD	Work Loss Days
WTP	Willingness-to-Pay
$2,005	U.S. Dollars in calendar year 2005

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Executive Summary

The Environmental Protection Agency (EPA) is finalizing a comprehensive three-part program to reduce emissions of particulate matter (PM) and oxides of nitrogen (NO_x) from locomotives and marine diesel engines below 30 liters per cylinder displacement. Locomotives and marine diesel engines designed to these more stringent standards will achieve PM reductions of 90 percent and NO_x reductions of 80 percent, compared to engines meeting the current Tier 2 standards. These standards will also yield sizeable reductions in emissions of nonmethane hydrocarbons (NMHC), carbon monoxide (CO), and hazardous compounds known as air toxics.

This program is part of EPA's ongoing National Clean Diesel Campaign (NCDC) to reduce harmful emissions from diesel engines of all types. The anticipated emission reductions will significantly reduce exposure to harmful pollutants and also provide assistance to states and regions facing ozone and particulate air quality problems that are causing a range of adverse health effects, especially in terms of respiratory impairment and related illnesses.

We project that by 2030, this program will reduce annual emissions of NOx and PM by 800,000 and 27,000 tons, respectively. The annual monetized $PM_{2.5}$- and ozone-related health benefits of this rule in 2030 will range from $9.2 billion to $11 billion, assuming a 3 percent discount rate, or between $8.4 billion to $10 billion, assuming a 7% discount rate. The estimated annual social cost of the program in 2030 is projected to be significantly less, at $740 million.

This Regulatory Impact Analysis provides technical, economic, and environmental analyses of the emission standards. Chapter 1 provides industry characterization for both the locomotive and marine industry. Chapter 2 presents air quality modeling results and describes the health and welfare effects associated with particulate matter (PM), ozone, and air toxics. Chapter 3 provides our estimates of the current emission inventories and the reductions that can be expected from implementation of the more stringent standards. Chapter 4 contains our technical feasibility justification for the emission limits, and Chapter 5 contains the estimated costs of complying with those standards. Chapter 6 presents the estimated societal benefits of the rulemaking. Chapter 7 contains our estimates of the market impacts of the more stringent standards and the distribution of costs among stakeholders. Finally, Chapter 8 contains our analysis of several alternative control scenarios we considered during the development of this rulemaking.

1. Emission Standards

The program we are finalizing addresses emissions from all types of diesel locomotives, including line-haul, switch, and passenger rail, and all types of marine diesel engines below 30 liters per cylinder displacement (collectively called “marine diesel engines.”).[A] These include marine propulsion engines used on vessels from recreational and small fishing boats to super-yachts, tugs and Great Lakes freighters, and marine auxiliary engines ranging from small gensets to large generators on ocean-going vessels. Each of these markets is described in Chapter 1.

We are finalizing a comprehensive three-part emission control program for locomotives and for marine diesel engines that will dramatically reduce the emissions from these sources. The standards and our technical feasibility justification are contained in Chapter 4.

The first part consists of near-term engine-out emission standards, referred to as Tier 3 standards, for newly-built locomotives and marine diesel engines. These standards reflect the application of engine-out PM and NO_x reduction technologies and begin to phase in starting in 2009. The second part consists of longer-term standards, referred to as Tier 4 standards, for newly-built locomotives and over 600 kW marine diesel engines. These standards begin to take effect in 2015 for locomotives and in 2014 for marine diesel engines. . For most engines, these standards are similar in stringency to the final standards included in the 2007 highway diesel and Clean Air Nonroad Diesel programs and are expected to require the use of high-efficiency aftertreatment systems to ensure compliance. These standards will be enabled by the availability of ultra-low sulfur diesel fuel (ULSD). Third, we are adopting more stringent emission standards for existing locomotives when they are remanufactured. Also included in this rulemaking are provisions to eliminate emissions from unnecessary locomotive idling and standards which apply to existing marine diesel engines over 600 kW when they are remanufactured.

Locomotive Standards

The standards for newly-built line-haul, passenger, and switch locomotives and for existing 1973 and later Tier 0, Tier 1, and Tier 2 locomotives are set out in Tables 1 and 2. With some exceptions, these standards will apply to all locomotives that operate extensively within the United States. Exceptions include historic steam-powered locomotives and locomotives powered solely by an external source of electricity.

[A] In this RIA, Amarine diesel engine@ refers to compression-ignition marine engines below 30 liters per cylinder displacement unless otherwise indicated. Engines at or above 30 liters per cylinder are being addressed in separate EPA actions.

Table ES-1 – Standards for Line-Haul and Passenger Locomotives (g/bhp-hr)

standards apply to:	take effect in year:	PM	NO_x	HC
Remanufactured Tier 0 & 1	2008 as available, 2010 required	0.22	7.4[a]	0.55
Remanufactured Tier 2	2008 as available, 2013 required	0.10	5.5	0.30
New Tier 3	2012	0.10	5.5	0.30
New Tier 4	2015	0.03	1.3	0.14

[a] For Tier 0 locomotives originally manufactured without a separate loop intake air cooling system, these standards are 8.0 and 1.00 g/bhp-hr for NO_X and HC, respectively.

Table ES-2 – Standards for Switch Locomotives (g/bhp-hr)

standards apply to:	take effect in year:	PM	NO_x	HC
Remanufactured Tier 0	2008 as available, 2010 required	0.26	11.8	2.10
Remanufactured Tier 1	2008 as available, 2010 required	0.26	11.0	1.20
Remanufactured Tier 2	2008 as available, 2013 required	0.13	8.1	0.60
New Tier 3	2011	0.10	5.0	0.60
New Tier 4	2015	0.03	1.3	0.14

Marine Standards

The standards for newly-built marine diesel engines are set out in Tables 3, 4, 5, and 6. The Tier 3 standards will apply to all marine diesel engines with per cylinder displacement up to 30 liters. The Tier 4 standards will apply only to commercial marine diesel engines above 600 kW.

For the purposes of this emission control program, Category 1 marine diesel engines are those with per cylinder displacement up to 7 liters. Category 2 marine diesel engines are those with per cylinder displacement from 7 to 30 liters. High power density engines are those with a power density above 35 kW/liter).

Table ES-3 – Tier 3 Standards for Marine Diesel C1 Commercial Standard Power Density

MAXIMUM ENGINE POWER	L/CYLINDER	PM g/bhp-hr *(g/kW-hr)*	NOx+HC[d] g/bhp-hr *(g/kW-hr)*	MODEL YEAR
<19 kW	<0.9	0.30 *(0.40)*	5.6 *(7.5)*	2009
19 to <75 kW	<0.9[a]	0.22 *(0.30)*	5.6 *(7.5)*	2009
		0.22 *(0.30)*[b]	3.5 *(4.7)*[b]	2014
75 to 3700 kW	<0.9	0.10 *(0.14)*	4.0 *(5.4)*	2012
	0.9- <1.2	0.09 *(0.12)*	4.0 *(5.4)*	2013
	1.2- <2.5	0.08 *(0.11)*[c]	4.2 *(5.6)*	2014
	2.5- <3.5	0.08 *(0.11)*[c]	4.2 *(5.6)*	2013
	3.5- <7.0	0.08 *(0.11)*[c]	4.3 *(5.8)*	2012

Notes:

[a] <75 kW engines at or above 0.9 L/cylinder are subject to the corresponding 75-3700 kW standards.

[b] Option: 0.15 g/bhp-hr (*0.20 g/kW-hr*) PM / 4.3 g/bhp-hr (*5.8 g/kW-hr*) NOx+HC in 2014.

[c] This standard level drops to 0.07 g/bhp-hr (*0.10 g/kW-hr*) in 2018 for <600 kW engines.

[d] Tier 3 NOx+HC standards do not apply to 2000-3700 kW engines.

Table ES-4 Tier 3 Standards for Marine Diesel C1 Recreational and Commercial High Power Density

MAXIMUM ENGINE POWER	L/CYLINDER	PM g/bhp-hr *(g/kW-hr)*	NOx+HC g/bhp-hr *(g/kW-hr)*	MODEL YEAR
<19 kW	<0.9	0.30 *(0.40)*	5.6 *(7.5)*	2009
19 to <75 kW	<0.9[a]	0.22 *(0.30)*	5.6 *(7.5)*	2009
		0.22 *(0.30)*[b]	3.5 *(4.7)*[b]	2014
75 to <3700 kW	<0.9	0.11 *(0.15)*	4.3 *(5.8)*	2012
	0.9- <1.2	0.10 *(0.14)*	4.3 *(5.8)*	2013
	1.2- <2.5	0.09 *(0.12)*	4.3 *(5.8)*	2014
	2.5- <3.5	0.09 *(0.12)*	4.3 *(5.8)*	2013
	3.5- <7.0	0.08 *(0.11)*	4.3 *(5.8)*	2012

Notes:

[a] <75 kW engines at or above 0.9 L/cylinder are subject to the corresponding 75-3700 kW standards.

[b] Option: 0.15 g/bhp-hr (*0.20 g/kW-hr*) PM / 4.3 g/bhp-hr (*5.8 g/kW-hr*) NOx+HC in 2014.

Table ES-5 – Tier 3 Standards for Marine Diesel C2[a]

MAXIMUM ENGINE POWER	L/CYLINDER	PM g/bhp-hr *(g/kW-hr)*	NOx+HC[b] g/bhp-hr *(g/kW-hr)*	MODEL YEAR
< 3700 kW	7- <15	0.10 *(0.14)*	4.6 *(6.2)*	2013
	15- <20	0.20 *(0.27)*[c]	6.5 *(8.7)*[c]	2014
	20- <25	0.20 *(0.27)*	7.3 *(9.8)*	2014
	25- <30	0.20 *(0.27)*	8.2 *(11.0)*	2014

Notes:

[a] See note (c) of Table ES-6 for optional Tier 3/Tier 4 standards.

[b] Tier 3 NOx+HC standards do not apply to 2000-3700 kW engines.

[c] For engines below 3300 kW in this group, the PM Tier 3 standard is 0.25 g/bhp-hr *(0.34 g/kW-hr)*.

Table ES-6 – Tier 4 Standards for Marine Diesel C1 and C2

MAXIMUM ENGINE POWER	PM g/bhp-hr *(g/kW-hr)*	NOx+HC g/bhp-hr *(g/kW-hr)*	HC g/bhp-hr *(g/kW-hr)*	MODEL YEAR
at or above 3700 kW	0.09 *(0.12)*[a]	1.3 *(1.8)*	0.14 *(0.19)*	2014[c]
	0.04 *(0.06)*	1.3 *(1.8)*	0.14 *(0.19)*	2016[b,c]
2000 to <3700 kW	0.03 *(0.04)*	1.3 *(1.8)*	0.14 *(0.19)*	2014[c,d]
1400 to <2000 kW	0.03 *(0.04)*	1.3 *(1.8)*	0.14 *(0.19)*	2016[c]
600 to <1400 kW	0.03 *(0.04)*	1.3 *(1.8)*	0.14 *(0.19)*	2017[b]

Notes:

[a] This standard is 0.19 g/bhp-hr *(0.25 g/kW-hr)* for engines with 15-30 liter/cylinder displacement.

[b] Optional compliance start dates can be used within these model years; see discussion below.

[c] Option for C2: Tier 3 PM / NOx+HC at 0.10 / 5.8 g/bhp-hr *(0.14/7.8 g/kW-hr)* in 2012, and Tier 4 in 2015.

[d] The Tier 3 PM standards continue to apply for these engines in model years 2014 and 2015 only.

We are also finalizing standards for remanufactured marine diesel engines that will apply to engines above 600 kW (800 hp). This program requires the use of a certified remanufacture system when an engine is remanufactured if a certified system is available. The standard we are finalizing for these systems is a 25 percent reduction in PM emissions, compared to the engine's baseline emissions level. We expect that this PM reduction will be met by using incrementally-improved components that are replaced when an engine is remanufactured. The remanufacture systems sets a cost cap of $45,000 per ton of PM reduced, based on the incremental cost of the remanufacture system. We intend to assess the effectiveness of this voluntary program as early as 2012 to ascertain the extent to which engine manufacturers are providing certified remanufacture systems. If remanufacture system are not available or are not in the process of being developed and certified at that time for a significant number of engines, we may consider changes to the program.

2. Projected Inventory and Cost Impacts

Our analysis of the projected impacts of these standards can be found in Chapter 2 (air quality impacts), Chapter 3 (inventory impacts) and Chapter 6 (benefits).

Inventory Reductions

A discussion of the estimated current and projected inventories for several key air pollutants are contained in Chapter 3. Nationally, in 2007 these engines account for about 20 percent of mobile source NO_x emissions and 25 percent of mobile source diesel $PM_{2.5}$ emissions. Absent new emissions standards, we expect overall emissions from these engines to remain relatively flat over the next 10 to 15 years due to existing regulations such as lower fuel sulfur requirements and the phase-in of locomotive and marine diesel Tier 1 and Tier 2 engine standards, but starting in about 2025, emissions from these engines would begin to grow. Without new controls, by 2030, these engines would have become a large portion of the total mobile source emissions inventory constituting 35 percent of mobile source NO_x emissions and 65 percent of diesel PM emissions.

We estimate that these standards will reduce annual NO_x emissions by about 800,000 tons and $PM_{2.5}$ and 27,000 tons in 2030**.** Table 7 shows the emissions reductions associated with today's rulemaking for selected years, and the cumulative reductions through 2040 discounted at 3 and 7 percent. These reductions in PM and NO_x levels will produce nationwide air quality improvements.

Table ES-7 – Estimated Emissions Reductions Associated with the Locomotive and Marine Standards (Short tons)

YEAR	$PM_{2.5}$	PM_{10}[a]	NOx	VOC
2015	7,000	7,000	161,000	15,000
2020	14,000	15,000	371,000	28,000
2030	27,000	27,000	795,000	43,000
2040	37,000	38,000	1,144,000	55,000

[a] Note that, $PM_{2.5}$ is estimated to be 97 percent of the more inclusive PM_{10} emission inventory. In Section II we generate and present $PM_{2.5}$ inventories since recent research has determined that these are of greater health concern. Traditionally, we have used PM_{10} in our cost effectiveness calculations. Since cost effectiveness is a means of comparing control measures to one another, we use PM_{10} in our cost effectiveness calculations for comparisons to past control measures.

Engineering Costs

The engineering cost analysis for these standards can be found in Chapter 5. The total engineering costs associated with this rulemaking are the summation of the engine and equipment compliance costs, both fixed and variable, the operating costs, and the costs associated with the locomotive and marine remanufacturing programs. These costs are summarized in Table 8.

Table ES-8 – Total Engineering Costs of the Program ($Millions)

YEAR	ENGINE COSTS	EQUIPMENT COSTS	OPERATING COSTS	COSTS OF REMANUFACTURING PROGRAM	TOTAL COSTS
2011	$138	$0	$0	$143	$281
2012	$80	$0	$0	$135	$215
2015	$123	$24	$30	$89	$266
2020	$82	$17	$187	$63	$349
2030	$99	$20	$535	$105	$759
2040	$98	$17	$806	$161	$1,082
NPV at 3%	$1,764	$260	$5,264	$2,120	$9,407
NPV at 7%	$974	$122	$2,057	$1,153	$4,307

These engineering costs are allocated to NO_x and PM reductions in Table 9. About half of the costs of complying with the program are operating costs, with the bulk of those being reductant-related costs associated with SCR technology. Since SCR is a technique for reducing NO_x emissions, this means that most of the operating costs and, therefore, the majority of the total engineering costs of the program are associated with NO_x control.

Table ES-9 – Total Engineering Costs, Allocated by Pollutant ($Millions)

YEAR	PM COSTS	NOx COSTS
2011	$121	$160
2012	$94	$121
2015	$116	$150
2020	$106	$242
2030	$181	$578
2040	$240	$842
NPV at 3%	$2,680	$6,727
NPV at 7%	$1,333	$2,973

Cost per Ton of Reduced Emissions

Using the inventory and engineering cost information, we can estimate the cost per ton of pollutant reduced as a result of the more stringent standards. Table 10 contains the estimated cost per ton of pollutant reduced based on the net present value of the engineering costs and inventory reductions from 2006 through 2040. This estimate captures all of the engineering costs and emissions reductions including those associated with the locomotive and marine remanufacturing programs. Table 10 also presents the estimated cost per ton of pollutant reduced for 2030 using the annual costs and emissions reductions in that year alone.

That estimates includes engineering costs and emission reductions that will occur from the new engine standards and locomotive and marine remanufacturing programs in that year.

Table ES-10 – Program Cost per Ton Estimates

POLLUTANT	2006 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 3%	2006 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 7%	LONG-TERM COST PER TON IN 2030
NOx+NMHC	$720	$750	$690
PM	$8,440	$9,620	$6,620

3. Estimated Benefits and Economic Impacts

Estimated Benefits

We estimate that the requirements in this rulemaking will result in substantial benefits to public health and welfare and the environment, as described in Chapter 6. The benefits analysis performed for this rulemaking uses sophisticated air quality and benefit modeling tools and is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality and peer-reviewed studies of the dollar values of those public health and welfare effects.

The range of benefits associated with this program are estimated based on the risk of several sources of PM- and ozone-related mortality effect estimates, along with all other PM and ozone non-mortality related benefits information. These benefits are presented in Table ES-11. The benefits reflect two different sources of information about the impact of reductions in PM on reduction in the risk of premature death, including estimates of mortality derived from the epidemiological literature (using both the American Cancer Society (ACS) cohort study and the Six Cities study) and an expert elicitation study conducted by EPA in 2006. In order to provide an indication of the sensitivity of the benefits estimates to alternative assumptions, in Chapter 6 of the RIA we present a variety of benefits estimates based on two epidemiological studies (including the ACS Study and the Six Cities Study) and the expert elicitation. EPA intends to ask the Science Advisory Board to provide additional advice as to which scientific studies should be used in future RIAs to estimate the benefits of reductions in PM.

The range of ozone benefits associated with the final standards is also estimated based on risk reductions estimated using several sources of ozone-related mortality effect estimates. There is considerable uncertainty in the magnitude of the association between ozone and premature mortality. This analysis presents four alternative estimates for the association based upon different functions reported in the scientific literature. We use the National Morbidity, Mortality and Air Pollution Study (NMMAPS), which was used as the primary basis for the risk analysis in the ozone Staff Paper and reviewed by the Clean Air Science Advisory Committee (CASAC). We also use three studies that synthesize ozone mortality data across a large number of individual studies. Note that there are uncertainties within each study that are not fully captured by this range of estimates. Chapter 6 of the RIA presents the results of each of the ozone mortality studies separately.

Recognizing that additional research is needed to more fully establish underlying mechanisms by which such effects occur, we also consider the possibility that the observed associations between ozone and mortality may not be causal in nature. EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits associated with ozone control strategies.

The range of total ozone- and PM-related benefits associated with the final standards is presented in Table ES-11. We present total benefits based on the PM- and ozone-related premature mortality function used. The benefits ranges therefore reflect the addition of each estimate of ozone-related premature mortality (each with its own row in Table ES-11) to estimates of PM-related premature mortality, derived from either the epidemiological literature or the expert elicitation.

Table ES-11– Estimated Monetized PM- and Ozone-Related Health Benefits of the Locomotive and Marine Engine Standards

2030 Total Ozone and PM Benefits – PM Mortality Derived from Epidemiology Studies[a]		
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2006$)[c,d]
NMMAPS	Bell et al., 2004	$9.7 to $20
Meta-analysis	Bell et al., 2005	$11 to $21
	Ito et al., 2005	$11 to $21
	Levy et al., 2005	$11 to $22
Assumption that association is not causal		$9.2 to $20
2030 Total Ozone and PM Benefits – PM Mortality Derived from Expert Elicitation[b]		
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2006$)[c,d]
NMMAPS	Bell et al., 2004	$5.2 to $37
Meta-analysis	Bell et al., 2005	$6.2 to $38
	Ito et al., 2005	$6.7 to $39
	Levy et al., 2005	$6.7 to $39
Assumption that association is not causal		$4.7 to $37

Notes:

[a] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to both estimates of PM2.5-related premature mortality derived from the ACS (Pope et al., 2002) and Six-Cities (Laden et al., 2006) studies, respectively.

[b] Total includes ozone and PM2.5 benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table VI-5.

[d] Results reflect the use of a 3 percent discount rate. Monetary results presented in Table VI-3 use both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

We estimate that by 2030, the annual emission reductions associated with these more stringent standards will annually prevent 1,100 PM-related premature deaths (based on the ACS cohort study), between 50 and 250 ozone-related premature deaths (assuming a causal relationship between ozone and mortality), 120,000 work days lost, and approximately 1,000,000 minor restricted-activity days.

Benefit-Cost Analysis

Using the ACS-based estimate of PM-related premature mortality incidence, we estimate that the monetized benefits of this rule in 2030 will range between approximately $9.2 and $11 billion, assuming a 3 percent discount rate. Using the range of results derived from the expert elicitation, we estimate that the monetized benefits in 2030 will range from approximately $4.7 billion to $39 billion, assuming a 3 percent discount rate. These estimates reflect the remanufactured marine engine program that we are finalizing.

The annual cost of the program in 2030 are estimated to be significantly less, at approximately $740 million.

Economic Impact Analysis

We also performed an economic impact analysis to estimate the market-level changes in prices and outputs for affected markets, the social costs of the program, and the expected distribution of those costs across stakeholders.. This analysis can be found in Chapter 7. We estimate the social costs of the new program to be approximately $738 million in 2030.[B, C] The rail sector is expected to bear about 62.5 percent of the social costs of the program in 2030, and the marine sector is expected to bear about 37.5 percent. In each of these two sectors, these social costs are expected to be born primarily by producers and users of locomotive and marine transportation services (62 and 36 percent, respectively). The remaining 2 percent is expected to be borne by locomotive, marine engine, and marine vessel manufacturers and fishing and recreational vessel users.

The impact of these costs on society are expected to be minimal, with the prices of rail and marine transportation services in 2030 estimated to increase by less about 0.6 percent for locomotive transportation services and about 1.1 percent for marine transportation services.

[B] All estimates presented in this section are in 2005$.

[C] The estimated 2030 social welfare cost of $738 million is based on an earlier version of the engineering costs developed for this rule, which estimated $740 million engineering costs in 2030. The final engineering cost estimate for 2030 is $760 million.

4. Alternative Program Options

In the course of designing our rulemaking, we investigated several alternative approaches to both the engine and fuel programs. Chapter 8 contains a description of these alternatives and an analysis of their potential costs and benefits.

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CHAPTER 1: Industry Characterization

In order to assess the impacts of emission regulations upon the affected industries, it is important to understand the nature of the industries impacted by the regulations. These industries include marine diesel engine manufacturers and marinizers, boat or marine vessel builders which have marine diesel engines installed on them, vessel operators which either purchase new diesel engines or remanufacture existing engines greater than 600kW, the manufacturers of locomotives and locomotive engines, the owners and operators of locomotives (i.e., railroads), and remanufacturers of locomotives and locomotive engines. This chapter provides market information for each of these affected industries for background purposes.

1.1 Marine

1.1.1 Introduction

The regulations for marine diesel engines will directly impact five industries: 1) manufacturers of marine diesel engines, 2) diesel engine marinizers, 3) marine diesel engine remanufacturers, 4) boat or vessel builders which install marine diesel engines installed on their vessels, and 5) vessel operators who own existing marine diesel engines greater than 600 kW. Much of this marine industry characterization was taken from a report done for us by RTI, International.[1]

1.1.1.1 Marine Diesel Market Overview

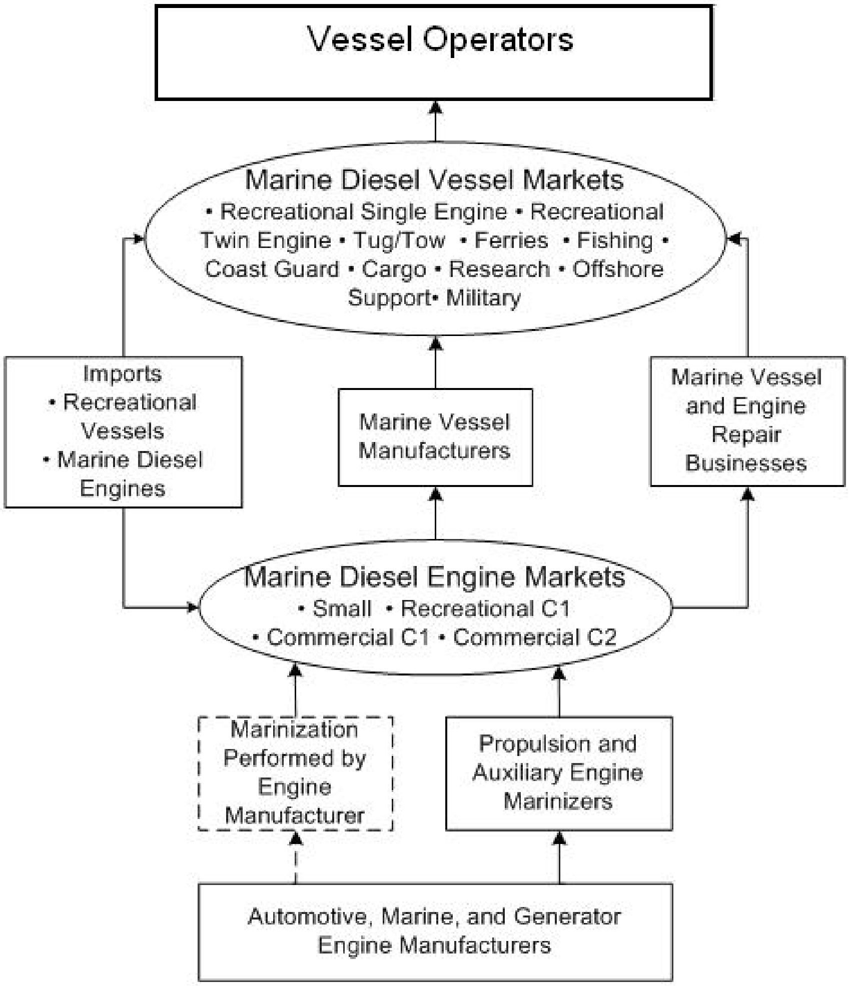
Marine diesel engines include both engines used for propulsion on marine vessels, and those used for marine vessel auxiliary power needs. Diesel marine engines are generally derived from engines originally designed and manufactured for land-based nonroad applications. These nonroad engines are then adapted for use in marine applications through the process of marinization, either by the original engine manufacturer, or by a post-manufacturer marinizer (PMM). The marinization process is discussed in further detail in section 1.1.2.2.2.

Propulsion engines can vary dramatically in size and power, from the smallest engines used in recreational sailboats, to very large engines used in ocean-going commercial vessels. Similarly, auxiliary engines cover a very broad range of sizes and rated power. Auxiliary engines can be used for a variety of purposes, including primary or emergency electrical power generation, and the powering of onboard equipment such as pumps, winches, cable and pipe laying machinery, and dredging equipment. A description of the various engine categories used for regulatory purposes is contained in section 1.1.2.1.

As with marine diesel engines, marine vessels include a very broad range of vessel sizes and types. These include small recreational vessels, as well as commercial vessels such as tow and tug boats, patrol boats, commercial fishing vessels, research vessels, passenger vessels (tour boats and ferries), offshore support vessels which service offshore drilling platforms, and a variety of other specialized commercial vessels.

Figure 1-1-1 shows the links between the various market segments of the marine diesel engine industry and the marine vessel industry, as discussed further in the following sections.

Figure 1-1-1 Marine Diesel Market Segment Flow Chart



1.1.1.2 Current US Emission Regulations

We adopted Tier 2 emission standards for Category 1 (C1) marine diesel engines over 37 kW and for category 2 (C2) marine diesel engines in 1999 (64 CFR 73300, December 29, 1999). These standards are shown in Table 1-1.

Table 1-1 Tier 2 Emission Standards for C1 (over 37 kW) and C2 Commercial Marine Diesel Engines

Category	Displacement (liters/cylinder)	Starting Date	NO_x+THC (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
1	Power ≥37 kW, disp.	2005	7.5	0.40	5.0
	0.9 ≤ disp. < 1.2	2004	7.2	0.30	5.0
	1.2 ≤ disp. < 2.5	2004	7.2	0.20	5.0
	2.5 ≤ disp. < 5.0	2007	7.2	0.20	5.0
2	5.0 ≤ disp. < 15.0	2007	7.8	0.27	5.0
	15.0 ≤ disp. < 20.0, and power < 3300	2007	8.7	0.50	5.0
	15.0 ≤ disp. < 20.0, and power ≥ 3300	2007	9.8	0.50	5.0
	20.0 ≤ disp. < 25.0	2007	9.8	0.50	5.0
	25.0 ≤ disp. < 30.0	2007	11.0	0.50	5.0

We applied the Tier 2 emission standards for C1 engines shown in Table 1-1 to recreational marine diesel engines, but with applicable dates two years behind those for the corresponding commercial marine diesel engines (67 FR 68242, November 8, 2002).

Following the initial adoption of the Tier 2 standards just discussed, we adopted the Tier 1 emission standards in 2003. These standards became effective with the 2004 model year (68 FR 9746, February 28, 2003). These NO_x-only standards apply to commercial marine diesel engines with a per-cylinder displacement of greater than 2.5 liters per cylinder. As shown in Table 1-2 the standards vary depending on the rated speed of the engine.

Table 1-2 Tier 1 Standards for Commercial Marine Diesel Engines over 2.5 Liters per Cylinder

Rated engine speed (rpm)	NO_x (g/kW-hr)
<130	17
130-2000	$45 \text{ X rpm}^{-0.2}$
>2000	9.8

Prior to today's action, there were no emission regulations specifically for marine diesel engines less than 37 kW. Rather, these engines were covered by the Tier 2 standards for nonroad compression ignition (CI) engines, as shown in Table 1-3 (63 FR 56968, October 23, 1998).

Table 1-3 Tier 2 Emission Standards for Marine Diesel Engines Below 37 kW

Engine Power	$NMHC+NO_X$ (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
kW < 8	7.5	0.80	8.0
8 ≤ kW < 19	7.5	0.80	6.6
19 ≤kW < 37	7.5	0.60	5.5

1.1.1.3 Current European Standards and International Maritime Organization (IMO) Standards

The European Union (EU) has a program in place dealing with marine fuels: marine fuel Directive 2005/33. This directive, which limits the sulfur content of distillate fuels used in EU territory has four components. First, until August 10, 2006, the fuel sulfur content of distillate fuel cannot exceed 2,000 ppm. This applies to DMA, DMB, DMC, and DMX grades.[A] From August 11, 2006 to December 31, 2007, this requirement is relaxed for DMB and DMC grades, which are then pegged to the 15,000 ppm SECA limit. That requirement applies to fuels placed on the market during that period. From January 1, 2008 to December 31, 2009, the fuel sulfur limit for DMA and DMX grades falls to 1,000 ppm. Finally, beginning January 1, 2010, a fuel sulfur limit of 1,000 ppm applies to all marine gas oils (DMA, DMB, DMC, and DMX) placed on the market, and to all types of marine fuels used by ships at berth in EU ports and by inland waterway vessels. These last limits apply to any fuel used onboard a vessel. Exemptions apply for ships that spend less than 2 hours at berth, ships that use shore-side electricity while at berth, and hybrid sea-river vessels while they are at sea.

Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL) addresses air pollution from ships or ocean-going vessels, as opposed to the Category 1 and 2 marine diesel engines which are the subject of this final rule. Annex VI was adopted by the Parties to MARPOL at a Diplomatic Conference on September 26, 1997, and it went into force May 20, 2005. As of July 31, 2007, the Annex has been ratified by 44 countries, representing 74.1 percent of the world's merchant shipping tonnage.[2]

[A] ASTM specifications for marine fuels identify four kinds of marine distillate fuels: DMX, DMA, DMB, and DMC. DMX is a special light distillate intended mainly for use in emergency engines. DMA (also called MGO) is a general purpose marine distillate that must contain no traces of residual fuel. These fuels can be used in all marine diesel engines but are primarily used by Category 1 engines. DMB, also called marine diesel oil, is not typically used with Category 1 engines, but is used for Category 2 and 3 engines. DMB is allowed to have a trace of residual fuel, which can be high in sulfur. DMC is a grade of marine fuel that may contain some residual fuel and is often a residual fuel blend. Residual fuel is typically designated by the prefix RM (e.g., RMA, RMB, etc.). These fuels are also identified by their nominal viscosity (e.g., RMA10, RMG35, etc.). Most residual fuels require treatment by a purifier-clarifier centrifuge system, although RMA and RMB do not require this.

Globally harmonized regulation of ship emissions is generally recognized to be the preferred approach for addressing air emissions from ocean-going vessels. It reduces costs for ship owners, since they would not be required to comply with a patchwork of different standards that could occur if each country was setting its own standards, and it can simplify environmental protection for port and coastal states.

The significance of international shipping to the United States can be illustrated by port entrance statistics. In 1999, according to U.S. Maritime Administration (MARAD) data, about 90 percent of annual entrances to U.S. ports were made by foreign-flagged vessels (75,700 total entrances; 67,500 entrances by foreign vessels; entrances are for vessels engaged in foreign trade and do not include Jones Act[3] vessels).

The emission control program contained in Annex VI was the first step for the international control of air pollution from ships. However, as early as the 1997 conference, many countries "already recognized that the NOx emission limits established in Regulation 13 were very modest when compared with current technology developments."[4] Consequently, a Conference Resolution was adopted at the 1997 conference that invited the Marine Environment Protection Committee (MEPC) to review the NOx emission limits at a minimum of five-year intervals after entry into force of the protocol and, if appropriate, amend the NOx limits to reflect more stringent controls.

The United States began advocating a review of the NOx emission limits in 1999.[5] However, MEPC did not formally consider the issue until 2005, after the Annex went into effect. Negotiations for amendments to the Annex VI standards, including NOx and SOx emission limits, officially began in April 2006, with the most recent round of negotiations taking place in April 2007. The United States submitted a paper to that meeting (April 2007 Bulk Liquids and Gases Sub-Committee meeting, referred to as BLG-11) setting out an approach for new international engine and fuel standards. That approach forms the basis of the program outlined in the recently published Advance notice of proposed rulemaking for Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder.[6] Discussions are expected to continue through Summer 2008 and are expected to conclude at the October 2008 MEPC meeting. We will continue to coordinate our national rule for Category 3 emission limits with our activities at IMO.

1.1.2 Marine Diesel Engine Manufacturers

Diesel (compression-ignition) engines are designed to be quite robust in order to withstand the very high temperatures and pressures associated with compression-ignition. As a result, they tend to be very reliable and have very long service lives. Their energy efficiency and simple design result in low operating and maintenance costs. As a result, diesel engines tend to dominate commercial marine applications, where cost and reliability are key purchase decisions for the vessel operator. Diesel engines account for only a small portion of the recreational marine market, however, as their initial purchase price is high relative to gasoline (spark-ignition) engines. The benefits of lower operating costs are not nearly as important in the recreational market, where engines tend not to get much use as compared to commercial applications.

The terms "commercial" and "recreational" are defined in 40 CFR Part 94, *Control of Emissions for Marine Compression-Ignition Engines* (Code of Federal Regulations, 2006). The definitions in section 94.2 state that a commercial engine is an engine installed on a commercial vessel. Likewise, a recreational engine is an engine installed on a recreational vessel. As adopted in this final rule in 40 CFR Part 1042, "recreational vessel" is defined as a vessel that is intended by its manufacturer to be operated primarily for pleasure purposes, although such a vessel could be chartered, rented or leased. Further, a recreational vessel includes only those vessels less than 100 gross registered tons carrying six or fewer passengers, and cannot be used solely for competition.

This industry characterization is concerned with the U.S. market for marine diesel engines, which encompasses all diesel marine engines installed on marine vessels to be flagged (registered) in the United States. This includes engines made in the U.S., engines imported for installation in vessels made in the U.S., and engines included in vessels made overseas and imported into the U.S. Unless otherwise noted, the production and engine characteristics data presented in the following sections were obtained from the Power Systems Research OELink database.[7]

1.1.2.1 Engine Categories and Characteristics

For the purposes of this industry characterization, we looked at four broad categories of diesel marine engines, based on the categories that currently exist for emission regulation purposes. These categories are shown in Table 1-4.

Table 1-4 Diesel Marine Engine Categories and Applications

Category	Power	Displacement per Cylinder	Applications
Small	≤37 kW	Any	Auxiliary, Recreational Propulsion
Recreational Category 1	>37 kW	< 5 liters	Recreational Propulsion
Commercial Category 1	>37 kW	< 5 liters	Auxiliary, Commercial Propulsion
Commercial Category 2	>37 kW	≥ 5 liters and < 30 liters	Auxiliary, Commercial Propulsion
Commercial Category 3	>37 kW	≥ 30 liters	Commercial Propulsion

Given the broad range of commercial and recreational marine vessels types, it is difficult to identify typical applications for each engine category. Nonetheless, the following paragraphs provide an overview of the general characteristics and typical applications of engines in each category.

Small: Engines in this category range from 4 to 43 horsepower (hp) and are characterized by low costs and high sales volumes. Most small engines are used for auxiliary purposes on marine vessels or for propulsion on recreational sailboats. In 2002 they accounted for approximately 26 percent of the marine diesel engines produced or imported in the U.S. market. They are typically marinized land-based nonroad diesel engines; we are not aware of any marine engines of this size made solely for marine application.

Category 1 (C1) Recreational: Engines in this category range from 52 to 3,155 hp and are characterized by high power density (power to weight ratio) and low annual hours of operation relative to commercial engines. Such engines are typically operated no more than 200 to 250 hours per year, and often less. These engines are used for propulsion in recreational vessels, which are designed for speed and planing operation. In 2002 they accounted for approximately 34 percent of the marine diesel engines produced or imported in the U.S. market.

Recreational vessels are designed primarily for speed, and this imposes certain constraints on the type of engine they can use. For a marine vessel to reach high speeds, it is necessary to reduce the surface contact between the vessel and the water, and consequently these vessels typically operate in a planing mode. However, the accompanying high engine speeds are sustained for only short periods of time compared to the total operation of the vessel (i.e., long enough for the vessel to get up on plane), and the duty cycle on which these engines are certified reflects these operations.

Planing imposes two important design requirements. First, the vessel needs to have a very high power, but lightweight, engine to achieve the speeds necessary to push the vessel onto the surface of the water. Therefore, recreational engine manufacturers have focused on achieving higher power output with lighter engines (this is also referred to as high power density). The tradeoff is less durability, and recreational engines are warranted for fewer hours of operation than commercial marine engines. The shorter warranty period is not a great concern, however, since recreational vessels, and therefore their engines, are typically used for fewer hours per year than commercial engines, and spend much less time operating at higher engine loads. Second, the vessel needs to be as light as possible, with vertical and horizontal centers of gravity carefully located to allow the hull of the vessel to be lifted onto the surface of the water. Therefore, recreational vessel manufacturers have focused on designing very lightweight hulls. They are typically made out of fiberglass, using precisely designed molds. The tradeoff is a reduced ability to accommodate any changes to the standard design. For these reasons, recreational vessels are typically designed around a specific engine or group of engines, and engines that are heavier or that are physically larger cannot be used without jeopardizing the vessel's planing abilities or, in many cases, designing a new fiberglass mold for a modified hull.

Category 1 (C1) Commercial: Engines in this category are very similar to engines in the C1 recreational category in displacement, but tend to have lower hp ratings than recreational marine diesel engines in order to provide increased durability required in commercial applications. In contrast to C1 recreational engines, C1 commercial engines are typically used 750 to 4,000 hours per year. They are typically used for propulsion in vessels with displacement hull designs. They are also used for a wide variety of auxiliary power needs on marine vessels. In 2002 they accounted for approximately 39 percent of the marine diesel engines produced or imported in the U.S. market.

In contrast to recreational marine vessels, commercial vessels are typically larger displacement hull vessels, and instead of operating on the surface of the water, for speed, they are pushed through the water. The speed at which a displacement vessel can operate is limited by its hull design and above that limit, there are quickly diminishing returns on power: little vessel speed increase is achieved by increasing power. Because vessel speed is limited by the hull design, there is little incentive to over power the vessel, and engines on these types of commercial vessels tend to be lower power when compared to recreational vessels of similar size. Commercial engines operate for long periods at about 80-90% of rated power and are designed primarily with durability and fuel consumption in mind.

Category 2 (C2): Engines in this category are typically derived from engines originally designed for use in locomotives or for land-based stationary power generation. Such engines typically operate 3,000 to 5,000 hours or more per year, and are designed to be durable and have a very long service life. Under our current program, all C2 marine diesel engines are handled the same way; there is no distinction between recreational or commercial engines in this category. In 2002 they accounted for approximately one percent of the marine diesel engines produced or imported in the U.S. market.

As we were developing this rule, engine manufacturers brought to our attention another category of marine diesel engines that do not fit neatly in the above scheme. These are high power-density marine diesel engines used in some commercial vessels, including certain kinds of crew boats, research vessels, and fishing vessels. Unlike most commercial vessels, these vessels are built for higher speed, planing operation, which allows them to reach research fields, oil platforms, or fishing beds more quickly. These engines may have smaller service lives because of operation at these higher speeds. Our current program does not distinguish between these commercial engines and those used on displacement vessels with respect to useful life periods. Further, this industry characterization does not specifically address these engines as a unique group.

A final category of marine diesel engines, Category 3 (C3) engines, have displacements of 30 liters per cylinder or greater. Such engines are typically only used in large ocean-going vessels, and are not considered in this industry characterization; these engines are not covered by the final rule. Table 1-5 shows a summary of the general characteristics of engines in each of the four categories considered in this industry characterization.

Table 1-5 Engine Characteristics for the Considered Engine Categories

	Small	Recreational Category 1	Commercial Category 1	Category 2
Cylinders	1–4	3–16	3–24	5–20
Horsepower	4.2–42.4	52–3,155	37.5–2,500	300–9,190[a]
Engine Speed (rpm)	1,800 – 3,000	1,800 – 3,000	1,800 – 3,000	750 – 1,500
Weight (lbs)	26–246	156–7,491	106–7,900	7,850–35,000
Cycle:				
2	0.0%	10.2%	9.5%	41.0%
4	100.0%	89.8%	90.5%	59.0%
Configuration:				
H-Block	8.1%	0.0%	0.0%	0.0%
Inline	91.9%	65.3%	73.3%	33.7%
V-Block	0.0%	34.7%	26.7%	66.3%
Cooling:				
Air	5.9%	0.0%	0.4%	0.0%
Oil	0.0%	0.0%	0.1%	0.0%
Water	94.1%	100.0%	99.5%	100.0%

[a] While the PSR database shows one C2 engine family with a 300 hp rating, C2 engines are generally over 1000 hp at minimum.

Table 1-6 shows the total number of engines in each category which were sold in the United States in 2002.

Table 1-6 Marine Diesel Engine Sales by Engine Category in 2002

Application Category	Sales in 2002	Percent of Total
Small	10,761	26.4%
Recreational C1	13,952	34.2%
Commercial C1	15,826	38.8%
Commercial C2	277	0.7%
Total	40,816	

1.1.2.2 Supply Side

Marine diesel engines are typically derived from land-based nonroad engines. These engines are adapted for use in the marine environment through a process known as marinization. In this section we will discuss nonroad engine design, production and costs, followed by descriptions of the marinization process and the companies engaged in this activity. Finally we will discuss engine dressing and rebuilding practices for marine diesel engines.

1.1.2.2.1 Nonroad Diesel Engine Design and Production

Engine blocks are cast in a foundry, most often from gray iron. Depending on the size and complexity of the engine, the block may be formed by impression molding or two-piece sand-casting. Smaller, more complex parts, including cylinder heads, exhaust manifolds, and cylinder liners, are cast from ductile iron, typically using sand cores to allow formation of the complicated shapes. All castings must be cleaned and deburred prior to further processing. In addition, ductile iron parts will also usually be heat treated to relieve stress and harden the alloys. Table 1-7 lists the materials and primary production processes for various engine components.[8]

Table 1-7 Engine Component Materials and Production Processes

Component	Primary Materials	Primary Process
Block	Iron, aluminum	Casting
Cylinder head	Iron, aluminum	Casting, machining
Intake manifold	Plastic, aluminum	Casting, machining
Connecting rods	Powder metal, steel	Molding, forging, machining
Pistons	Aluminum	Forging, machining
Crankshaft	Iron, steel, powder metal	Molding, forging, machining
Valves	Steel, magnesium	Stamping, machining
Exhaust systems	Stainless steel, aluminum, iron	Extruding, stamping

The cast block, cylinder head, and cylinder liners, along with crankshafts, gears, connecting rods, and other engine parts, are next machined to exact specifications in a machining center. Holes are drilled, parts reshaped, excess metal removed, and the metal surfaces polished in the machining area. The operation of the finished engine depends critically on the precision of the machining work at this stage.

The third major step in engine manufacturing is assembly. This area is usually physically isolated from the dirty upstream operations so that contaminants are not introduced into the completed engines, thus affecting their operation or shortening the engine’s life. In a typical plant, subassemblies are first put together on separate lines or in separate bays; then the subassemblies are brought together for final assembly. The completed engines are visually inspected and then evaluated on-line on a test bench or in a test cell to ensure their performance will meet expectations.

1.1.2.2.2 Engine Marinization

Land-based nonroad diesel engines generally need to be modified in some ways to make them suitable for installation on marine vessels. The process by which this is done is known as marinization. The marinization process results in changes to the emission characteristics of the nonroad engine. For this reason, a marinized nonroad engine must be certified to marine diesel engine emission standards even though the base nonroad engine is certified to the nonroad diesel engine emission standards. Sometimes, land-based nonroad diesel engines can be adapted for use in marine applications without changing the emission characteristics of the engine. This process is called engine dressing, and is discussed in section 1.1.2.2.5. Marinization typically involves three significant modifications: choosing and optimizing the fuel management system, configuring a marine cooling system, and making other peripheral changes. These changes are detailed in the following paragraphs.

Fuel and Air Management: High-performance engines are preferred for most recreational and some light duty commercial applications. These engines are built to maximize their power-to-weight ratio (provide more power with less added weight), which is typically done by increasing power from a given cylinder displacement. This is usually accomplished by installing a new fuel injection system, which injects more fuel directly into the cylinder to increase power. This can require changes to the camshaft, cylinder head, and the injection timing and pressure. Currently, the design limits for increased fuel to the cylinder are smoke and durability. Modifications made to the cooling system also help enhance performance. By cooling the charge, more air can be forced into the cylinder. As a result, more fuel can be injected and burned efficiently because of the increase in available oxygen. In addition, changes are often made to the pistons, cylinder head components, and the lubrication system. For example, aluminum piston skirts can be used to reduce the weight of the pistons. Cylinder head changes include changing valve timing to optimize engine breathing characteristics. Marinizers do not typically go as far as to physically modify the cylinder head.

Cooling System: To mitigate performance problems, engine manufacturers historically used cooling systems that cooled by circulating seawater through the engine that was pumped from outside the boat. Even though many currently operating marine diesel engines still use seawater to cool the engine, almost all newly built engines use a closed cooling system that recirculates coolant through the engine block. These engines still use raw seawater by using it to draw heat out of the engine coolant. These closed systems help prevent corrosion and allow the engine to operate at higher temperatures. As part of the cooling system, water-jacketed exhaust manifolds, pumps, and heat exchangers are added. Marine diesel engines may also have larger oil pans to help keep oil temperatures down.

Other Additions and Modifications: Marine engines are often installed in engine compartments without much air flow for cooling, which can result in a number of exposed hot surfaces (leading to safety concerns) or performance problems from overheating the engine. To address safety concerns and to comply with U.S. Coast Guard regulations, marine diesel engines are designed to keep engine and exhaust component (exhaust manifold, turbocharger and exhaust pipe) temperatures cool. Recreational and light duty commercial engines can accomplish this by running cool water through a jacket around the exhaust system components. Larger engines generally use a thick insulation around the exhaust pipes.

Marinization might also include replacing some engine parts with parts made of materials more durable in a marine environment. These changes include more use of chrome and brass to prevent corrosion. Because of the unique marine engine designs, marinizers also add their own front accessory drive assembly. Finally, marine engines must also be coupled with the lower drive unit to be applicable to a specific vessel.

1.1.2.2.3 Nonroad Diesel Engine Costs of Production

The U.S. Census Bureau does not differentiate cost of production figures for marine diesel engines (North American Industry Classification System [NAICS] 333618B106). However, because small, recreational C1, commercial C1, and commercial C2 engines are derived from nonroad diesel engines, costs of production for nonroad engines could be used to illustrate costs of production of marine diesel engines (NAICS 3336183). Costs of production figures are divided into major input categories of labor, materials, and capital expenditures. Of these categories, purchased materials account for the largest share of total costs. Based on data from the most recent Economic Census, costs of materials represent about 64 percent of the value of shipments, followed by labor at about 11 percent and capital expenditures at about 3 percent. (These numbers correspond with the broader “other engine manufacturing” category [NAICS 333618].)

Table 1-8 lists the primary materials used in engine components.[9] No breakdown of cost of materials used in production is available from the 2002 Economic Census for the specific category of marine diesel engines (NAICS 333618B106) nor for nonroad diesel engines (NAICS 3336183), but based on the broader “other engine manufacturing” category (NAICS 333618), cost of materials are dominated by cast and formed metal. Iron and steel accounted for 13 percent of material costs; aluminum accounted for 7 percent; injection fuel pumps for 5.6 percent; pistons, valves, and piston rings for 3.5 percent; and engine electrical equipment for 3.5 percent. All other materials and components, parts, containers, and supplies accounted for 52 percent; no single material accounted for more than 2 percent of material costs.

Table 1-8 Nonroad and “Other Engine” Costs of Production and Materials Consumed in 2002

NAICS	Value of Shipments ($\$10^6$)	Labor ($\$10^6$)[a]	Cost of Materials ($\$10^6$)[a]	Capital Expenditures ($\$10^6$)[a]
333618 Other engine equipment manufacturing	18,586	2,145	11,800	730
		11.5%	63.5%	3.9%
3336183 Diesel, semi-diesel, and dual-fuel engines (except automobile, highway truck, bus, tank)	2,003	215	1,287	59
		10.7%	64.3%	2.9%
Materials Consumed by 333618	Cost ($\$10^6$)	Share of Cost of Materials		
Iron and steel[b]	1,449	13.1%		
Aluminum[c]	770	6.9%		

Notes:

[a] Percentages refer to the share of the total value of shipments.

[b] NAICS codes 33211101, 33151001, 33120007, 33120016, 33120033.

[c] NAICS codes 33152005, 33152003, 33631100.

1.1.2.2.4 Nonroad Diesel Engine Manufacturers and Marinizers

As was previously discussed, marine diesel engines are typically derived from similar size land-based diesel engines through the marinization process. Marinization is normally performed by two types of firms, and has an impact on the engine's emission characteristics.

First, there are large engine manufacturers such as Cummins, Caterpillar, and Deere that marinize their land-based nonroad engines. They are referred to as domestic engine manufacturers (DEMs), and they are usually involved in every step of the manufacturing process of a marine engine. Foreign engine manufacturers (FEMs) are similar to DEM, but they are owned by foreign parent companies (this also pertains to DDC and EMD, which are owned by foreign investment companies now). Production of marine engines begins on the nonroad production line; however, at some stage of the production process, an engine is moved to a different assembly line or area where production is completed using parts and processes specifically designed for marine applications.

Second, postmanufacture marinizers (PMMs), or simply marinizers, are smaller manufacturers that purchase complete or semi-complete land-based engines from engine manufacturers and complete the marinization process themselves using specially designed parts, potentially modifying fuel and cooling systems.

Table 1-9 lists DEM, FEM, and PMM companies. Only four U.S.-based engine manufacturers produce and marinize their marine diesel engines. Cummins is the only company involved in two types of production. In addition to marinizing their own, Cummins (through its subsidiary Onan) produces generators using Kubota engines and therefore is included in both the DEM and postmanufacture marinizers categories.

Table 1-9 Marine Engine Manufacturers

Domestic Engine Manufacturers	Foreign Engine Manufacturers	Postmanufacture Marinizers
Caterpillar	Deutz	Bombardier[a]
Cummins	EQT (parent to MTU)	Brunswick
Deere & Company	Greenbriar Equity, LLC (parent to EMD)	Cummins
General Electric	MAN	Daytona Marine[a]
	Rumo	Fairbanks Morse[a]
	Volvo	Klassen
	Yanmar	Kohler
		Marine Corp. of America[a]
		Marine Power
		NREC Power Systems
		Peninsular Diesel
		Reagan Equipment[a]
		Stewart & Stevenson
		Sword Marine Technology
		Valley Power Systems (parent to Alaska Diesel)
		Westerbeke

[a] These companies' production is not included in the 2004 PSR database.

1.1.2.2.5 Marine Engine Dressing

Marine engine dressing refers to the modifications made to a land-based engine that enable it to be installed on a marine vessel. Unlike PMMs, however, the changes made by marine dressers do not affect the emission characteristics of the engine. These modifications can be made by engine manufacturers or marine dressing firms. Modifications typically include installing mounting supports and a generator (in the case of an auxiliary engine) or propeller gears (in the case of propulsion engines). Other modifications consist of adding adaptors, water-cooled exhaust manifolds, water tanks, electronic instrumentation, and alarm systems. There are many manufacturers of this type. However, because these companies do not do anything to the engines to change their emission characteristics, they are exempted from the regulations. Thus, their coverage will be omitted in this profile.

1.1.2.2.6 Marine Engine Remanufacturing

Marine remanufacturers are engaged in the manufacture or assembly of remanufactured marine diesel engines. We have identified about 10 U.S. companies (aftermarket suppliers or aftermarket parts manufacturers and engine manufacturers) that could potentially remanufacture marine engines. Some of these companies are only involved in the remanufacture of locomotives. Two companies are both locomotive and marine remanufacturers that have already certified models.

1.1.2.3 Demand Side

Marine diesel engines can be distinguished according to whether they are used on commercial or recreational applications. As discussed above, the basic difference derives from the nature of the requirements on the engine in each application: more power density in recreational applications and more durability in commercial applications. In this section, we look at the characteristics of the four key segments of this industry; Recreational marine C1 and small (at or below 37 kW), Commercial C1, and C2 diesel engine markets.

Table 1-10 presents the total number of engines produced in and imported to the United States broken down by application category. According to the data in the PSR database, the largest single category is marine engines produced for propulsion purposes in recreational applications (17,954). A slightly smaller number was produced for all auxiliary functions (16,377) and the rest for propulsion purposes in commercial applications (6,524). Based on the engine category, the majority of the engines produced or imported were classified as commercial C1, followed by recreational C1 and small. Category 2 is the smallest category with 277 engines produced in 2002.

Table 1-10 Marine Diesel Engine Production by Application and Use Type (2002)

Use Type	Small (≤37 kW)	C1 Recreational	C1 Commercial	C2
Commercial propulsion	NA	NA	6,389	135
Marine auxiliary	6,798	NA	9,437	142
Pleasure propulsion	3,963	13,952	NA	NA
Total	10,761	13,952	15,826	277

A further look into the characteristics of a commercial fleet was accomplished by taking a random sample of nearly 400 vessels from the Inland River Record (2006).[10] That sample suggests that the average age of vessels in that fleet is 30 years (with vessels built between 1944 and 2004), and the average horsepower of these vessels is 840 hp (with a range of 160-4,400 hp). About 68% of the engines in these vessels were built after 1972, and 31% were both greater than 800 hp and built after 1972. In addition, about 65% of the engines that are greater than 800 hp were derived from locomotive engines. Although this sample reflects only the characteristics of the vessels included in the Inland River Record (primarily tug and towboats), it provides a detailed look into one database of existing vessels.

1.1.2.3.1 Recreational Applications

Recreational boats (especially the larger ones powered by diesel engines) are generally considered discretionary goods; demand for them is typically price elastic.

There are several reasons why consumers might choose diesel engines over gasoline engines for recreational applications. First, diesel engines are more durable and reliable. Second, diesel engines have better fuel consumption.

Based on the National Marine Manufacturers Association (NMMA) sales data, there were approximately 5,760 diesel-powered (out of a total 10,200 diesel and gas-powered inboard cruiser boats) recreational boats sold in 2002. NMMA also estimated that among 10,200 boats, 92.2 percent had a twin engine.[11] Under these ratios, we estimated 11,070 recreational marine diesel engines were sold for propulsion purposes in the United States in 2002. This number differs from 13,952 engines imported or produced in the United States in 2002, as reported in the PSR database. Some of the engines produced are used as the replacement engines; however, the PSR OELink database is probably not entirely accurate. Because the NMMA estimate is derived from surveying a large portion of the industry stakeholders, their consumption estimate seems more reliable.

Not included in that estimate are small marine diesel engines. PSR data indicate that 10,761 small marine diesel engines were produced in 2002, with approximately 64 percent of those being used for auxiliary purposes and the remainder used as maneuvering engines on recreational applications and as cruising engines on sailboats.

1.1.2.3.2 Commercial C1 Applications

Engines in this category are inputs into various commercial applications, such as seasonal and commercial fishing vessels, emergency rescue vessels, ferries, and coastal freighters.

Commercial vessels are inputs into a wide range of production processes that generate products and services. As a result, the demand for C1 engines is linked directly to the demand for boats, and indirectly through the supply chain to the demand for final products and services produced with commercial ships and boats.

No data are readily available on the volumes of commercial boats produced annually in the United States. However, based on the 2004 Workboat Construction survey of approximately 400 commercial boats scheduled to be delivered in 2005, we estimate that 40 percent of them were C1, 55 percent were C2, and 5 percent were C3 (Workboat, 2005). Using these estimates, we find that 160 C1 engine-powered commercial vessels were produced in the United States in 2004. Once again, this number does not correspond with 6,389 engines listed by PSR. More than likely Workboat Construction journal's survey lists the largest commercial ships and boats, and many smaller commercial boats are unaccounted for.

1.1.2.3.3 Commercial C2 Applications

Commercial C2 engines might be used on crew and supply boats, trawlers, and tug and tow boats. Many of the engines are also used as large auxiliary engines on ocean-going vessels. Based on the Workboat Construction survey estimate, there were 220 C2 engine-powered commercial vessels built in the United States in 2004.[12] This number is lower compared with 2002 production volume (277 engines) listed by PSR.

Like commercial C1 engines, commercial C2 engines are inputs in vessels, which are in turn inputs in production processes that generate products and services. Therefore, demand for commercial C2 engines is linked directly to the demand for commercial C2 vessels and indirectly to the demand for products and services produced with these vessels.

1.1.2.4 Market Structure

Figure 1-1-2 and Figure 1-1-3 present small and recreational C1 marine diesel engine market breakdown by the type of a supplier. In 2002, a majority of the small marine diesel engines (60 percent) were supplied by engine marinizers, with about half of that value supplied by engine dressers, and only 11 percent by foreign engine manufacturers (FEM) that oversee the entire production process. No domestic engine manufacturers (DEM) supplied engines to this market. The situation is opposite for the recreational C1 market, where DEMs supply 45 percent of engines, and FEMs supply 26 percent. Marinizers accounted for 28 percent, and dressers for less than 1 percent of the recreational C1 market supply.

Table 1-11 details the top three engine manufacturers and marinizers in the small (at or below 37 kW) and C1 recreational categories. The majority of the engines in the small category are supplied by U.S.-based marinizer Westerbeke (48 percent). In 2002, Japanese manufacturer Yanmar and U.S.-based marinizer Kohler both had approximately 10 percent of the market share. Cummins, a DEM, serves as a marinizer in this market. Kubota engines, marinized by Cummins, accounted for approximately 3.5 percent of small marine diesel engine market supply in 2002.

Figure 1-1-2 Small (≤37 kW) Marine Diesel Engine Market Supply by Manufacturer Type (2002)

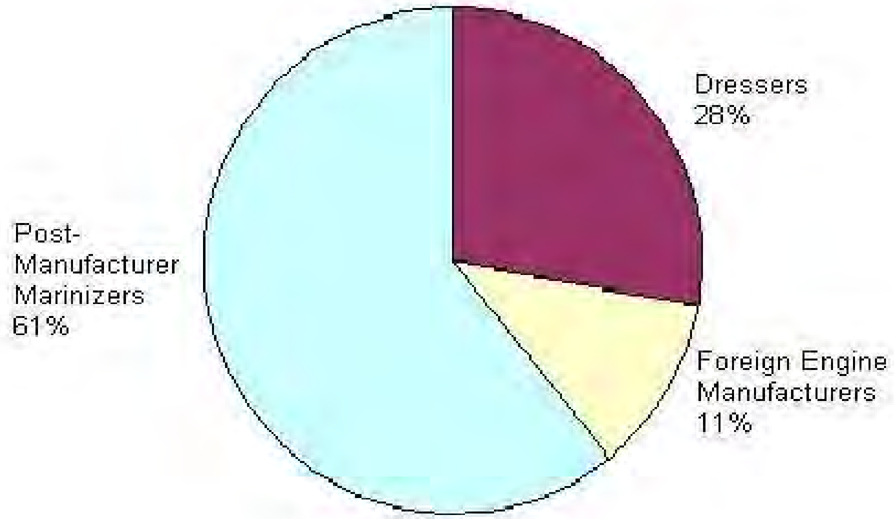


Figure 1-1-3 C1 Recreational Marine Diesel Engine Market Supply by Manufacturer Type (2002)

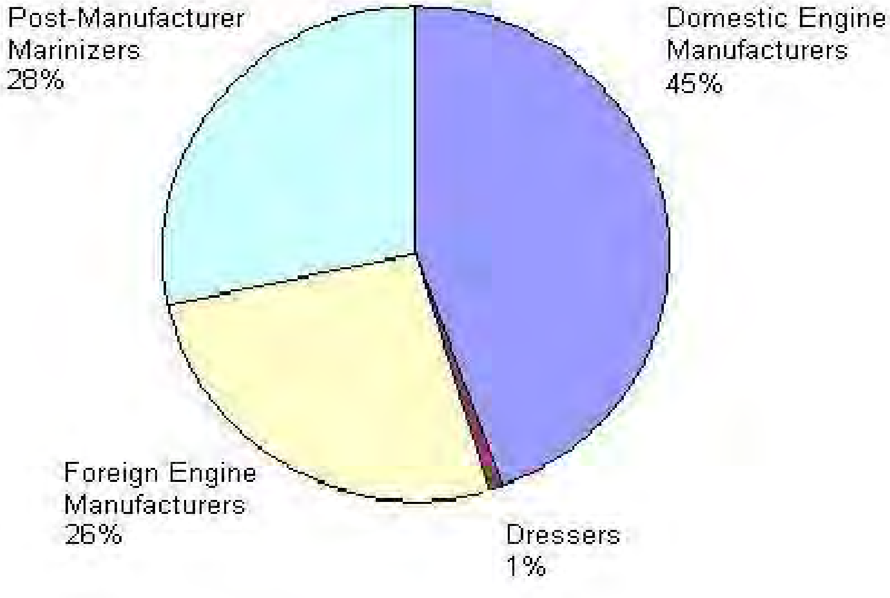


Table 1-11 Top Three Small and Recreational C1 Marine Diesel Engine Manufacturers and Marinizers (2002)

	2002 Production	Market Share
C1		
Engine Manufacturers		
Caterpillar		
Cummins		
Yanmar		
Top 3 Firms' Production	9,524	68.3%
Engine Marinizers		
Westerbeke		
Peninsular Diesel		
Brunwick Corporation		
Top 3 Firms' Production	2,800	20.1%
Total Dressers	23	0.2%
Total C1 Market	13,952	
Small (≤37 kW)		
Engine Manufacturers	(D)	(D)
Yanmar		
Engine Marinizers		
Westerbeke		
Valley Power Systems, Inc.		
Kohler		
Top 3 Firms' Production	7,136	66.3%
Total Dressers	2,000–3,000[a]	25%–30%[a]
Total Small Market	10,761	

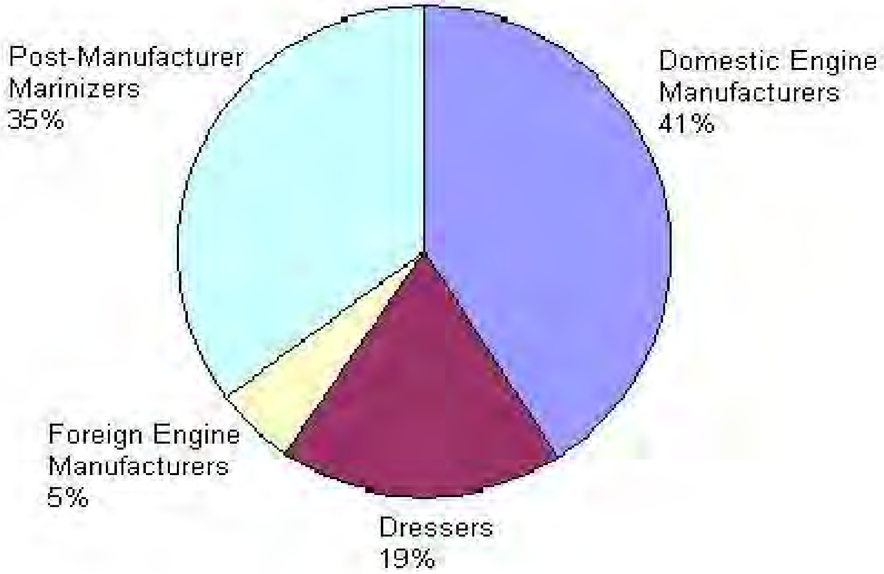
[a] The range is provided to avoid disclosing proprietary information of individual companies.

(D) = Data have been withheld to avoid disclosing proprietary information of individual companies.

1.1.2.4.1 C1 Commercial Applications

The supply structure of the commercial C1 marine diesel engines market resembles the supply structure of the recreational C1 market, with DEMs and PMMs supplying 76 percent of the engines to the market (Figure 1-1-4). As opposed to the recreational C1 market, dressers supply a larger portion of the commercial C1 market (19 percent), with FEMs supplying 5 percent.

Figure 1-1-4 Commercial C1 Marine Diesel Engine Market Supply by Manufacturer Type (2002)



Commercial C1 marine diesel engine market shares are listed by the type of manufacturer in Table 1-12. DEMs Caterpillar and Deere and engine marinizer Kohler have approximately equal market shares of 15 percent each. They are followed by U.S.-based marinizer Westerbeke with an 11 percent market share. Even though engine dressers are not covered by this rule, it is worth noting that the vast majority of the engines supplied in the commercial C1 market by these companies are auxiliary engines.

Table 1-12 Top Three Commercial C1 Marine Diesel Engine Manufacturers and Marinizers (2002)

C1	2002 Production	Market Share
Engine Manufacturers		
Caterpillar		
Deere & Company		
Cummins		
Top 3 Firms’ Production	6,452	40.8%
Engine Marinizers		
Kohler		
Westerbeke		
Valley Power Systems, Inc.		
Top 3 Firms’ Production	5,690	36.0%
Total Dressers	1,383	8.7%
Total C1 Market	15,826	

1.1.2.4.2 Commercial C2 Applications

The commercial C2 marine diesel market is not supplied by dresser companies; most of the supply comes from marinizers, which supply approximately half of its volume. U.S.-based companies are dominant in the commercial C2 marine diesel engine market. Among engine manufacturers, Caterpillar, and among marinizers, General Motors and Stewart and Stevenson, together compose 78.4 percent of the market. Caterpillar is followed by Japanese manufacturer Yanmar and German MAN B&W with 11 and 6 percent, respectively (Table 1-13).

Table 1-13 Top Three Commercial C2 Marine Diesel Engine Manufacturers and Marinizers (2002)

C2	2002 Production	Market Share
Engine Manufacturers		
Caterpillar	87	
Greenbriar Equity LLC	73	
Yanmar	31	
Top 3 Firms' Production	191	69.0%
Engine Marinizers		
Stewart and Stevenson	(D)[a]	(D)
Total Dressers	—	0.0%
Total C2 Market	277	

[a] (D) = Data have been withheld to avoid disclosing proprietary information of individual companies.

1.1.2.4.3 Pricing Behavior of Marine Diesel Engine Markets

Discussions about market competitiveness usually focus on two types of pricing behavior: perfect competition (price-taking behavior) and imperfect competition (lack of price-taking behavior). Under the former scenario, buyers and sellers take (and thus are "price takers") the market price set in a competitive equilibrium: the market price equals the value consumers place on the marginal product, as well as the marginal cost to producers. Under this scenario, firms have some ability to influence the market price of the output they produce. For example, a firm might produce a commodity with unique qualities that differentiate its product from its competitors' product. The value consumers place on the marginal product, the market price, is greater than the cost to producers. Thus, the social welfare is reduced under this scenario.

As evident from the market share information presented in this report, marine diesel engine markets are moderately (small and commercial C1) to highly (recreational C1 and commercial C2) concentrated and thus have a potential for emergence of imperfect competition. Nevertheless, our analysis suggests mitigating factors will limit prices from rising above the marginal cost; therefore, the assumption of perfect competition is justified.

First, the threat of entry encourages price-taking behavior. Industries with high profits provide incentives to new firms to enter the market and lower the market price to their competitive levels. In all of the marine diesel markets, domestic and foreign candidates can enter any of these markets without incurring significant costs.

Second, the data on capacity utilization rates published by the Federal Reserve (for machinery, NAICS 333) suggest that excess capacity exists in the broad category that also includes converted internal combustion engines industry (NAICS 333618B106). February 2006 data present an industry utilization rate of 82.6 percent. If these data do, in fact, indicate excess capacity in the marine diesel engine industry, then the ability to raise prices is limited by excess idle capacity.

Third, other theories place less value on market shares as a determinant of pricing behavior and examine the role of potential competition instead. For instance, three conditions of perfectly contestable markets demonstrate how potential competition may lead to perfect competition:[13]

- New firms have access to the same production technology, input prices, products, and demand information as existing firms
- All costs associated with entry can be fully recovered
- After learning about new firms' entry, existing firms cannot adjust prices before these new firms supply the market

Although the extent to which these conditions apply to marine diesel engine markets is not clear, the theory suggests that market shares alone should not necessarily be considered as an indicator of imperfect competition in the market.

1.1.2.5 Historical Market Data

1.1.2.5.1 Recreational Applications

The historical market statistics are presented as a means to assess the future of marine diesel engine production. Information on production trends is presented here.

Historical production volumes for recreational C1 and small marine diesel engine markets are presented in Table 1-14. The small marine diesel engine market demonstrated continuous growth in production between 1998 and 2002, growing by 37 percent since 1998. The recreational C1 market experienced a slight peak in 2000 with 7 percent growth and then leveled off in 2002 at a slightly higher volume than it was in 1998.

Table 1-14 Historical Market Trends for Small and Recreational C1 Marine Diesel Markets

	Recreational C1	Small
2002	13,952	10,761
2001	13,754	9,833
2000	14,408	9,576
1999	13,836	7,997
1998	13,446	7,853
Percentage Change	3.8%	37.0%

1.1.2.5.2 Commercial C1 Applications

The commercial C1 engine market demonstrated a strong steady growth in the past 5 years. Starting at 10,508 engines produced and imported into the United States in 1998, it grew by more than 50 percent and equaled 15,826 engines in 2002 (Table 1-15).

Table 1-15 Historical Market Trends Commercial C1 Marine Diesel Market

Year	Production
2002	15,826
2001	14,078
2000	12,838
1999	12,178
1998	10,508
Percent Change	50.6%

1.1.2.5.3 Commercial C2 Applications

The commercial C2 market has a relatively small volume of sales compared to the recreational and commercial C1 markets. Nevertheless, the commercial C2 market experienced significant growth in the past 5 years. In the period from 1998 to 2002, market volume more than doubled and equaled 277 engines in 2002 (Table 1-16).

Table 1-16 Historical Market Trends Commercial C1 Marine Diesel Market

Year	Production
2002	277
2001	231
2000	200
1999	138
1998	134
Percentage Change	106.7%

1.1.3 Marine Vessel Manufacturers

Marine vessels include a wide variety of ships and boats. Several alternative definitions exist to distinguish between ships and boats. For this profile, ships are defined as those marine vessels exceeding 400 feet in length. They are built to purchasers' specifications in specialized "Main Shipyard Base" ship yards, and typically powered by Category 3 diesel engines. Under this definition most of the vessels powered by small, C1 or C2 diesel engines would be considered boats. In this section, the terms "vessel" and "boat" will be used interchangeably. Vessels powered by C1 and C2 engines vary widely; they may be made from fiberglass-reinforced plastic (FRP or fiberglass), aluminum, wood, or steel. Some vessels are serially produced using assembly line methods; others are individually built to meet purchasers' specifications in boatyards or in the same yards that build ships. Small boats may be powered by small spark-ignition (gasoline) engines. Vessels covered by this profile include a small share of recreational boats: inboard cruisers, especially those over 40 feet in length. In addition the profile covers diesel-powered commercial and governmental vessels such as tug/tow boats, fishing vessels, passenger vessels, cargo vessels, offshore service vessels and crew boats, patrol boats, and assorted other commercial vessels.

The Economic Census includes two industry sectors, NAICS 336611 Ship Building and Repairing and NAICS 336612 Boat Building, that together cover the marine vessel types addressed in this profile. Each NAICS includes some vessels not included in this profile. NAICS 336612 defines boats as “watercraft not built in shipyards and typically of the type suitable or intended for personal use.”; thus, NAICS 336612 includes essentially recreational vessels; within this NAICS, NAICS 3366123 covers inboard motor boats, including those powered by diesel engines. Thus, the diesel-powered recreational vessels covered by this profile represent only a relatively small share of NAICS 336612. NAICS 336611 comprises establishments primarily engaged in operating a shipyard, fixed facilities with drydocks and fabrication equipment capable of building a “watercraft typically suitable or intended for other than personal or recreational use.”[14] Commercial and governmental vessels powered by small, C1 and C2 diesel engines are included in NAICS 336611, along with larger ships that are powered by C3 engines and thus not covered by this profile.

1.1.3.1 Overview of Vessels

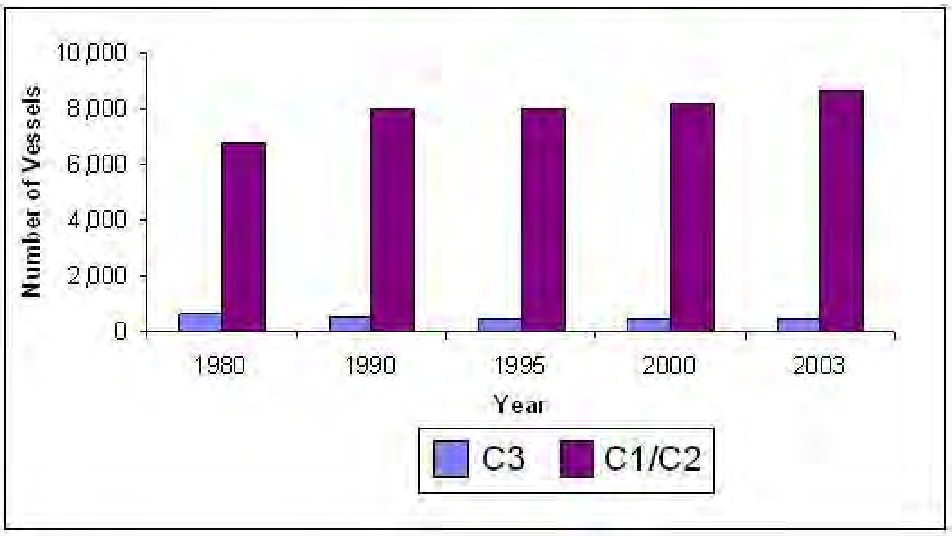
This profile covers a wide variety of vessels, including recreational vessels and smaller commercial, service, and industrial vessels, generally less than 400 feet in length. Commercial vessels under 400 feet long dominate inland and coastal waters where shallow drafts restrict access by larger ships. Depending on their mission, C1- and C2-powered vessels also may operate in the Great Lakes, coastwise, intercoastal, noncontiguous, and/or transoceanic environments. The principal commercial boat types are tugboats, towboats, offshore supply boats, fishing and fisheries vessels, passenger boats, and industrial boats, such as cable- and pipe-laying boats, oceanographic boats, dredges, and drilling boats. Passenger boats include crewboats, excursion boats, and smaller ferries.

Most commercial vessels covered by this profile are U.S.-built, U.S.-owned and U.S.-operated. Under provision of the Jones Act (Section 27, Merchant Marine Act, 1920), vessels transporting merchandise between U.S. ports must be built in and documented under the laws of the United States and owned and operated by persons who are citizens of the United States. Because C1 and C2 diesel engines are frequently used to power vessels that operate in inland waters or coastwise, they are generally operating between U.S. ports. Thus, many cargo vessels powered by C1 and C2 diesel engines are required to be U.S.-built, -owned, and -operated, unless a waiver is granted by the Secretary of the Treasury.

Generally excluded from this profile, because they are powered by C3 engines, are larger merchant and military vessels, typically exceeding 400 feet in length, that engage in waterborne trade and/or passenger transport or military operations. Commercial and government-owned (e.g., military) ships operate in Great Lakes, coastwise, intercoastal, noncontiguous (between United States mainland and its noncontiguous territories, such as Alaska, Hawaii, and Puerto Rico), and/or transoceanic routes. The principal commercial ship types are dry cargo ships, tankers, bulk carriers, and passenger ships. Dry cargo ships include break bulk, container, and roll-on/roll-off vessels. Passenger ships include cruise ships and the largest ferries. Military ships include aircraft carriers, battleships, and destroyers. Also excluded from the profile are the smallest recreational, commercial, and government vessels, which are powered by gasoline outboard, stern-drive, or inboard engines. Figure 1-1-5 illustrates the size of the U.S. commercial fleet over time from 1980 to 2003 and the distribution between larger and smaller vessels. Compared with smaller commercial vessels, larger commercial vessels represent a small fraction of the U.S. commercial fleet.

Figure 1-1-5 includes vessels as small as 1,000 gross tons in the ship, rather than boat population, and omits key categories of boats (smaller vessels), such as supply boats and fishing boats.[15] It is very difficult to develop useful criteria which will allow the separation of vessel populations into those powered by the various engine categories. Nonetheless, this analysis provides some insight as to the relative proportion of vessels in the U.S. fleet powered by C1/C2 engines versus C3 engines.

Figure 1-1-5 U.S. Commercial Fleet (1980 to 2003)



1.1.3.2 Overview of Vessel Manufacturers

This report classifies vessel manufacturing facilities (“yards”), according to the types of vessels manufactured. The Economic Census reports on two industry segments that are related to vessel manufacture—shipbuilding and repairing (NAICS 336611) and boatbuilding (NAICS 336612). Shipbuilding facilities typically have drydocks. NAICS 336612 encompasses facilities that build “watercraft suitable for personal or recreational use,” which corresponds closely to recreational boats, and NAICS 336611 includes facilities that build larger commercial and government vessels. Both NAICS codes include vessels not covered by this profile.

NAICS 336611 includes generally one-of-a-kind vessels built in a shipyard with drydock facilities, including vessels powered by Category 1 and 2 diesel engines, as well as the larger Category 3 engines. Most vessels manufactured by this NAICS code are for commercial or governmental applications (e.g., Coast Guard, military, Army Corps of Engineers, municipal harbor police).

NAICS 336612 covers generally recreational vessels. These may be built using repetitive methods, such as an assembly line process or individually; it includes those powered by gasoline, alcohol, and diesel engines. Within NAICS 336612, only larger (over 40 feet) inboard cruisers are predominantly powered by diesel engines. This segment of NAICS 336612 (NAICS 3366123 Inboard Motorboats) includes only 82 establishments, less than 7 percent of the total in the NAICS code. Because most of the smaller inboard motorboats are SI-powered, the number of facilities manufacturing diesel-powered recreational vessels is even smaller. The information summarized in Table 1-17 shows information about establishments and companies in NAICS 336611 and 336612, and indicates that there are a large number of small establishments in both of these industry segments.[16] Most companies in both NAICS codes are single-establishment companies.

Table 1-17 2002 Economic Census Data on Shipbuilding and Boatbuilding Industries

	NAICS 336611 (shipbuilding)	NAICS 336612 (boatbuilding)
Number of establishments	639	1,123
Number of companies	586	1,063
Establishments with 100+ employees	91	134
Establishments with 500+ employees	21	16

Within NAICS 336611, the U.S. Maritime Administration (MARAD) classifies yards as either first-tier or second-tier according to building capacity. In the Report on Survey of U.S. Shipbuilding and Repair Facilities, MARAD (2003) identifies 24 first-tier yards, which form the “major shipbuilding base” (MSB) in the United States. The 24 MSB yards satisfy several requirements, including at least one construction position capable of accommodating a vessel that is 400 feet in length or over and an unobstructed waterway leading to open water (i.e., locks, bridges) and the channel water must be a minimum of 12 feet deep. While MSB yards are the only ones to manufacture large ships, many of them also produce smaller commercial vessels. Second-tier yards do not meet these criteria and include many small- and medium-sized yards that construct and repair boats.[17]

1.1.3.3 Recreational Vessels

This section describes the recreational boat manufacturing industry, with special attention to the segment of the industry using diesel engines.

1.1.3.3.1 Types of Recreational Vessels

U.S. boatbuilders construct a variety of recreational boats, including ski/wakeboard boats, powerboats, racing boats, sailboats, recreational fishing boats, and yachts. Only a small segment of recreational boats are powered by diesel engines and thus addressed by this profile. Diesel-powered types of vessels include inboard cruisers and most of the larger yachts.

1.1.3.3.2 Supply of Recreational Vessels

Boats for personal and recreational use can be manufactured from many different materials, including fiberglass-reinforced plastic (FRP), aluminum, rotationally molded (rotomolded) polyethylene or other thermoplastic materials, and wood. Only relatively large (over 40 foot) inboard cruisers commonly use diesel engines; diesel engines used in recreational vessels are almost exclusively C1 engines, although C2 engines may be used on the largest yachts. Among recreational boats, large inboard cruisers are less likely to be serially produced; because they are quite costly, they tend to be customized to buyers' specifications. Like smaller serially produced boats, the most common hull material is FRP.

1.1.3.3.3 Production Process

The most common material used in boat manufacturing is FRP. Boats made from FRP are typically manufactured serially. Using FRP makes it very difficult to incorporate purchaser preferences into a vessel's design because 1) many features are designed into fiberglass molds, making customization time consuming and expensive and 2) vessels constructed from FRP are very sensitive to changes in their vertical or horizontal centers of gravity, making it difficult to change a particular design. In some cases, boat manufacturers produce the FRP hulls and decks used in constructing their boats; in other cases the FRP hulls and decks of boats are manufactured by a contractor for the boat manufacturer.

The process typically used to manufacture these boats is known as open molding. In this process, separate molds are used for the boat hull, deck, and miscellaneous small FRP parts such as fuel tanks, seats, storage lockers, and hatches. The parts are built on or inside the molds using glass roving, cloth, or mat that is saturated with a thermosetting liquid resin such as unsaturated polyester or vinylester resin. The liquid resin is mixed with a catalyst before it is applied to the glass. The catalyzed resin hardens to form a rigid shape consisting of the plastic resin reinforced with glass fibers.

The FRP boat manufacturing process generally follows the following production steps:

- Before each use, the molds are cleaned and polished and then treated with a mold release agent that prevents the part from sticking to the mold

- The open mold is first spray coated with a pigmented polyester resin known as a gel coat that will become the outer surface of the finished part. The gel coat is mixed with a catalyst as it is applied so that it will harden

- After the gel coat has hardened, the inside of the gel coat is coated with a skin coat of polyester resin and short glass fibers and then rolled with a metal or plastic roller to compact the fibers and remove air bubbles. The fibers are applied in the form of a chopped strand mat or chopped roving from a chopper gun; the skin coat is about 90 mils (0.09 inches) thick and is intended to prevent distortion of the gel coat (known as "print through") from the subsequent layers of fiberglass and resin

- After the skin coat has hardened, additional glass reinforcement in the form of chopped roving, chopped strand mat, woven roving, or woven cloth is applied to the inside of the mold and saturated with catalyzed polyester resin. The resin is usually applied with either spray equipment or by hand using a bucket and brush or paint-type roller. The saturated fabric is then rolled with a metal or plastic roller to compact the fibers and remove air bubbles

- More layers of woven glass or glass mat and resin are applied until the part is the desired thickness; the part is then allowed to harden while still in the mold. As the part cures, it generates heat from the exothermic reactions that take place as the resin hardens; very thick parts may be built in stages to allow this heat to dissipate to prevent heat damage to the mold

- After the resin has cured, the part is removed from the mold and the edges are trimmed to the final dimensions

- The different FRP parts of the boat are assembled using small pieces of woven glass or glass mat and resin, adhesives, or mechanical fasteners

- After the assembly of the hull is complete, the electrical and mechanical systems and the engine are installed along with carpeting, seat cushions, and other furnishings and the boat is prepared for shipment

- Some manufacturers paint the topsides of their boats to obtain a superior finish; the larger boats generally also require extensive interior woodwork and cabin furnishings to be installed

As noted above, only the larger inboard cruisers are likely to have diesel propulsion engines. Of all inboard cruisers, 56 percent are diesel-powered. For boats less than 40 feet in length, less than 35 percent are diesel-powered; for those over 40 feet in length, 85 percent are diesel-powered. Table 1-18 provides estimates of inboard cruiser retail sales by engine type and length of boat. In 2003, 5,191 diesel-powered inboard cruisers were sold; of these, 3,032 were 41 feet or longer. Another 988 diesel-powered cruisers ranged from 36 to 40 feet in length. Only 454 were 30 feet long or less.[18]

Table 1-18 Estimates of Inboard Cruiser Retail Unit Sales by Engine Type and Length of Boat

	1997		1999		2001		2003	
Boat Length	Gas	Diesel	Gas	Diesel	Gas	Diesel	Gas	Diesel
30' and under	917	178	1,064	435	1,059	495	279	454
31'–35'	1,525	309	2,199	673	2,458	953	1,294	717
36'–40'	1,048	492	1,142	804	1,280	991	1,984	988
41' and over	529	1,302	428	2,655	420	3,144	572	3,032
Total	4,019	2,281	4,833	4,567	5,217	5,583	4,109	5,191

Table 1-19 summarizes the sales data from 1997 through 2003 for recreational boats. In 2003, an estimated 9,200 inboard cruisers were sold; 97 percent of inboard cruisers over 31 feet long were powered by twin engines. Sales in the United States are expected to continue to decrease as more and more of the larger recreational boats are being built overseas (e.g., Taiwan).[19]

Table 1-19 Estimates of Inboard Cruiser Retail Unit Sales by Single vs. Twin Engine and Length of Boat

	1997		1999		2001		2003	
Boat Length	Single	Twin	Single	Twin	Single	Twin	Single	Twin
30' and under	789	306	1,028	471	1,004	550	463	271
31'–35'	91	1,742	97	2,775	155	3,256	86	1,925
36'–40'	51	1,490	112	1,834	233	2,038	136	2,815
41' and over	30	1,801	23	3,060	32	3,532	20	3,584
Total	961	5,339	1,260	8,140	1,424	9,376	705	8,595

While not all inboard cruisers are diesel-powered, the production costs for inboard cruisers as a group are likely representative of the relative costs of various inputs used in producing diesel-powered inboard cruisers. Production costs for builders of inboard cruisers include the costs of materials, labor, and capital equipment. Materials costs are more than double the cost of labor for these producers and represent roughly half of the value of shipments of inboard cruisers (see Table 1-20).[20] Because diesel engines are generally more expensive than gasoline engines, materials may represent an even larger share of diesel-powered inboard cruiser costs.

Table 1-20 Costs of Production for NAICS 3366123, Inboard Motorboats, Including Commercial and Military, Except Sailboats and Lifeboats

Establishments	Number	Payroll ($1,000)	Number	Hours (1,000)	Wages ($1,000)	Cost of Materials ($1,000)	Capital Expenditures ($1,000)	Value of Shipments ($1,000)
82	13,412	427,949	10,457	20,773	299,815	1,197,464	39,900	2,384,478

1.1.3.3.4 Demand for Recreational Vessels

Recreational boats are final consumer goods, and are generally considered discretionary purchases. Demand for recreational boats is typically characterized by elastic demand.

1.1.3.3.5 Industrial Organization for Recreational Vessel Manufacturers

Recreational boat builders are located along all coasts and major waterways. Table 1-21 provides sales and employment information of recreational diesel boat builders.[21,22,23] Of the 36 companies for which data were identified, only 9 employ more than 500 employees. Two large, multi-facility companies (Genmar and Brunswick) employ 21,000 and 6,000 employees respectively. Companies with fewer than 500 employees would be considered small businesses under the criteria of the Small Business Administration for NAICS 336612. Based on that definition, the majority of firms producing recreational diesel boats would thus be considered small entities.

Table 1-21 Employment Distribution of Companies that Build Recreational Boats

Employment Range	Number of Firms	Revenue Range ($Millions)
0–100	11	1.3 – 8.5
101–250	9	9.2 – 45.0
251–500	7	20.2 – 101.7
501–1,000	4	63.2 – 131.0
1,000+	5	45.60 – 5,229
Total number of firms	36	

Although there are a few large companies in the recreational diesel boat building industry, there are many more small companies. The boat yards are located on water bodies throughout the country, and many serve somewhat regional markets. Because there are a relatively large number of suppliers, because there is increasing competition from foreign suppliers, and because barriers to entry and exit are low, it is reasonable to characterize the markets for recreational diesel vessels as competitive. As described in section 1.1.2.4.3, the potential for competition and entry (contestable markets) forces existing producers to behave in a competitive manner.

1.1.3.3.6 Markets and Trends in the Recreational Vessel Manufacturing Industry

As summarized in Table 1-22, prices for inboard cruisers 41 feet and longer have displayed no clear trend during the period 2001–2003.[24] Prices in most categories dipped in 2003, reaching prices below 2001 levels. This may result from increased competition from foreign suppliers.

Table 1-22 Estimated Average Retail Selling Price of Recreational Inboard Boats by Length of Boat

Boat Length	1997	1998	1999	2000	2001	2002	2003
41' and over	$490,409	$475,869	$469,866	$516,146	—	—	—
41'–49'	—	—	—	—	$449,990	$419,873	$384,329
50'–59'	—	—	—	—	$963,197	$898,256	$842,578
60'–65'	—	—	—	—	$2,166,030	$2,280,029	$2,220,833
66' and over	—	—	—	—	$3,627,189	$4,464,111	$2,816,731

Information from NMMA indicates that the number of larger recreational boats being built abroad, in places like Taiwan, has increased significantly in the last few years.[25] A recent NMMA report on recreational boat sales compiled U.S. Department of Commerce import and export data, as reported in the U.S. International Trade Commission database. The 2003 data confirmed that the trade imbalance continues to grow. Factors affecting this growth include the rising cost of shipping, trade disputes between the U.S. and Europe, and the strength of the dollar, which makes it difficult for U.S. boatbuilders to offer competitive pricing overseas.

Table 1-23 shows that exports of vessels declined from 1997 to 2001, then increased, posting a substantial increase between 2002 and 2003.[26] Imports continue to outpace exports, with the trade balance deficit roughly tripling between 1997 and 2003. However, because of the substantial increase in exports, the deficit actually fell between 2002 and 2003.

Table 1-23 Value of Imported and Exported Vessels (in $Millions)

	1997	1998	1999	2000	2001	2002	2003
Boats export	$678.6	$674.8	$698.5	$662.0	$560.4	$600.5	$746.5
Boats import	$835.0	$874.7	$984.2	$1,074.8	$1,113.1	$1,157.7	$1,207.2
Trade balance	–$156.40	–$199.90	–$285.70	–$412.80	–$552.70	–$557.20	–$460.70

1.1.3.4 Commercial Vessels

This section builds on earlier work by EPA to characterize commercial vessels and identify how many of each type are powered by C1 and C2 diesel engines. U.S. boat builders construct a wide variety of commercial vessels. Most of these boat builders are single-establishment companies and manufacture a limited number of boat designs. A handful of yards (e.g., Halter Marine) also have the capacity to build ships that would be powered by C3 engines. Most commercial and government boats are manufactured individually or customized to purchaser's specifications.

U.S. boatyards build boats primarily used on inland and coastal waterways between U.S. ports. This is because cargo vessels on these routes must satisfy Jones Act requirements (U.S. Department of Transportation, 1998)(Section 27 of the Merchant Marine Act of 1920) that any vessel transporting merchandise between U.S. ports be built in the U.S., and be owned and operated by U.S. citizens. For this reason, the U.S. commercial boatbuilding industry has a protected local market and does not face the intense foreign competition that recreational boat builders or shipbuilders constructing large C3 vessels for international trade do. Clients include waterways operators (e.g., tugboats and pushboats), offshore petroleum exploration and drilling companies (e.g., liftboats, crewboats, supply boats), fisheries companies (e.g., fishing and fish processing boats), industrial companies, (e.g., cable-laying boats), and research organizations (e.g., oceanographic research vessels).

The markets for commercial and governmental vessels can be modeled as if they were competitive. While the Jones Act prohibits foreign manufacture of cargo vessels trading between U.S. ports and the Passenger Services Act imposes a fee of $200 per passenger on carriers transporting passengers between U.S. ports unless the vessels are U.S.-built, -owned, and -operated, most U.S. markets for commercial vessels have relatively low barriers to entry and exit. There are a significant number of U.S. firms in each market segment, and they compete for both government and commercial contracts.

For the commercial boat market, we collected much of the background information in a separate report.[27] Although the objective of that report was to develop inputs for emissions inventory modeling, the report provides a general characterization of commercial vessels, and estimates both C1 and C2 vessel counts for various applications. This report adopts the same commercial/governmental vessel categories and definitions.

1.1.3.4.1 Tug and Towboats

Towboats, also known as tugboats, include boats with rounded bows used for pulling (towboats) and boats with square bows for pushing barges, known as pushboats. Towboats that pull or push barges are referred to as line-haul boats, and are the largest category of towboats. Specialized towboats may also be used for maneuvering ships in harbors, channel dredging, and construction activities. Towboats vary widely in size and configuration, ranging from small harbor tugs less than 30 feet in length to large ocean-going tugs over 100 feet.

Data from WorkBoat Magazine’s annual construction survey are shown in Table 1-24.[28] Participating in this survey is voluntary, and only 56 of more than 500 companies that build commercial boats and ships responded. The voluntary nature of the survey may result in some selection bias such that the respondents are not fully representative of the nonrespondents. This effect may be relatively stable over time, however, so that trends in the data may be indicative of trends in the industry as a whole.

Table 1-24 shows that the number of towboats (including towboats, pushboats, tugs, and AHTS) in production increased from 39 in 2003 to 57 in 2004, and 73 in 2005. The Category 2 Vessel Census estimated that 3,164 of 4,337 towboats in existing databases had C1 engines.[29] Thus, it is likely that the majority of the newbuilt towboats are also powered by C1 engines. According to the Vessel Census, the majority of these towboats operate in the U.S. Gulf and U.S. Inland areas.

Table 1-24 U.S. Commercial Boat Orders, 1993, 1994, 1997 and 2003, 2004, 2005

	Number of Boats Produced					
Vessel Type	1993	1994	1997	2003	2004	2005
Number of survey respondents	85	83	84	40	46	56
Casino/gaming	34	27	6			
Passenger (dive, dinner, excursion, ferries, sightseeing, water taxi, charter)	102	95	68	44	31	40
Crew, crew/supply pilot, personnel launch	27[a]	41	44	17	31	18
Supply/service		5	81	37	25	29
Liftboat, utility	26[b]		34	5	7	8
Pushboat, towboat, tug	28	60	88[c]	39	57	73
Fire, rescue		5	7	2	12	2
Boom, spill response	60	33	38	4	10	6
Small craft (assorted), tender	44[d]	124[e]	38	17	7	14
Patrol (military, nonmilitary)	99[f]	89	48	74	69	92
Other military			79	27	6	24
Others	26	33	38	110[g]	149	155
Total number of boats	446	512[h]	569	376	405	460

Notes:

[a] Supply boats were consolidated with crew/supply boats and pilot boats.

[b] General workboats were consolidated with utility boats in the 1993 survey.

[c] AHTSs were consolidated with pushboats, towboats, and tugs.

[d] Research and survey boats were consolidated with tenders in the.1993 survey and in the table for 2004 and 2005.

[e] Research, survey, and utility boats were consolidated with the assorted small craft and tenders in the 1994 survey.

[f] Fireboats were consolidated with the patrol boats in the 1993 survey.

[g] The total number of “other” boats in included nonself-propelled vessels (2003–42 vessels, 2004–92 vessels, 2005–80 vessels).

[h] The total number of boats in 1994 did not include the 111 RIBS, skiffs, or small utility, or the 26 support, minehunter, or landing craft reported.

1.1.3.4.1.1 Supply of Tugs and Towboats

The majority of towboats are manufactured individually according to buyer specifications. Some of the smallest ones may be serially produced. Towboats are durable, all but the smallest are made of steel, and have relatively large engines for their dimensions.

Commercial shipyards and boatyards building towboats use a variety of manufacturing processes, including assembly, metal finishing operations, welding, abrasive blasting, painting, and the use of engines for crane operation and boilers. The typical ship construction process begins with steel plate material. The steel is formed into shapes, abrasively cleaned (blasted), and then coated with a preconstruction primer for corrosion protection. This is usually done indoors at the bigger shipyards and most facilities have automated these steps. Using the preformed steel plates, small subassemblies are then constructed and again a primer coat is applied. Larger subassemblies are similarly put together and primed to protect the steel substrate material. At some point in the construction, components are moved outdoors to work areas adjacent to the drydock. Final assembly and engine installation are done at the drydock.

Based on statistics for the shipbuilding NAICS code, NAICS 336611, materials account for more than 50 percent of the production costs, and labor for approximately 40 percent. Energy costs, investment in capital equipment, rental payments, and business services all account for smaller shares of total value of shipments.

1.1.3.4.1.2 Demand for Tugs and Towboats

Towboats are purchased by towing companies that move cargo on barges on coastal routes or on the nation's rivers. According to the American Waterways Operators (AWO), the tugboat, towboat, and barge industry include more than 4000 operating tugs/towboats and more than 27,000 barges. These vessels move more than 800 million tons of raw materials and finished goods each year, including more than 20 percent of the nation's coal, more than 60 percent of the nation's grain exports, and most of New England's home heating oil and gasoline.[30] In addition to commodity transportation, tugs are needed within harbors to maneuver ships to and from their berths, and to assist with bunkering and lightering. The demand for towboats is thus derived from the demand for commodity transportation services, which in turn is derived from the demand for the commodities being transported. According to the AWO, mandated replacement of single hulled barges with double hulled barges in the oils transportation sector will result in some replacement of the towing vessel fleet as larger tugs are required to move heavier barges. Further, the harbor tug fleet will continue to be modernized to include alternatives to conventional tugs for shipdocking and tanker escort services. In general, the size of the tow and tug fleet is shrinking somewhat, but industry capacity is increasing as older vessels are being replaced with larger, more powerful vessels.[31]

1.1.3.4.2 Commercial Fishing Vessels

Commercial fishing vessels are dedicated to procuring fish for market and may be distinguished by whether they tow nets or are engaged in "hook and line" fishing, or are multipurpose vessels that support a variety of fishing activities. Fishing vessels vary widely in size and configuration. Smaller fishing vessels may be serially produced using fiberglass, similar to recreational boats. Larger fishing vessels are generally built individually to buyer's specifications. The largest fishing vessels also serve as factory ships with the capacity to sort, clean, gut, and freeze large quantities of fish.

The Vessel Census, based on the Coast Guard's Merchant Vessels of the U. S. (MVUS) database, estimates that there are more than 30,000 commercial fishing vessels operating in the U.S., with the largest number being in Alaska, followed by Washington and Texas. Other states with large numbers of commercial fishing vessels include California, Florida, Louisiana, and Maine. Of the roughly 30,000 commercial fishing vessels identified, 8,130 are listed as definitely C1 and another 21,300 are characterized by the report's authors as probably C1.[32] If accurate, this means that all but 700 or so commercial fishing vessels are powered by C1 engines, and that the remaining 700 are powered by C2 engines. The C2 vessel census suggests that the actual number of C2 powered fishing vessels may be less than half this number.[33] Less than 1 percent of commercial fishing vessels were identified as gasoline-powered.

Given that the vast majority of commercial fishing vessels are powered by C1 engines, it seems reasonable to assume that the majority of these vessels are also similar to recreational vessels in construction. Small commercial fishing vessels must be able to travel rapidly to and from fishing grounds given that their operations have them going to fishing grounds and returning to port each day. Thus, many of these vessels have fiberglass hulls and are designed for planning operation, much like recreational vessels.

1.1.3.4.2.1 Supply of Commercial Fishing Vessels

Smaller commercial fishing vessels are generally produced using fiberglass with a production method similar to that used for recreational boats. Mid-size fishing boats may be made of fiberglass, aluminum, or steel, and are likely produced individually to buyers' specifications. The largest fishing boats, factory ships, are produced individually at shipyards and a few exceed the 400 foot length that is covered by this profile. Serial and individual production methods are described above.

1.1.3.4.2.2 Demand for Commercial Fishing Vessels

Commercial fishing boats are inputs into the production of fish for sale to consumers, restaurants, retailers, and processors. Reduced catch in many of the nations' fisheries has resulted in lower returns for fishermen, and thus in a declining number of commercial fisherman and declining demand for commercial fishing vessels. This decline is projected to continue.[34] To the extent that governmental efforts to replenish stocks and increase catch are successful, some increase in the number of commercial fishermen and fishing boats may occur in the future.

1.1.3.4.3 Patrol Vessels

Patrol boats such as Coast Guard vessels (government, Department of Homeland Security), include small boats used by harbor police and other law enforcement agency patrols, as well as larger vessels such as cutters. Small boats used by the Coast Guard include approximately 1,400 boats ranging from 12 to 64 feet, which operate close to shore. Coast Guard cutters are at least 65 feet in length, and range up to more than 400 feet in length. The Vessel Census identified 158 of 235 cutters that were powered by C2 engines.[35] The smaller boats operated by the Coast Guard were determined to be powered by C1 engines. Fast pursuit boats may be powered by gasoline engines. The majority of patrol boats not operated by the Coast Guard are relatively small and thus most likely powered by C1 engines, or SI outboards for the smallest patrol boats.

1.1.3.4.3.1 Supply of Patrol Boats

Patrol boats are generally manufactured from aluminum (two major manufacturers of patrol boats, Seaark Marine and SAFE Boats, Inc., both manufacture aluminum boats in large numbers). Other aluminum boatbuilders with government work, including military as well as state and local agencies, include Kvichak Marine, Northwind Marine, Rozema, All American

Marine, ACB, Almar, Munson and Workskiff. While their designs can be customized, these aluminum boats are largely serially produced. Significant inputs include aluminum, engines, and labor. Some small patrol boats are inflatable, with reinforced rigid hulls made of steel. Larger patrol boats such as Coast Guard cutters are made of steel.

1.1.3.4.3.2 Demand for Patrol Boats

Government agencies, including the Coast Guard, the Military, the Army Corps of Engineers, as well as harbor police and municipalities are the major purchasers of patrol boats. The need to increase vigilance along our coasts and in our harbors since the September 11 attacks has led to a tremendous increase in demand for Coast Guard patrol boats, which is likely to continue to be strong for several more years as the fleet is built up.[36] The Workboat Construction Survey shows that contracts have risen from 48 in 1997 to 92 in 2005.

1.1.3.4.4 Passenger Vessels

Passenger vessels powered by C1 or C2 diesel engines include ferries, excursion boats, and water taxis. Ferries are self-propelled vessels that carry passengers from one location to another, either with or without their automobiles. Ferries may be owned by states or private companies, and generally operate over set routes according to regular schedules. Water taxis are generally smaller than ferries and operate on a for-hire basis. The Vessel Census studied ferries, and identified 106 that were powered by C2 engines and 508 powered by C1 engines. Water taxis are generally powered by spark-ignition (SI) engines, although some may be powered by C1 inboard engines. Excursion boats are generally powered by C1 engines, although some of the larger ones that approach small cruise ships in size, are powered by C2 engines.

1.1.3.4.4.1 Supply of Passenger Vessels

Passenger vessels may be made of aluminum or steel. For example, Derektor Shipyards had orders to deliver three aluminum ferries ranging from a 92 foot high speed catamaran ferry to a passenger/vehicle ferry that was 239 feet long. Two other companies had orders for large steel ferries, including two 310-foot Staten Island Ferries. Larger ferries and other passenger vessels are likely powered by C2 engines, while smaller ones are likely C1 or even SI outboard or sterndrive for the smallest and lightest ones.

1.1.3.4.4.2 Demand for Passenger Vessels

Ferries and water taxis are needed for transportation services, and are generally used in urban areas. Other types of passenger vessels, including excursion boats, dinner boats, and floating casinos, are needed for recreational purposes. Some of these, such as whale watching boats, are very small; others such as floating casinos and some excursion boats may be more than 100 feet in length. Workboat’s 2005 Construction Survey showed orders for 19 dinner, excursion, or sightseeing boats and also for 19 ferries or water taxis. Both types of passenger boats are likely to respond to cyclical patterns in the economy, as both commuting and recreation increase when the economy is strong.

1.1.3.4.5 Research Vessels

Research vessels include vessels equipped with scientific monitoring equipment used to track wildlife, map geological formations, monitor coastal water quality, measure meteorological conditions, and conduct other scientific investigations. They vary widely in size and complexity and may be made of aluminum, fiberglass, or steel. They may be powered by SI outboard engines, C1, or C2 inboard engines, depending on their size. While they may be built on a standard hull design, the fittings are highly individualized based on their task, and may be technically complex. Of 12 research vessels reported in the Workboat 2005 Construction Survey, most are made of aluminum and are less than 80 feet in length. Two are made of steel and are about 150 to 200 feet in length. Of the purchasers listed, three of the vessels were ordered by the National Oceanic and Atmospheric Administration (NOAA) and one by a university. The instruments and other scientific equipment are a special and potentially expensive cost element for these vessels. Demand for the vessels is a function of demand for the research products that they support.

1.1.3.4.6 Offshore Support Vessels

Offshore support vessels (OSVs) include a variety of vessels used to construct, operate, maintain, and service offshore oil platforms. Of the categories listed in Table 1-24, crew, crew/supply, personnel, supply/service and liftboat/utility vessels are all vessel types that support the offshore oil industry. This is a diverse category, including a wide range of sizes, materials, and configurations. Platform supply boats and crew/supply boats tend to be over 150 feet in length and may be made of steel or aluminum. Lift boats tend to be about 150 feet in length and made of steel. OSVs listed in Workboat's 2005 Construction Survey range from 145 feet to 280 feet and are made of steel. At the other end of the spectrum are smaller aluminum crew and utility boats. Most offshore oil activity in the U.S. is in the Gulf of Mexico; thus, most offshore support vessels operate there.

Demand for offshore support vessels depends largely on the status of the offshore oil industry. Changes in that industry over the past 15 years have resulted in reduced numbers of rigs farther from shore. Thus, while fewer support vessels may be needed, they may be required to be larger and more seaworthy. The Gulf Coast hurricanes of 2005 had a substantial impact on the offshore oil industry and offshore support vessels. Many platforms and offshore support vessels suffered damage due to the storms. Demand for offshore support vessels has increased drastically, and day rates have more than doubled. This will likely result in an increase in construction of offshore support vessels in the next few years, relative to recent years.

Table 1-25 gives a summary of the types of boats currently under contract to be built at U.S. boatyards based on information taken from the Marine Log website and Workboat's 2005 Construction Survey, using the commercial boat categories described above.[37]

Table 1-25 Boats Under Construction by Type and Client, December 2005 Contracts

Type of Boat	Commercial Clients	Government Clients	Total
Tow/Tug	31	7	38
Fishing	0	1	1
Coast Guard	0	92	92
Ferry	19	2	21
Cargo	75	0	75
Research	1	2	3
Offshore Support	31	0	31
Great Lake/Others	3	1	4
Military	0	64	64
Total	140	169	329

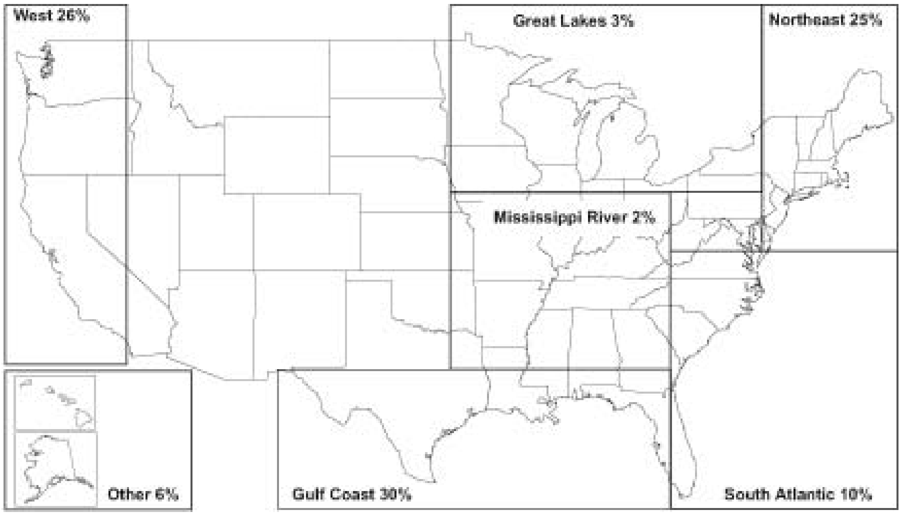
1.1.3.5 Industry Organization

This section examines the organization of the boat building industry, including characterizing firms in the industry, and examining market structure.

1.1.3.5.1 Location and Number of Vessel Manufacturers

There are several hundred yards that build many different types of boats powered with small engines (≤37 kW) as well as larger C1 and C2 engines. Boat builders are located along all coasts and major inland waterways of the United States. Figure 1-1-6 shows the geographic distribution of boat builders in the United States. A majority of them are located in the Gulf Coast, the Northeast, and the West Coast, and account for approximately 30 percent, 25 percent, and 26 percent of the boatbuilding industry, respectively. Collectively, these three regions represent 345 boat builders, including 128 builders on the Gulf Coast, 107 in the Northeast and 110 on the West Coast - 80 percent of all companies in the 1998 Boat builder Database.

Figure 1-1-6 Major Boatbuilding Regions of the United States



1.1.3.5.2 Firm Characteristics

Table 1-26 summarizes company financial data for companies that produce commercial vessels powered by C1 and C2 engines.[21,22,23] The available data capture total company employment and sales figures including any subsidiaries and operations including boat repair that may not be related to boatbuilding. Because many companies may produce boats powered by both SI and CI engines, or may produce larger vessels powered by C3 engines, not all of the boatbuilding employment and revenues listed in Table 1-26 are associated with vessels powered by C1 and C2 engines.

Table 1-26 Employment Distribution of Companies that Build Commercial and Government Boats

Employment Range	Number of Firms	Revenue Range ($Millions)
100 or fewer	29	0.15 – 7.0
101–250	12	12.0 – 50.0
251–500	5	11.0 – 30.9
501–1,000	3	42.0 – 73.0
1,001 or more	13	82.0 – 29.9
Total number of firms	62	

Almost all companies that produce commercial or governmental vessels powered by C1 or C2 engines are classified under NAICS 336611. Of an estimated 589 firms in that NAICS code, company names, employment, and sales data were obtained for only 62. Using the Small Business Administration’s small business criterion for NAICS 336611 (1,000 employees), 49 of the 62 (79 percent) of the companies for which data were obtained would qualify as small entities.

1.1.3.5.3 Markets and Trends in Commercial Vessel Manufacturing

Markets for commercial and governmental vessels can be modeled as competitive. While products are differentiated rather than homogeneous, there are many yards that produce similar types of vessels, and compete for both commercial and governmental contracts. Barriers to entry and exit are relatively low, at least domestically. For commercial cargo vessels working between U.S. ports, foreign competition is limited by the Jones Act. Similarly, passenger vessels plying exclusively domestic routes are constrained by the U.S. Passenger Services Act. Nevertheless, because the technology and materials for boat building are widely available, costs of entry into the market are fully recoverable, and barriers to entry and exit are thus low which results in domestic commercial boat manufacturers facing markets that are contestable and therefore competitive.

The U.S. boatbuilding industry is currently influenced by several key factors. These factors suggest a continued increase in the number of commercial boats built in the United States:

- Increasing demand for the T-class vessels. (The U.S. Coast Guard defines T-class vessels as boats not designed to see the open ocean, such as cruise boats, dinner and gambling boats, crew boats in the Gulf of Mexico, and off-shore vessels);

- Increasing demand for offshore supply vessels to repair and service offshore oil rigs, including repairing or replacing rigs and OSVs damaged or destroyed by Gulf Coast hurricanes in 2005;

- Increasing demand for oil (e.g., drillships and semisubmersible rigs);

- Expansion of demand for casino boats;

- Decisions by leading boat builders to reopen facilities and expand their labor forces provide strong indications that they anticipate continued growth in the market for commercial and governmental vessels. An increase in demand for new boats will mean more business for the commercial U.S. boatbuilding industry, as foreign builders are ineligible to build for segments of this market. Some of the larger boat builders in the United States also build boats for foreign owners/operators, particularly for foreign militaries. As noted in the table summarizing current shipyard/boatyard contracts, there are at least three yards doing work with foreign governments (e.g., Egypt and Oman)

In summary, U.S. boat builders are cautiously optimistic about the future because almost every segment of the U.S. flag fleet is facing significant replacement requirements. The commercial boat builders are expected to continue to be a major consumer of marine diesel engines.

1.1.4 Vessel Operators

The U.S. Economic Census provides an overview of the Water Transportation subsector and the subsectors which provide water transporation for passengers and cargo using water crafts such as ships, barges, and boats. While there is no database that directly links these firms to type of Commercial C1 and C2 marine diesel engines they use in their businesses, the survey data does provide a very helpful overview of the industry where these engines predominate. Information is organized by the North American Industry Classification System (NAICS) Codes and the data was gathered in 2002 Economic Census.

The Water Transporation Subsector is composed of two industry groups: (1) one for deep sea, coastal, and Great Lakes- NAICS 4831; and (2) one for inland water transportation- NAICS 4832. This split typically reflects the difference in equipment used. Scenic and sightseeing water transportation services are not included in this subsector but rather are taken account of in subsector 487, Scenic and Sightseeing Transportation. Harbor Tug Services are included in subsector 488330 and Fishing is captured in subsector 1141. Table 1-27 provides the breakdown for each of the subsectors.

Table 1-27 Industry Subsectors with Employment Level defining Small Business Standards

NAICS CODE	Industry	Total Firms
	Deep Sea	
483111	Freight	235
483112	Passenger	77
	Coastal & Great Lakes	
483113	Freight	443
483114	Passenger	124
	Inland	
4832112	Freight (Towing)	310
4832121	Passenger (Ferry)	250
1141	Fishing	2084
487	Scenic & Sightseeing	1609
488330	Harbor Tugs Service	657
	TOTAL	5789

Approximately 5800 firms are represented in the Water Transporation subsector and affiliated sectors which purchase and use commercial vessels propelled by either C1 or C2 marine diesel engines. U.S. economic census data reveals that in 2002 about 65 percent of these firms had annual revenues of less than $1 million while 87 percent had revenues less than $5 million. In summary, when taking into account all firms in these subsectors about 88 percent of all revenue was generated by 12 percent (~720) of the 5800 firms.

1.2 Locomotive

1.2.1 Introduction

The regulations for locomotives and locomotive engines are expected to directly impact three industries. These industries are: (1) locomotive and locomotive engine original equipment manufacturers (OEMs); (2) owners and operators of locomotives (railroads); and (3) remanufacturers of locomotives and locomotive engines including OEMs, railroads, and independent remanufacturers. Locomotive manufacturers are companies that make or import complete "freshly" manufactured locomotives.[B] Remanufacturers are companies that certify kits for remanufactured locomotives.[C] A brief overview of these industries follows, along

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[B] Freshly manufactured locomotives are those which are powered by freshly manufactured engines, and contain fewer than 25 percent previously used parts (weighted by the dollar value of the parts).

[C] Remanufactured locomotives are locomotives in which all of the power assemblies are replaced with freshly manufactured (containing no previously used parts) or refurbished power assemblies. Remanufacturing includes with descriptions of the national economic impact of railroads and current regulations in effect for railroads.

1.2.2 Current U.S. Emission Regulations

The Agency's 1998 Locomotive Rule (63 FR 18978; April 16, 1998) created a comprehensive emission control program that subjected manufacturers and railroads (including all Class I and some small Class II and III railroads) to emission standards, test procedures and a full compliance program. The unique feature of this program was the regulation of the engine remanufacturing process, including the remanufacture of locomotives originally manufactured prior to the effective date of that rulemaking. Regulation of the remanufacturing process was critical because locomotives are generally remanufactured four to eight times during their total service lives of approximately 40+ years. Locomotives powered by an external source of electricity, historic steam-powered locomotives, and locomotives freshly manufactured prior to 1973 were not covered by the 1998 regulations.

Three separate sets of emission standards (Tiers) were adopted in the 1998 rulemaking, with applicability of the standards dependent on the date a locomotive was manufactured. The first set of standards (Tier 0) applied to locomotives and locomotive engines originally manufactured from 1973 through 2001. The second set of standards (Tier 1) applied to locomotives and locomotive engines originally manufactured from 2002 to 2004, and the final set of standards (Tier 2) applied to locomotives and locomotive engines originally manufactured in 2005 or later. All of these standards must be met when a locomotive is "freshly manufactured" and at each subsequent remanufacture. The emission standards set in 1998 for line-haul and switch duty-cycles are shown in Table 1-28.

Table 1-28 Maximum Permissible NO_x, CO, HC, and PM Rates by Tier

(g/bhp/hr)	Tier 0 Line-Haul Duty-Cycle	Tier 0 Switch Duty-Cycle	Tier 1 Line-Haul Duty-Cycle	Tier 1 Switch Duty-Cycle	Tier 2 Line-Haul Duty-Cycle	Tier 2 Switch Duty-Cycle
NO_x	9.5	14.0	7.4	11.0	5.5	8.1
CO	5.0	8.0	2.2	2.5	1.5	2.4
HC	1.00	2.10	0.55	1.20	0.30	0.60
PM	0.60	0.72	0.45	0.54	0.20	0.24

In addition to the separate sets of emissions standards established by the 1998 rulemaking, additional requirements for compliance with these emission standards were promulgated, and are described in 40 CFR Part 92. These provisions apply to manufacturers, remanufacturers, and owners and operators of locomotives, and locomotive engines manufactured on or after January 1, 1973. The three most significant requirements for

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the following: replacing an engine, upgrading an engine, and converting an engine to enable it to operate using a fuel other than it was originally manufactured to use.

railroads relate to: 1) remanufacture of locomotives 2) maintenance of locomotives, and 3) testing of locomotives.

The regulations require that post-1972 locomotives be covered by an EPA Certificate of Conformity when they are remanufactured. (*See Applicability of Locomotive Emission Standards*, EPA420-F-99-037, for more information about which locomotives are covered by these regulations). The certificate certifies that the locomotive was remanufactured in a specific manner such that it complies with EPA's emission standards. Each certificate covers a group of similar locomotives that is referred to as an "engine family." A railroad may apply directly to EPA to obtain a certificate, or may rely on a supplier or remanufacturer that has obtained a certificate. The company that obtains the certificate is referred to as the certificate holder, and is responsible for ensuring that the locomotive complies with EPA's emission standards.

The regulations also require that railroads perform emission-related maintenance on all regulated locomotives. This requirement is described in 40 CFR 92.1004. Emission-related maintenance is specified by the certificate holder and approved by EPA at the time of certification. The certificate holder is required to provide the emission-related maintenance instructions to the railroads. Emission-related maintenance generally includes regular replacement of fuel injectors and air filters, as well as the use of fuels and lubricants meeting the specifications of the certificate holder. In most cases, it will also include frequent inspection of other emission-related components to ensure that they are functioning properly. This section of the regulations also prohibits any maintenance that would reasonably be expected to adversely affect the emission performance of the locomotive.

EPA also established two testing programs to monitor the in-use emissions of locomotives. The fist program is run by the certificate holders, the second program is run by the Class I freight railroads and is described in 40 CFR 92.1003. Under this program, which began on January 1, 2005, each Class I freight railroad is required to test 0.15 percent of its locomotive fleet each year using the specified EPA test procedure (40 CFR Part 92 Subpart B). This railroad testing program focuses on the locomotives in the fleet that have exceeded their useful life values. (Useful life values are defined as the period specified in a certificate during which the locomotive is designed to comply with the standards; it is generally equivalent to 750,000 miles or more.)

1.2.2.1 Certification

Locomotive manufacturers must produce compliant locomotives, and they must be certified. In order for a locomotive to be certified, a company must certify the engine together with the locomotive. An engine manufacturer can certify, but it must certify the complete locomotive. Railroads must purchase all new locomotives with a valid certificate of conformity, and when remanufacturing a locomotive must have a valid certificate of conformity. However, small railroads are generally provided an exemption for the existing uncertified locomotives in their fleet, as well as any uncertified locomotives that they may purchase from other railroads in the future.

1.2.3 Supply: Locomotive Manufacturing and Remanufacturing

1.2.3.1 Locomotive Manufacturing

1.2.3.1.1 Types of Locomotives

Locomotives generally fall into three broad categories based on their intended use: switcher, passenger, and line-haul locomotives. Switch locomotives, typically 2000 hp or less, are the least powerful locomotives, and are used in freight yards to assemble and disassemble trains, or for short hauls of trains that are made up of only a few cars. Some larger switchers can be rated as high as 2300 hp. Passenger locomotives are powered by engines of approximately 3000 hp, with high-speed electric passenger locomotives powered by engines with 6000 hp or more. Freight or line-haul locomotives are used to power freight train operations over long distances. Older line-haul locomotives are typically powered by engines with 2000-3000 hp, while newer line-haul locomotives are powered by engines with 3500-5000 hp. In some cases, older line-haul locomotives (especially those with lower powered engines) are used in switch applications. The development of line-haul locomotives with even higher horsepower ratings, such as 6000 hp or more continues, but it is not clear if this will be the future of locomotive engines.

1.2.3.1.2 Type of Propulsion Systems

Locomotives can be subdivided into three general groups on the basis of the source of energy powering the locomotive: 1) “all-electric” 2) “engine-powered” 3) “hybrid”. In the "all-electric" group, externally generated electrical energy is supplied to the locomotive by means of overhead lines, a third rail that runs between or alongside the rails, or an onboard electric storage device such as a battery. Locomotives of this type have existed for over 125 years.[38] An example of this type of locomotive is commonly seen on commuter trains. Emission control requirements for all-electric locomotives would be achieved at the point of electrical power generation, and thus are not included in this rulemaking.

In the "engine-powered" group of locomotives, fuel (usually diesel in the U.S., although natural gas options are also being pursued) is carried on the locomotive. The energy contained in the fuel is converted to power by burning the fuel in the locomotive engine. A small portion of the engine output power is normally used directly to drive an air compressor to provide brakes for the locomotive and the train. However, the vast majority of the output power from the engine is converted to electrical energy in an alternator or generator which is directly connected to the engine. This electrical energy is transmitted to electric motors (traction motors) connected directly to the drive wheels of the locomotive for propulsion, as well as to motors which drive the cooling fans, pumps, etc., necessary for operation of the engine and the locomotive.[D] In the case of passenger locomotives, electrical energy is also supplied to the train’s coaches to provide heat, air conditioning, lights, etc. (i.e., "hotel

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[D] Essentially all "engine powered" locomotives used in the U.S. employ a diesel engine and the electrical drive system described above. The term "diesel-electric" has therefore become the most common terminology for these locomotives.

power"). In some passenger trains, electrical energy required for the operation of the passenger coaches is supplied by an auxiliary engine mounted either on the locomotive or under the floor of a passenger car.

The third category, "hybrid" is a combination of the "electric" and "engine-powered" groups, and was first developed and used in the 1920's, although at the time it wasn't very successful due to a lag in battery technology. Today's hybrid locomotive technology is considered to be "battery dominant" and uses a small diesel engine and generator to charge a battery pack; the battery pack then supplies energy on demand to the traction motors.[39] The engine can be 250-640 hp (200-480 kW) and typically operates at a constant speed, which allows the engine to be optimized for efficiency. Further fuel savings are achieved by running this engine only during times when it is needed to generate power to keep the batteries at a certain charge level.[40] This technology is currently only available for switcher locomotives, although it is being developed for use on line-haul locomotives.[41]

1.2.3.1.3 Locomotive Design Features and Operation

1.2.3.1.3.1 Sizing Constraints

Similar to the variation in horsepower, locomotive size determines the work it may perform. Switch locomotives tend to be about 40 to 55 feet long, while line-haul locomotives are typically 60 to 76 feet long. Locomotive length is roughly correlated with engine size, and thus the difference in length has become more significant as locomotive engines have become larger and more powerful. Locomotive length is also related to the number of axles found on a locomotive. In the past, a typical locomotive had four axles (two trucks with two axles each). While there still are a large number of four-axle locomotives in service, all newly manufactured line-haul locomotives have six axles (two trucks with three axles each). There are two primary advantages of having more axles on the locomotive. First, additional axles allow locomotives to be heavier without increasing the load on each individual axle (and thus the load on the rail). Second, six-axle locomotives typically have greater tractive power at low speeds, which can be critical when climbing steep grades. The use of six-axles on a locomotive does increase its overall length, and continues to lead to the discontinuation of the practice of converting old line-haul locomotives into switch locomotives, as these larger six-axle locomotives are too long to be practical in most switch applications.

1.2.3.1.3.2 Operational Characteristics

One unique feature of locomotives that makes them different than other currently regulated mobile sources is the way power is transferred from the engine to the wheels. Most mobile sources utilize mechanical means (i.e., a transmission) to transfer energy from the engine to the wheels (or other point where the power is applied). Because there is a mechanical connection between the road, vehicle engine and the wheels, the relationship between engine rotational speed and vehicle speed is mechanically dictated by the gear ratios in the transmission and final drive (e.g., the differential and rear axle). This results in engine operation which is very transient in nature, with respect to changes in both speed and load. In contrast, locomotive engines are typically connected to an electrical alternator or generator to convert the mechanical energy to electricity. As noted above, this electricity is then used to power traction motors which turn the wheels. The effect of this arrangement is that a locomotive engine can be operated at a desired power output and corresponding engine speed without being constrained by vehicle speed. The range of possible combinations of locomotive speed and engine power vary from a locomotive speed approaching zero with the engine at rated power and speed, to the locomotive at maximum speed and the engine at idle speed producing no propulsion power. This lack of a direct, mechanical connection between the engine and the wheels allows the engine to operate in an essentially steady-state mode, in a number of discrete power settings, or notches. Notches are throttle positions that load the engine at different power levels. There are typically eight power notches on a locomotive, as well as idle positions.

Dynamic braking is another unique feature of locomotives setting them apart from other mobile sources. Dynamic braking is especially important given the traction problems that locomotives must overcome. Locomotives generate an enormous amount of power that can be applied to the wheels when they start to roll, however, the use of steel wheels (which provide less rolling resistance) also make it difficult to start moving a locomotive. On straight sections of rail, some locomotives have a built-in system that will put sand on the rails in order to increase traction. The ridges on the sides of the wheels provide traction during cornering to keep the wheels on the rails, and some locomotives are equipped with an oil system that puts oil on the sides of the rails to reduce friction on the sides of the wheels during turns and cornering.

In dynamic braking the traction motors act as generators, where the generated power is dissipated as heat through an electric resistance grid; this feature decreases overall braking distance and wear on the wheels. While the engine is not generating motive power (i.e., power to propel the locomotive, also known as tractive power) in the dynamic brake mode, it is generating power to operate resistance grid cooling fans. The power generated from braking then heats up these resistance grids and is dissipated into the air as heat. As such, the engine is operating in a power mode that is different than the power notches or idle settings discussed above. While most diesel-electric locomotives have a dynamic braking mode, some do not (generally switch locomotives). The potential energy that could be recovered during dynamic braking and utilized by the locomotive is one area researchers are focusing on to increase locomotive efficiency. GE noted that “the energy dissipated in braking a 207-ton locomotive during the course of one year is enough to power 160 households for that year.”[41] However, it is very difficult to capture and store this energy. The power generated from dynamic breaking is instantaneous and high enough that it cannot be effectively used by the locomotive at the time it is generated. If the energy could be stored in batteries, or a mechanical device such as a flywheel, tremendous fuel savings could be gained, and therefore development of these types of systems continues.[42,43]

Hotel power or "Head End Power" (HEP) is power used to operate lighting, heating, ventilation and air conditioning, and all other electrical needs of the crew and passengers alike on locomotives equipped with this feature. This power can be provided by the lead locomotive or by an additional engine, and is distributed to the rest of the cars as needed. The design of locomotives for use in passenger train service (without additional engines used to provide HEP) provides for a locomotive to be operated in either of two distinct modes. In one mode, the locomotive engine provides only propulsion power for the train. In this mode, the engine speed changes with changes in power output, resulting in operation similar to freight locomotives. In the second mode, the locomotive engine supplies HEP to the passenger cars, in addition to providing propulsion power for the train. Hotel power provided to the passenger cars can amount to as much as 800 kW (1,070 hp). In contrast to operation in the non-hotel power mode, the engine speed remains constant with changes occurring in power output when operating in hotel power mode. Thus, the two modes of operation utilize different speed and load points to generate similar propulsion power. These differences in speed and load points mean that locomotive engines will have different emissions characteristics when operating in hotel power mode than when operating in non-hotel power mode.

1.2.3.1.3.3 Design Characteristics

In 1909 Rudolph Diesel helped construct the first diesel locomotive, and in 1918 the first diesel-electric switch locomotives were put into service.[44] By the 1950's diesel-electric locomotives had replaced steam powered locomotives because they required less fuel, maintenance, and man-power.[45] Locomotives use diesel engines because they are much more efficient, reliable, and can generate tremendous power. The diesel engine is one of the most efficient transportation powerplant available today. Thermal efficiency of locomotive diesel engines is 40% or higher, which results from high power density (via high turbocharger boost), high turbocharger efficiencies, direct fuel injection with electronic timing control, high compression ratios, and low thermal and mechanical losses. Many locomotive engines achieve the equivalent of one million miles before overhaul.[43] Durability is critical as a locomotive breakdown on the tracks can bottleneck the entire system; these failures are very costly to the railroads because of the importance of timeliness to their customers, and the difficulty in getting replacement locomotives to the location of the failure. The trend toward higher power locomotives is naturally resulting in a trend of fewer locomotives per train, thereby increasing the likelihood that a train would become immobilized by the failure of a single locomotive.

Another unique design feature of locomotives is the design of the engine cooling system and procedures used to control engine coolant temperature. Normal practice in locomotive design has been to mount the radiator on the roof of the locomotive and not to use a thermostat. Control of coolant temperature is achieved by controlling the heat rejection rate at the radiator. The rate of heat rejection at the radiator can be controlled by means such as turning fans on and off or employing a variable speed fan drive, or by controlling the amount of coolant flow to the radiator (using non-thermostat controls). A related point of difference between road vehicle and locomotive engine cooling systems is that antifreeze is not generally used in locomotives. Locomotives use water, not antifreeze to cool their engines because water is much more efficient at removing heat. Using antifreeze would require a cooling system approximately 20% larger than the current design (which holds approximately 450 gallons of water).[46] The size of a locomotive is limited by the existing track and tunnel infrastructure which restricts the height, width, and length of a locomotive. Locomotives usually run in consists (groups) which means that any locomotive following the lead locomotive will not have the same effective cooling as the one in front because the air it encounters will be warmer. The practice of "following" creates additional cooling problems, especially in tunnels which call for special design considerations.

The final unique design feature noted here is the manner in which new designs and design changes are developed. The initial design of any new locomotive model and the production of prototype models are done in much the same manner as is the case with other mobile sources. Locomotive manufacturers have indicated that this process can be expected to require from 12 to 24 months for significant changes such as those required to comply with Tier 0 standards. Unlike most other mobile sources, prototype locomotives are typically sold or leased to their customers (the railroads) for extended field reliability testing. Only after this testing is completed is the new design/design change certified and placed into normal production.

1.2.3.2 Line-Haul Manufacturing

1.2.3.2.1 Manufacturers

Locomotives used in the United States are primarily produced by two manufacturers: Electromotive Diesel (EMD) and General Electric Transportations Systems (GETS). EMD manufactures its locomotives primarily in London, Ontario and their engines in La Grange, Illinois. The GETS locomotive manufacturing facilities are located in Erie, Pennsylvania, while their engine manufacturing facilities are located in Grove City, Pennsylvania. These manufacturers produce both the locomotive chassis and propulsion engines; they also remanufacture engines. MotivePower's Wabtec division, headquartered in Wilmerding, Pennsylvania, has produced some mid-horsepower locomotives suited for commuter or long-distance service using engines manufactured by Caterpillar, Inc.[47] They also manufacture a switcher locomotive that runs on liquefied natural gas. The Cummins Engine Company, Inc., headquartered in Columbus, Indiana, produces V12 and V16 diesel engines for use in locomotives.[48] The EPA has identified four diesel locomotive manufacturers, one of which can be considered a small business according to SBA guidelines.[49] There are also a few companies such as Steward and Stevenson or Brookville Mining Equipment that manufacture small switch locomotives (under 700 bhp and not covered by this rulemaking) for use in mines or other specialized purposes.[50]

EMD was founded in 1922 and acquired by General Motors in 1930 and subsequently sold by General Motors in 2005 to the Greenbriar Equity Group and Berkshire Partners, and is now called Electro-Motive Diesel, Inc. While they primarily manufacture a 2-stroke diesel locomotive engine, they began manufacturing a 4-stroke engine in 1997. They currently produce five national models ranging from 3000-6000hp, and offer international models as well as custom built locomotives. EMD employs approximately 2,600 people and designs, manufactures, market, sells, and services freight and passenger diesel-electric locomotives worldwide.[51] GE was formed by Thomas Edison who developed his first experimental electrical locomotive in 1880, GE also built and put into the service the world's first diesel-electric switcher locomotive in 1924 that remained in service until 1957. GE currently produces at least five national models, two international models, passenger locomotives, and is developing a hybrid locomotive. GE's Transportation division employs approximately 8,000 people and also engineers, manufactures, markets and services their diesel locomotive products worldwide.[52]

1.2.3.2.2 Production

Due to the long total life span of locomotives and their engines, annual replacement rates of existing locomotives with freshly-manufactured units are very low. Table 1-29 illustrates the historical replacement rates for locomotives in the Class I railroad industry. Sales of new locomotives have averaged approximately 780 units per year over the last ten years. This replacement rate indicates a fleet turnover time of about 30 years for Class I railroads. Fleet turnover is the time required for the locomotive fleet to be entirely composed of locomotives that were not in service in the applicable base year. Class II and III railroads generally buy used locomotives from Class I railroads, although occasionally purchase new switchers or line-haul locomotives.

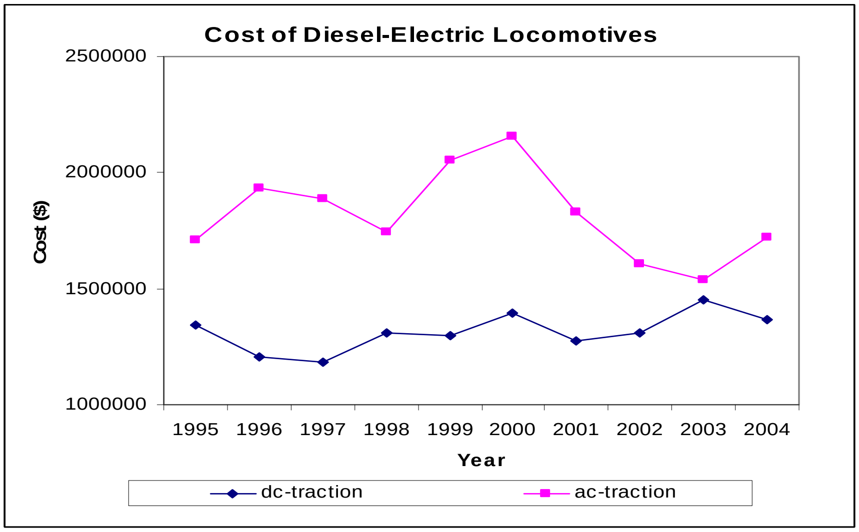
Table 1-29 Class I New Locomotive Turnover Rates[53]

Year	Number of New Locomotives Installed	Total Number of Locomotives in Service	Percent Turnover of New
1995	928	18,812	4.9%
1996	761	19,269	3.9%
1997	743	19,684	3.8%
1998	889	20,261	4.4%
1999	709	20,256	3.5%
2000	640	20,028	3.2%
2001	710	19,745	3.6%
2002	745	20,506	3.6%
2003	587	20,774	2.8%
2004	1,121	22,015	5.1%

1.2.3.2.3 Cost

The cost of a locomotive can vary between $1.5 million to $2.2 million, depending on the configuration and options installed. Figure 1-1-7 shows data from the AAR’s Railroad Ten-Year Trends 1995-2004 publication. Some of the variation from year to year can be attributed to differences in features, but it appears the overall trend in the price of AC locomotives is downward, while DC locomotive pricing remains steady.

Figure 1-1-7 Cost of New Locomotives[53]



1.2.3.3 Switcher Manufacturing

1.2.3.3.1 Manufacturers

The majority of switchers in operation today are former line-haul locomotives that have been assigned to a yard, and they are usually quite old. This trend will most likely abate over time because the size and power of most new locomotives can make them unsuitable for switching operations. While EMD does offer a traditional new switch locomotive, other companies are offering switchers with alternative power plants (such as hybrid or gen-set locomotives) that are usually built off of an old switcher platform.

Motive Power, headquartered in Wilmerding, PA offers a switching locomotive fueled by liquefied natural gas, which they build on cores supplied by a railroad. A core is a locomotive that is no longer in service which will be completely torn-down and reconfigured reusing any of its own salvageable parts as well as new parts. Motive Power is a large company with nearly 5,000 employees; they service other industries such as marine, transit and power generation. National Railway Equipment Co. (NREC) based in Houma, Louisiana with facilities also in Illinois manufactures a “gen-set” switcher locomotive (powered by multiple smaller diesel engines) that is built from the ground up. They employ approximately 150 employees.[54] RailPower Technologies is headquartered in Brossard, Quebec but also has an American office in Erie, Pennsylvania. They employ approximately 100 people, and manufacture the GreenGoat hybrid yard switcher and are developing a natural gas switcher locomotive as well. Railpower also uses an old switcher locomotive core to build their platform on.[55]

1.2.3.3.2 Production

The existing fleet of retired line-haul switcher locomotives turns over very slowly. However, production of alternative technology switchers is beginning to increase. NREC is working with Union Pacific Railroad (UP) to build sixty 2,100 hp GS21B gensets equipped with three four-cycle, six-cylinder, 700hp Cummins QSK-19 engines.[56] These switchers are believed to reduce NO_x and PM by 80% and to reduce fuel consumption by up to 16% as compared to a conventional switcher. UP is also evaluating the GreenGoat hybrid switcher, which is also expected to reduce fuel consumption by up to 16% and NO_x and PM emissions by 80%. Norfolk Southern has recently ordered two gen-set switchers from from RailPower in the form of retrofit kits where their own maintenance staff will install this triple-engine system during a switcher rebuild.[57] While new switchers can cost upwards of $1.5 million dollars, the GreenGoat hybrid switcher can cost as little as $700,000 if a customer supplies a completely reconditioned GP-9 locomotive.[58] Note that the price of these and other switchers depends on whether or not a core is supplied and what features it will be built with.

1.2.3.3.3 Trends

Remote control locomotives (RCL) have been used in Canada and the U.S. for many years; however, Class I railroads have recently begun to implement this technology on a wider scale according to the Federal Railroad Administration (FRA).[59] Although RCL technology is mainly used in switch yards, this type of operation may be applied on line-hauls in the future. RCL requirements may affect cab design and require that special equipment is built into future switchers. Another growing trend is the retrofit and use of idle reduction technology on locomotives to decrease fuel consumption and increase the railroads efficiency, especially as the cost of fuel continues to increase.[60]

1.2.3.4 Remanufactured Locomotives

Since most locomotive engines are designed to be remanufactured a number of times, they generally have extremely durable engine blocks and internal parts. Parts or systems that experience inherently high wear rates (irrespective of design and materials used) are designed to be easily replaced so as to limit the time that the unit is out of service for repair or remanufacture. The prime example of a part that is designed to be readily replaceable on locomotive engines is the power assembly, which is composed of: pistons, piston rings, cylinder liners, fuel injectors and controls, fuel injection pump(s) and controls, and valves. Within the power assemblies, parts such as the cylinder head generally do not experience high wear rates, and may be reused after being inspected and requalified (i.e. determined to be within manufacturers specifications). The power assemblies can be remanufactured to bring them back to as-new condition, or they can be upgraded to incorporate the latest design configuration for that engine. In addition to the power assemblies, there are numerous other parts or systems that are also designed to be easily replaced on locomotives.[E] Engine

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[E] Bottom end components, such as crankshafts and bearings, are often remanufactured only during every other remanufacture event. Remanufacture events that do not include these bottom end components are sometimes referred to as "partial remanufactures" remanufacturing may be performed by the railroad that owns the locomotive, or by the original manufacturer of the locomotive. Remanufacturing is also performed by companies that specialize in performing this work.

During its forty-plus year total life span, a locomotive engine could be remanufactured as many as ten times (although this would not be considered the norm). Locomotive engine remanufacturing events are thus routine, and are usually part of scheduled maintenance. It is standard practice for the Class I railroads to remanufacture a line-haul locomotive engine every four to eight years. Typically newer locomotives, which have very high usage rates, are remanufactured every four years. Older locomotives are usually remanufactured less frequently because they are used less within each year. Such remanufacturing is necessary to ensure the continued proper functioning of the engine. Remanufacturing is performed to correct losses in power or fuel economy, and to prevent catastrophic failures, which may cause a railroad line to be blocked by an immobile train.

When a locomotive engine is remanufactured, it receives replacement parts which are either freshly-manufactured or remanufactured to as-new condition (in terms of their operation and durability).[F] This includes the emission-related parts which, if not part of the basic engine design, are also generally designed to be periodically replaced. The replacement parts are often updated designs, which are designed to either restore or improve the original performance of the engine in terms of durability, fuel economy and emissions. Because of a locomotive engine's long life, a significant overall improvement in the original design of the parts, and therefore of the engine, is possible over the total life of the unit. Since these improvements in design usually occur in the power assemblies (i.e., the components where fuel is burned and where emissions originate), remanufacturing of the engine essentially also makes the locomotive or locomotive engine a new system in terms of emission performance. A remanufactured locomotive would therefore be like-new in terms of emissions generation and control.

While Class I locomotives are remanufactured on a relatively frequent and scheduled basis of 4 to 8 years, Class II and III locomotives may be remanufactured on a longer schedule or may not be remanufactured at all. The typical service life of a locomotive (40 years) is often exceeded by small railroads that continue to use older locomotives. It is important to note that there is no inherent limit on how many times a locomotive can be remanufactured, or how long it can last, rather, the service life of a locomotive or locomotive engine is limited by economics. For example, in cases, where it is economical to cut out damaged sections of a frame, and weld in new metal, an old locomotive may be salvaged instead of being scrapped. Remanufacturers can also replace other major components, such as trucks or traction motors, to allow an older locomotive to stay in service. However, at some point, most railroads decide that the improved efficiency of newer technologies justifies the additional cost, and thus scrap the entire locomotive. Nevertheless, many smaller railroads,

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[F] In some cases, some components are remanufactured by welding in new metal and remachining the component to the original specifications.

especially switching and terminal railroads, are still using locomotives that were originally manufactured in the 1940s.

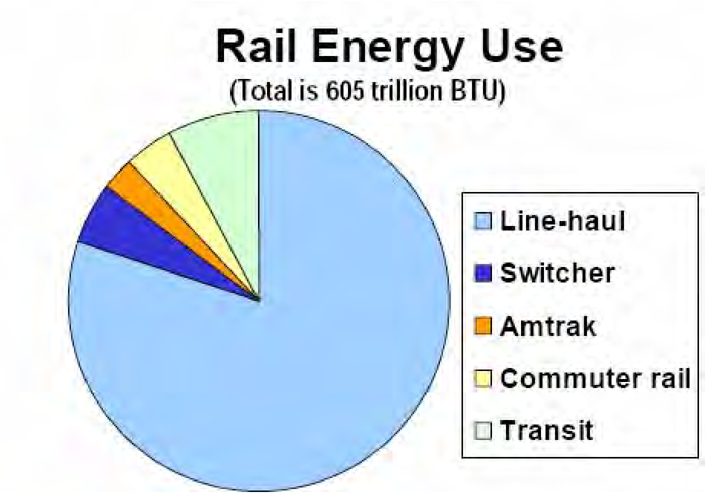
1.2.3.4.1 Remanufacturers

While the original manufacturers provide much of the remanufacturing services to their customers, there are several smaller entities that also provide remanufacturing services for locomotive engines. These businesses can be rebuilders licensed by the OEMs, in addition to the OEMs themselves. Moreover, some of the Class I and II railroads remanufacture locomotive engines for their own units and on a contractual basis for other railroads. EPA has been able to identify nine independent locomotive remanufacturers, four of which are small business entities. Many of these businesses are full service operations that remanufacture locomotive assemblies (such as trucks or air brake systems), sell new and used parts, repair wrecked locomotives or provide routine maintenance. A few of these operations remanufacture locomotives primarily for resale or lease, while others remanufacture engines for operating railroads or industrial customers. A few also offer contract maintenance; this may be tied to a locomotive lease, or may be offered separately to owners of locomotives. The size of these companies can vary tremendously. Some have as few as two employees, while others can have as many as 5,000 employees. The cost of a remanufacturing kit can vary depending on the model of locomotive and year of manufacture; an estimated range is $15,000 - $30,000 per kit.

1.2.4 Demand: Railroads

Railroads are said to transport freight more efficiently than other modes of surface transportation because they require less energy and emit fewer pollutants.[43] The 2006 Transportation Energy Data Book shows that rail transportation used approximately 7% of all diesel fuel used in transportation to move nearly 40% of all freight ton-miles (miles one ton of freight is moved). It is important to recognize, however, that this 7% represents the total amount of fuel used in all rail sectors including: line-haul, switcher, Amtrak, commuter rail, and transit rail, as shown in Figure 1-1-8.

Figure 1-1-8 Rail Energy Use



Source: Linda Gains, "Reduction of Impacts from Locomotive Idling", Argonne National Laboratory, 2003

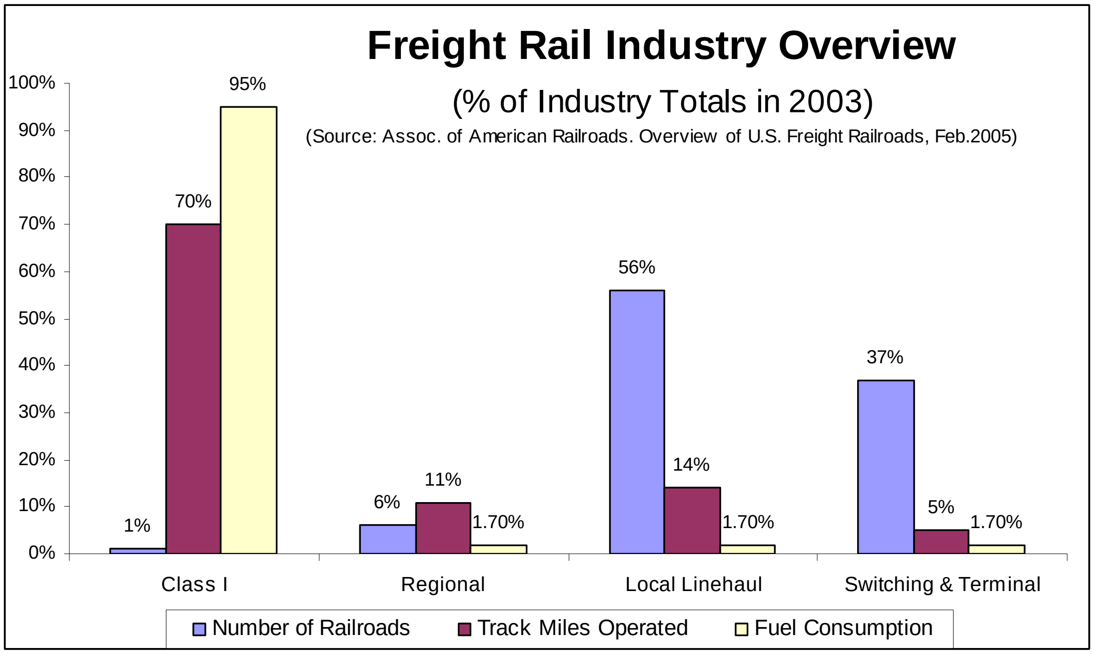
There are many other unique characteristics of the railroad industry, such as: track sharing, locomotive sharing, and fleet age. Track sharing is when a locomotive owned by one company travels over track that belongs to another company. This is not an inherent right and must be negotiated between the railroads. Locomotive sharing occurs when locomotives owned by different companies form one consist that hauls a train. This enables a company's locomotives to be fully utilized. Unlike most other methods of shipping, railroads are responsible for maintaining their own infrastructure such as tracks, and bridges, which is a very expansive network. The Class I railroads spent more than $320 billion or approximately 44% of their operating revenue between 1980-2003 to maintain and improve their infrastructure and equipment.[61] As locomotives grow larger and heavier, and as cars are designed to hold more weight, track is required that can handle this increased load. To date, of the 549 short line and regional railroads in existence, 333 have track that cannot handle these increased loads.[62]

1.2.4.1 Railroad Classification System (Class I, II and III)

In the United States, freight railroads are subdivided into three classes based on annual revenue by the federal government's Surface Transportation Board (STB) (STB regulations for the classification of railroads are contained in 49 CFR Chapter X). The STB regulations divide the railroads into three classes based on their annual carrier operating revenue.[63] As of 2005, Class I railroads had annual carrier operating revenues of at least $319 million, Class II railroads had annual carrier operating revenues between $40-$319 million, and Class III railroads had operating revenues of $40 million or less. The AAR further subdivides Class II and III railroads into regional and local railroads based on the miles of track over which they operate, in addition to their revenue. A regional railroad is a line-haul railroad that operates on at least 350 miles of track and/or earns revenue between $40 million and the Class I revenue threshold. A local railroad is a line-haul railroad which operates over less than 350 miles of track and has revenues less than $40 million. Class III also includes switching and terminal railroads. These types of railroads usually belong to the American Short Line and

Regional Railroad Association (ASLRRA). Figure 1-9 shows the differences in fuel consumption, number of railroads and the amount of track miles traveled for these different categories of railroads.

Figure 1-1-9 Freight Rail Industry Overview



1.2.4.2 Class I Characteristics

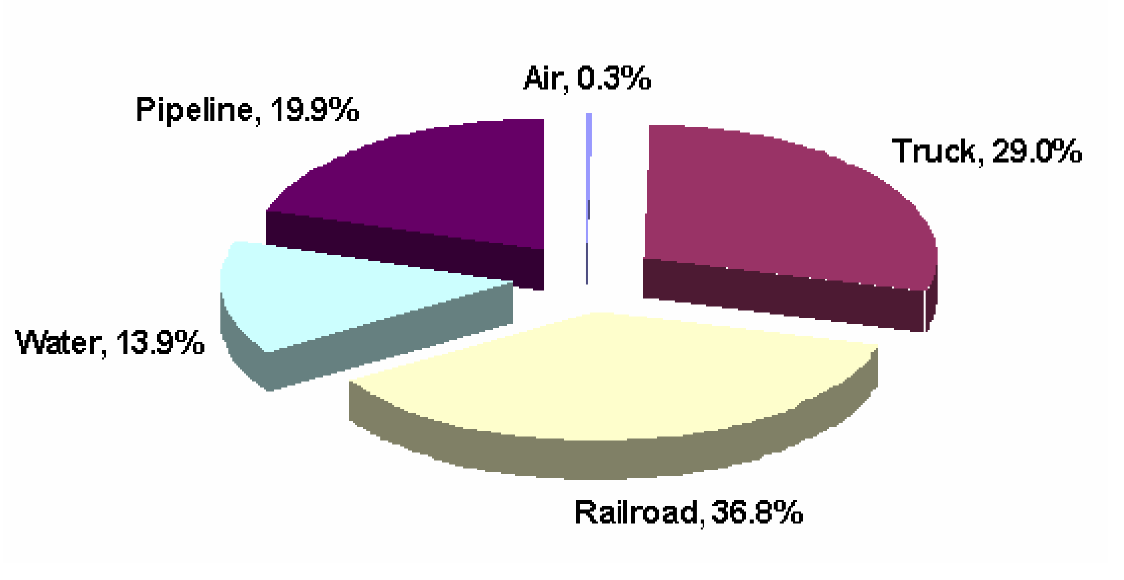
Current railroad networks (rail lines) are geographically widespread across the United States, serving every major city in the country. Approximately one-sixth of the freight hauled in the United States is hauled by train.[64] There are few industries or citizens in the country who are not ultimate consumers of services provided by American railroad companies. According to statistics compiled by AAR, Class I rail revenue accounted for 0.36 percent of the Gross National Product in 2004. Combined with the value of the freight they haul (which is nearly 40% of all freight as measured in ton-miles), it is obvious that efficient train transportation is a vital factor in the strength of the U.S. economy.

In order for Class I railroads to operate nationally, they need unhindered rail access across all state boundaries. If different states regulated locomotives differently, a railroad could conceivably be forced to change locomotives at state boundaries, and/or have state-specific locomotive fleets. Currently, facilities for such changes do not exist, and even if switching areas were available at state boundaries, it would be a costly and time consuming disruption of interstate commerce. A disruption in the efficient interstate movement of trains throughout the U.S. could have an impact on the health and well-being of not only the rail industry, but the entire U.S. economy as well.

Class I railroads are nationwide, long-distance, line-haul railroads which carry the bulk of the railroad commerce. There are currently 7 Class I freight railroads operating in the country, two of which are Canadian owned.[65] Class I railroads operated approximately 22,400 locomotives in the U.S., over 97,662 miles[G] of track, accounted for approximately 90 percent of the ton-miles of freight hauled by rail annually, and consumed 4.1 billion gallons of diesel fuel in 2004.[66,64] Of these, the two largest Class I railroads, Burlington Northern and Santa Fe (BNSF), and UP, accounted for the vast majority (63%) of the Class I locomotives in service in the U.S as of the end of 2004.[67] According to the 2004 AAR "Analysis of Class I Railroads," Class I railroads paid on average over $1.06 for a gallon of fuel in 2004 for a total expenditure of $4.2 billion which was 11% of their operating revenue. U.S. Class I railroads employ approximately 177,000 people, the vast majority of who are unionized, and as of 2004 received an average compensation of $65,000.

The Bureau of Transportation Statistics 2006 report shows that in terms of ton-miles of freight, railroads haul 36.8% of total ton-miles, followed by trucking (29%), pipline (19.9%), river/canal/barge (13.9%), and air (0.3%), also shown in Figure 1-1-10 . Rail is a primary means of transport for many bulk commodities, according to AAR, 65% of all coal produced in the U.S., 33% of all grain harvested in the U.S. and 75% of all new automobiles manufactured in the U.S. were transported by rail. As a primary mode of transportion for these items, the railroad industry normally sets the industry standard price ($/ton-mile). Rail transport is typically more fuel efficient and less expensive than other land-based sources of transport. In terms of BTUs of energy expended per ton-mile of freight hauled, Department of Energy statistics indicate that rail transport can be as much as three to four times more efficient than truck transport. The AAR has asserted that one double-stack train can carry the equivalent of 280 truckloads of freight.[68.69]

Figure 1-1-10 U.S. Freight Transportation Share by Mode



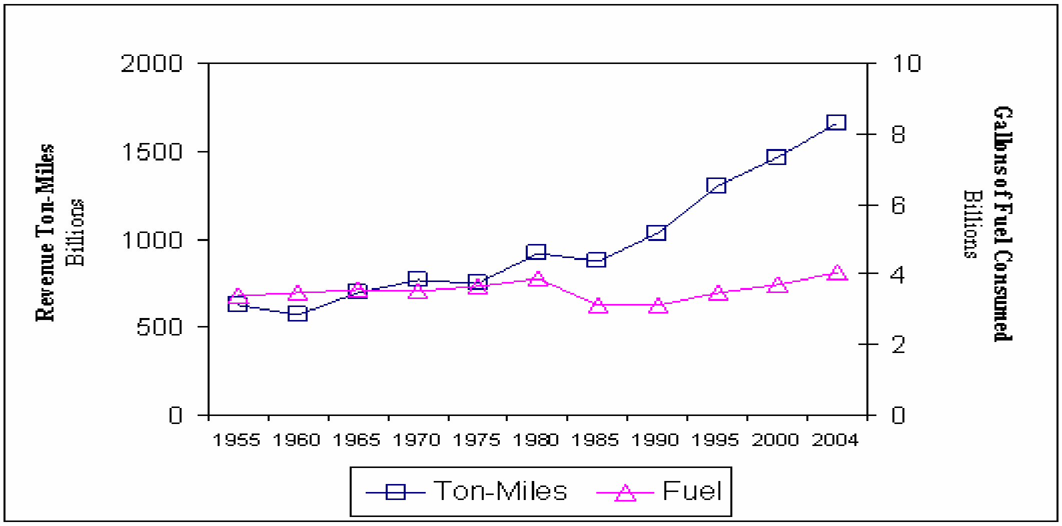
[G] This is the road length of track or the aggregate length of track excluding sidings and parallel tracks, actual track miles are 167,312.

Figure 1-12 and Table 1-30 show the long term growth trends in the amount of freight carried by Class I railroads and the amount of fuel consumed in carrying that freight.[66] Note that the ton miles of freight carried have almost tripled, while total fuel consumption has risen only 10-20%, showing an approximate 250% improvement in freight hauling efficiency since 1960. Efficiency increases have occurred for a number of reasons including: locomotive manufacturers have made continual progress in improving the fuel efficiency of their engines and the electrical efficiency of their alternators and motors, and railroads have made significant improvements to their operational efficiency. Fuel efficiency of the railroad industry overall has improved 16% over the last decade.[43] It is reasonable to project that the growth in the amount of freight hauled will continue in the future. It is less certain, however, whether fuel consumption will increase significantly in the near future.

Table 1-30 Annual Fuel Consumption and Revenue Freight For Class I Railroads

Annual Fuel Consumption and Revenue Freight For Class I Railroads			
Year	Revenue Freight (Million Ton-Miles)	Fuel Consumption (Million Gallons)	Ton-Miles of Freight moved per gallon of fuel
1960	572,000	3,500	160
1970	765,000	3,500	220
1980	919,000	3,900	240
1990	1,030,000	3,100	330
1995	1,300,000	3,400	380
2000	1,460,000	3,700	390
2001	1,500,000	3,700	410
2002	1,510,000	3,700	410
2003	1,550,000	3,800	410
2004	1,660,000	4,100	410

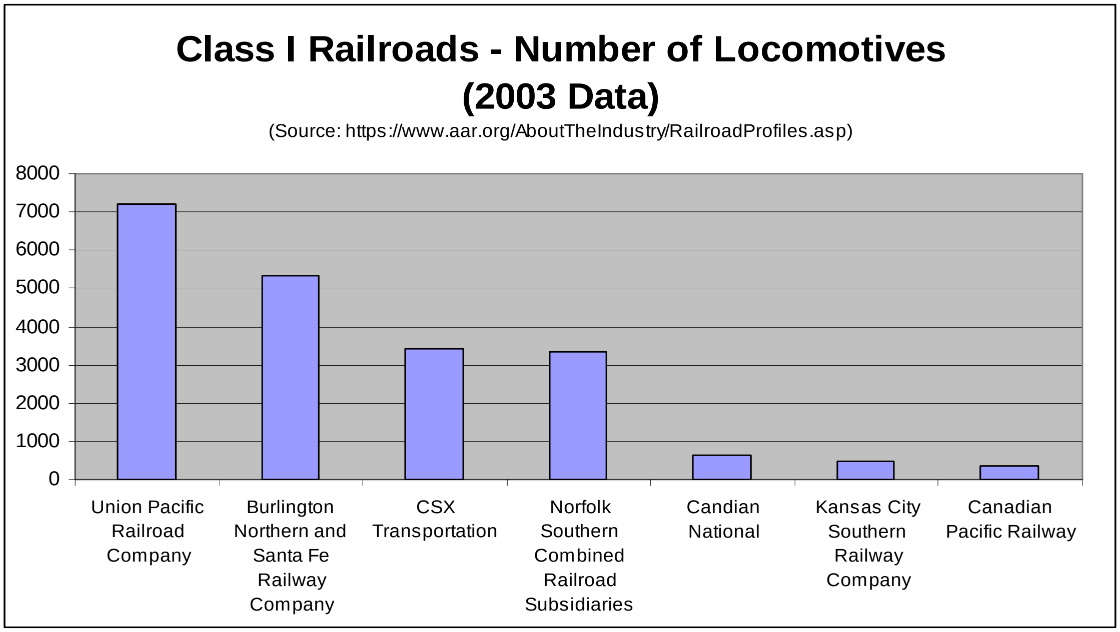
Figure 1-1-11 Fuel Consumption and Revenue Ton-Miles for Class I Railroads



1.2.4.2.1 Class I Market Share

UP operates over the most miles of track (32,616), has the largest number of employees (49,511), the greatest operating revenue ($12,180 million), but is surpassed in revenue ton-miles by BNSF (569 billion).[H] UP owns more miles of track than any other Class I (27,123), and operates the most locomotives (7,680), as shown in Table 1-31.

Table 1-31 Class I Railroads - Number of Locomotives



1.2.4.2.2 Locomotive Fleet

Historically, Class I railroads have purchased virtually all of the freshly-manufactured locomotives sold. As the Class I railroads replace their equipment with freshly-manufactured units, the older units are either sold by the Class I railroads to smaller railroads, are scrapped, or are purchased for remanufacture and ultimate resale (or leasing) by companies specializing in this work. The industry-wide replacement rate for locomotives is therefore actually lower than those indicated for the Class I railroads only. This would mean that the time required for the total locomotive fleet to turn over is longer.

Additionally, independent of cyclic changes in the industry, future locomotive replacement rates may actually decrease as higher powered locomotives pull longer trains leading to fewer locomotives in a consist. Locomotive manufacturers are now producing locomotives that have significantly more horsepower than older locomotives. Railroads have requested this change so that fewer locomotives are needed to pull a train. Placing more horsepower on a locomotive chassis increases overall train fuel efficiency. For example, it is

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[H] A revenue ton-mile is calculated by dividing freight revenue by total freight ton-miles, it is a measure of the level of revenue received by a railroad for hauling weight over distance. (AAR Railroad Facts, 2006) more fuel-efficient to use two 6000 hp locomotives, rather than three 4000 hp locomotives, to pull the same size train, because the weight of an entire locomotive can be eliminated. Thus, while three old locomotives may be scrapped, only two new locomotives need to be purchased as replacements.

On the other hand, the business outlook for the railroad industry has been improving in the last few years. As railroads have become increasingly cost-competitive with other shipping methods like trucking, they are attracting more business. This in turn increases demand for locomotive power to move the additional freight. Thus, while purchases of new locomotives may increase in the next few years, these locomotives will likely supplement, rather than replace, existing locomotives. Moreover, if freight demands continue to increase, it may become cost-effective to operate locomotives for longer periods than are estimated here.

1.2.4.2.3 Operation Profile

1.2.4.2.3.1 Fuel consumption[70]

Class I railroads consumed over 531 trillion BTUs in 2003. Locomotives traveled 1,538 million unit-miles in 2004, and averaged 69,900 miles per locomotive in 2004. The Surface Transportation Board reported that Class I railroads consumed 4.1 billion gallons of diesel fuel in 2004, for an average mile traveled per gallon of 0.13. The 4.1 billion gallons of diesel fuel used by the Class I railroads is 96% of all locomotive fuel used in the U.S. and 7.4% of all diesel fuel used for transportation in the United States. Class I railroads spent $4.2 billion which is nearly 11% of total operating expenses on fuel in 2004. Railroads are continually trying to reduce their fuel consumption through efforts such as idle reduction, and other operational improvements.[71] In a study done by the Department of Energy, the aerodynamic drag of coal cars has been shown to account for 15% of total round-trip fuel consumption on a coal train; intermodal cars that are double stacked also carry an aerodynamic fuel consumption penalty of approximately 30% due to drag. Experiments have been done to develop equipment such as fairings and foil that can reduce this drag loss on coal cars by up to 5% which would save 75 million gallons or 2% of total Class I fuel consumption in 2002.[43]

1.2.4.2.3.2 Maintenance Practices

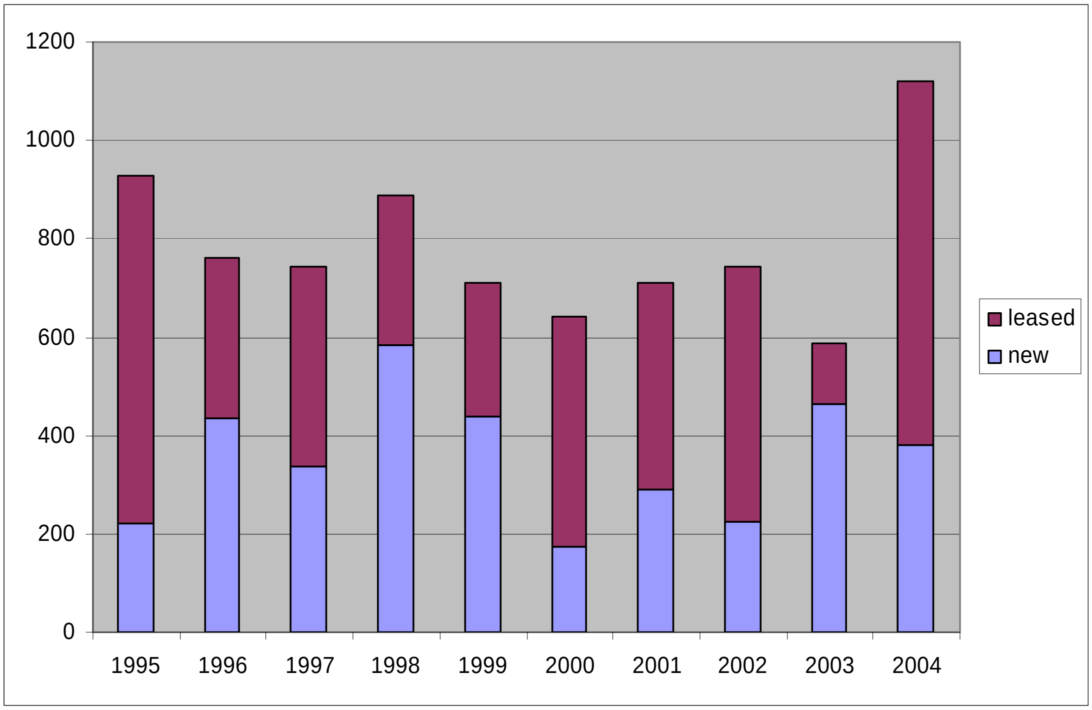
Locomotive maintenance practices also present some unique features. As is the case with other mobile sources, locomotive maintenance activities can be broken down into a number of subcategories including: routine servicing, scheduled maintenance, and breakdown maintenance. Routine servicing consists of providing the fuel, oil, water, sand (which is applied to the rails for added traction), and other expendables necessary for day-to-day operation. Scheduled maintenance can be classified as light (e.g., inspection and cleaning of fuel injectors) or heavy, which can range from repair or replacement of major engine components (such as power assemblies) to a complete an engine remanufacture. Wherever possible, scheduled maintenance (particularly the lighter maintenance) is timed to coincide with periodic federally-required safety inspections, which normally occur at 92-day intervals. Breakdown maintenance, which may be required to be done in the field, consists of the actions necessary to get a locomotive back into service. Because of the high cost of a breakdown in terms of lost revenue that could result from a stalled train or blocked track, every effort is made to minimize the need for this type of maintenance. In general, railroads strive to maintain a high degree of reliability, which results in more rigorous maintenance practices than would be expected for most other mobile sources. However, the competitive nature of the business also results in close scrutiny of costs to achieve the most cost-effective approach to achieving the necessary reliability. This has resulted in a variety of approaches to providing maintenance.

Maintenance functions were initially the purview of the individual railroads. Some major railroads with extensive facilities have turned to providing this service for other railroads. A few of the smaller railroads have also done the same, in particular for other small railroads. However, the tendency in recent years has been toward a diversification of maintenance providers. A number of independent companies have come into existence to provide many of the necessary, often specialized services involved in locomotive repair (e.g., turbocharger repair or remanufacture). The trend toward outside maintenance has also been accelerated by the policies of some of the larger railroads to divest themselves of not only maintenance activities, but ownership of locomotives as well. The logical culmination of this trend is the "power by the mile" concept, whereby a railroad can lease a locomotive with all the necessary attendant services for an agreed-upon rate.

1.2.4.2.4 Leasing

Locomotives are available for lease from OEMs, remanufacturers, and a small number of specialized leasing companies formed for that purpose. Leasing practices appear to be fairly standardized throughout the industry. Although lease contracts can be tailored on an individual basis, most leases seem to incorporate standard boilerplate language, terms and conditions. Under a typical lease, the lessee takes on the responsibility for safety certification and maintenance (parts and scheduled service) of the locomotive (including the engine), although these could be made a part of the lease package if desired. The lease duration ranges between 30 days and 5 years, with the average being 3 years Figure 1-12 shows that leasing has been a continuing trend among Class I railroads, with almost two-thirds of the locomotives placed into service in 2004 leased locomotives. Leasing among Class II and III railroads is not nearly as widespread.

Figure 1-1-12 Source: AAR Railroad Ten-year Trends 1995-2004: Number of Purchased and Leased Class I Locomotives



1.2.4.2.5 Traffic[70]

The value of goods transported by all modes of transportation between 1993 and 2003 increased by 43.6% to $8,397.2 billion, and the ton miles increased over that period by 29.6% to 3,138 billion ton-miles. The railroads share of the value market increased during that time by 25.7%, and the percent increase in their ton-miles shipped over that time was 33.8%. Ton-miles shipped using multiple modes of transportation also increased over this period such as Truck and Rail (20.8%), and Rail and Water (63.8%).

Figure 1-1-13 shows that the overall Class I traffic volumes are still increasing, and as the car miles and train miles converge, this means they are optimizing the number of cars a locomotive can carry most likely by using fewer more powerful locomotives to haul more cars.[64] The average length of a haul for Class I railroads has generally increased every year, and has almost doubled since 1960 when 461 miles was the average haul as compared to 2004 when 862 miles was the average haul length. Commuter rail has generally not increased its average haul length over this same time period. Class I train-miles, (a train-mile is the movement of a train, which can consist of multiple cars, the distance of one mile) were 535 million in 2004, Class I car-miles (a car-mile measures the distance traveled by every car in a train) were 37,071 million miles in 2004.[72]

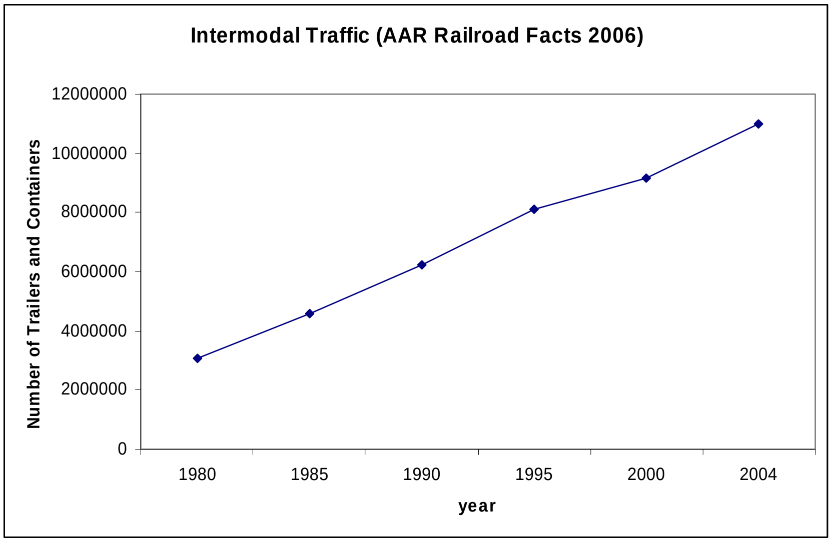
Figure 1-1-13 Class I Train Miles and Car Miles Source: AAR Ten Year Trends 1995-2004

1.2.4.3 Hauling Statistics[70]

Class I railroads hauled more than 1.6 million ton-miles of freight in 2003, which was 37% of all freight hauled in the US. Class I railroads also carried nearly 20 billion ton-miles of crude oil and petroleum products, which represented 2.2% of the total moved, while trucks carried 3.8%, pipeline 67%, and water carried 27%. As of 2002, railroads transported over 72 billion ton miles of hazardous materials, or 22% of all hazardous material which was shipped an average of 695 miles per shipment.[70] While railroads and trucks carry roughly equal hazmat ton-miles, trucks have nearly 16 times more accidental hazmat releases than do railroads.[61]

The 2006 FRA Freight Railroad Overview indicates that intermodal shipping is the fastest growing segment of rail traffic. Doublestack containers were introduced in the 1980's and since that time the number of trailer and container loadings has risen from 3.4 million to 11 million in 2004. Figure 1-1-14 shows the near doubling of this traffic in each of the past two decades. The Staggers Act of 1980 also legalized railroad-shipper contracts, and according to the STB, at least 55% of all traffic moves under contract, which allows railroads to increase efficiency by permitting better planning.

Figure 1-1-14 Class I Intermodal Traffic



1.2.4.4 Track Statistics[52]

As of 2004, Class I owned 97,662 miles of trackage. Since 1980, capital expenditures on trackage and other structures has increased 88% from $2.6 billion in 1990 to $4.9 billion in 2004 as railroad tracks have been upgraded to 130 pound per yard weighted rail to accommodate heavier loads being hauled per car. Class I railroads have increased their traffic (ton-miles) by approximately 81%, while they have decreased the miles of track they own by 41%. This has increased traffic density, and although double-stacking containers has helped to reduce traffic to some degree, this is still a concern due to the continual growth in ton-miles.[73]

1.2.4.5 Class II & III Characteristics[74,75]

In the 1970's, deregulation allowed the Class I railroads to stop operating many smaller lines that were unprofitable. This allowed many small independent railroads to take over that portion of the line and run it more efficiently and sometimes at a lower cost due to their enhanced flexibility as a small business. In 2004 there were 549 Class II and Class III railroads. In many cases, these smaller railroads are also able to receive financial assistance from local governments or associations of customers to help them upgrade their infrastructure (in many cases, the tracks are quite old and are not rated for the loads that today's cars typically carry).

In 2004, short lines originated or terminated one out of every four carloads moved by the domestic rail industry, and operated over 50,000 miles of track, which is nearly 29% of all U.S. rail mileage. They had over 19,000 employees and served over 11,700 customers and facilities. Of the track they operate, only 43% is capable of handling the heavier 286,000 ton axle weight cars. The total revenue for the Class II and III railroads in 2004 was almost $3 billion, while they spent nearly $433 million on capital expenditures, $397 million on maintenance of equipment, road and structures, and $221 million on fuel. More than half of the short line and regional railroads connect to two or more other railroads, and over 80% operate in only one state.

Statistics compiled by the ASLRRA in 2004 show that there are approximately 549 Class II and III railroads (not including commuter or insular railroads that serve a track within a factory). A more detailed breakdown of these small railroads can be found in Table 1-32. They consist primarily of regional and local line-haul and switching railroads, which operate in a much more confined environment than do the Class I railroads.[I] Class II and III railroads operated approximately 3,777 locomotives in 2004, and in survey taken in 2004 by the ASLRRA, locomotive fleet age data shows that over 92% of the locomotives owned by the Class II and III railroads are over twenty years old, slightly over 5% are 10-19 years old, and 2% are newer than 10 years old. Class II and III railroads used 552 million gallons of fuel in 2004, which is about 13% of the amount of diesel fuel used by Class I locomotives, in 2004. Employment has declined for all railroads including Class I railroads substantially since the 1990's, but nearly all railroads are predicting growth in hiring.

Table 1-32 Profile of Railroad Industry -2004[53]

Type of Railroad	Number of Railroads	Number of Employees
Class I Freight Railroad	7	157699
National Passenger Railroads	1	18,909
Regional Railroads	31	7422
Local/Line-Haul Railroads	314	5349
Switching and Terminal	204	6429
Class I Subsidiaries	102	3687
Commuter Railroads	21	25,296[76]
Shipper-Owned Railroads	68	NA
Government Owned Railroads	28	NA

Some of the smaller railroads are owned and operated by Class I railroads, many of which are operated as formal subsidiaries for financial purposes, but are run as standalone entities. In 2004, there were 31 regional railroads, 314 local line-haul railroads and 204 switching and terminal railroads, including subsidiaries (regional and local railroads may also have subsidiaries). A few of these are publicly held railroads and some are shipper-owned. Insular (in-plant) railroads are not included in this total. ASLRRA estimated that there are probably about 1,000 insular railroads in the U.S. These railroads are not common carriers, but rather are dedicated to in-plant use. They typically operate a single switch locomotive powered by an engine with less than 1000 hp. Finally, there are a handful of very small passenger railroads that are primarily operated for tours. These tourist railroads are included within the Class II and III railroads.

[I] "Regional railroad" and "local railroad" are terms used by AAR that are similar, but not identical, to "Class II" and "Class III", respectively.

1.2.4.6 Passenger Rail

1.2.4.6.1 Amtrak

Amtrak was formed in 1971 by Congress through the Rail Passenger Service Act of 1970 (P.L. 91-518, 84 Stat.1327) to relieve the railroads of the financial burden of providing passenger railway service. In return for government permission to leave the passenger rail business and avoid continued losses, many of the freight railroads donated equipment to Amtrak as well as $200 million in startup capital.[61] Amtrak is operated by the National Railroad Passenger Corporation of Washington, D.C. The U.S. Secretary of Transportation has the authority to designate Amtrak's destinations, which as of 2004 included 527 cities; other transit rail serve 2,909 destinations, some of which may be shared with Amtrak.[70] Amtrak traveled over 37 million train miles in 2004, and served on average, 777,000 people each day that depend on commuter rail services operated under contract by Amtrak, or that use Amtrak-owned infrastructure, shared operations and dispatching. On average, 69,000 people ride on up to 300 Amtrak trains each day[77]. Amtrak relies on receiving federal subsidies in order to operate, although it continually works to become independent and profitable.

Although Amtrak's rates are not regulated, it does depend on the amount of subsidies received from the Federal government; this is not unlike most other forms of passenger rail in the U.S that receive federal, state, or local subsidies. Amtrak competes with other modes of transportation, and this also affects its ability to charge higher rates. Fuel costs can dramatically affect rates and Amtrak’s need for subsidies. Between 2004 and 2005, Amtrak’s fuel costs increased 149% or by $43 million, and continue to increase substantially, despite efforts for improved fuel conservation methods that reduced its fuel consumption by nearly 10% during that same period.[78]

Amtrak is the sole large-scale provider of inter-city passenger transport. Its fleet includes 436 locomotives, 360 of which are diesel locomotives that used a reported 69.9 million of gallons of fuel in 2005. It also owns 76 electric locomotives. Recently, the FRA provided Amtrak with funding to purchase Acela locomotives, which are 4,000 horsepower gas turbine locomotives. These locomotives consume about the same amount of fuel as a diesel locomotive but produce about 1/10th of the $NO_{x.}$

Amtrak offers service to 46 states on 21,000 miles of routes, only 745 miles of which are actually owned by Amtrak and are located primarily in Michigan, and between Boston and Washington DC.**[Error! Bookmark not defined.]** Based on gross revenue, Amtrak is classified as a Class I railroad by the STB. However, unlike the Class I freight railroads Amtrak's current operating expenses exceed its gross revenue.

The average age of a passenger train from Amtrak is quite young; in fact, since 1980 it has remained under 14.5 years old. Amtrak was on-time 74% of the time in 2003, and 65% of that delay was caused by a host railroad. A host railroad is a freight or commuter railroad over which track Amtrak operates on for all or part of a trip, and delays can include signal delays, train interference, routing delays or power outages. Amtrak must pay these host railroads for use of this track and any other resources. In 2005, those payments were based on more than

25 million train miles (one train-mile is a mile of track usage by each train) which totaled more than $92 million.

The average Amtrak city-to-city fare was $55.15, with an average trip of 231 miles, and average revenue per passenger-mile is $0.251 for Amtrak.[70] In 2006, Amtrak was able to obtain an additional subsidy in order to remain operational in 2006, in the amount of $1.1 billion.[79] The future of Amtrak is uncertain, and may change if the Passenger Rail Reform Act is passed. This bill is currently in the House Subcommittee on Railroads, and would split Amtrak up into three different entities, two privately owned and one government owned corporation.

1.2.4.6.2 Commuter[80]

There are also 21 independent commuter rail systems operating in sixteen U.S. cities, consuming 72 million gallons of diesel fuel annually, operating over 6,785 miles of track. They employed approximately 25,000 employees in 2004. Many of these commuter railroads rely on Federal subsidies to improve their infrastructure, in some cases they also rely on state and local government subsidies to support their operations.

The average commuter fare in 2004 was $3.90, for an average trip length of 23.5 miles, with average revenue per passenger-mile of $0.154. An estimated 414 million people use commuter rail each year to result in over 9.7 billion passenger-miles. Like Amtrak, commuter rail operations also maintain a young fleet that has remained younger than 17 years old since 1985.

1.2.5 Existing Regulations

1.2.5.1 Safety

Achieving and maintaining the safe operation of commercial (common carrier) railroads in the U.S. falls under the jurisdiction of the Federal Railroad Administration (FRA), which is a part of the Department of Transportation. The FRA was created in 1966 to perform a number of disparate functions, including rehabilitating the Northeast Corridor rail passenger service, supporting research and development for rail transportation, and promoting and enforcing safety regulations throughout the railway system.

FRA safety regulations apply to railroads on a nationwide basis. In 49 CFR section 229 the regulations require safety inspections of each locomotive used in commercial operations: daily, every 92 days (i.e. the periodic inspection), annually, and biennial. Each subsequent inspection increases in complexity. The inspections are usually performed by the railroad which owns or leases the locomotive. FRA personnel review the findings of these inspections and any corrective actions identified and taken. Since each locomotive is required to be out of revenue service for inspection every 92 days, railroads commonly schedule their performance of preventive maintenance during these times. It appears likely that each locomotive is out of service for 12 to 24 hours during each FRA safety inspection and preventative maintenance period.[J] To limit the time that locomotives are out of service for these safety inspections and preventive maintenance, railroads maintain suitable facilities distributed across the nation. Thus, it appears that the railroads have had a long history of compliance with federal regulations, and have developed strategies to live within the regulations and to minimize any adverse business impacts that may have resulted.

1.2.5.2 Federal[81]

In 1980 Congress passed the Staggers Act (USCA 49 § 10101) which laid out the government's statutory objectives for the railroad industry which are to balance the efficiency and viability of the industry with the need for: reasonable rates, fair wages, public health and safety, and energy conservation. The railroads are governed by two separate federal agencies directly, both under the Department of Transportation, a cabinet-level department. The Federal Railroad Administration (FRA) regulates safety issues. The FRA sets safety standards for rail equipment and operation, and also investigates accidents on rail lines and at rail crossings. The FRA also plays a role in labor disputes to a small degree, by monitoring the progress of negotiations, projecting the economic impact of a strike and assisting the Secretary in briefing Congress if necessary. The STB is an adjudicatory body that was formed in 1966 to settle disputes and regulate the various modes of surface transportation within the U.S. Organizationally, the STB is part of the Department of Transportation (DOT), the STB deals with railway rate and service issues, railway restructuring and various other issues, including classification of railroads. The Surface Transportation Board (STB) regulates economic issues such as rates. The STB can also mandate access to locations in order to maintain competition in areas where mergers reduced the number of available carriers

1.2.5.3 Rates

Rail transportation accounts for 8.7% of all for-hire transportation services that are a measured in the GDP. The average freight revenue per ton-mile for Class I rail in 2004 was \$0.0235, with average operating revenue of \$40.5 billion. Freight rates, when adjusted for inflation have declined by an average of 1.1% a year between 1990 and 2004, due in large part to the passage of the Staggers Act, as shown in Figure 1-1-15.[82]

If a shipper believes a rate is unreasonable (only if that shipper does not have access to another railroad, and waterway or highway modes are not feasible), they can complain to the STB, which has a stand-alone rate standard. This means that they determine what a hypothetical new carrier to serve that shipper would need to charge to cover all of its costs including capital and construction. If this hypothetical rate is less than what the shipper is being charged, that charged rate is considered to be “unreasonably high” and the railroad can be ordered to reduce the challenged rate and pay reparations to the shipper. Complaints such as these are typically made by bulk shippers, such as coal or chemicals, who cannot use other modes of transportation such as highway or can't access other railroads.

[J] Values are an approximate estimate by FRA personnel.

Figure 1-1-15 Railroad Rate Trends Before and After Staggers Act of 1980[82]

Sources: U.S. Dept. of Labor, Bureau of Labor Statistics, Producer Price Index of Line-Haul Operating Railroads; U.S. Dept. of Commerce, Bureau of Economic Analysis, Implicit Price Deflator for Gross Domestic Product

1.2.6 Foreign Railroads in US

Locomotives that operate extensively within the U.S. are subject to the existing provisions of 40 CFR Part 92.

1.2.6.1 Mexico

In 2004, the Bureau of Transportation Statistics (BTS) says there were a total of 675,305 US/Mexico railcar crossings, that's an average of almost 1900 crossings a day, or one every minute. The Mexican Railroads and their 16,415 miles of track have been privately owned since a Constitutional amendment was passed in 1995 (see FRA "Border Issues"). They primarily haul NAFTA generated goods, such as cars, automobile parts, and other manufactured products. Mexico has two railroads, Ferrocarril Mexicano, which has a joint venture with UP, and Transportacion Ferroviaria Mexicana (TFM) of which Kansas City Southern has controlling interest.[83]

1.2.6.2 Canada

In 2004, the BTS says there were 1,950,909 border crossings into Canada by railcars. Canada is also home to two Class I railroads that operate extensively in the U.S., Grand Trunk Corporation which includes almost all of Canadian National’s (CN) U.S. operations, and Canadian Pacific Railway which operates its Soo Line primarily in the U.S.

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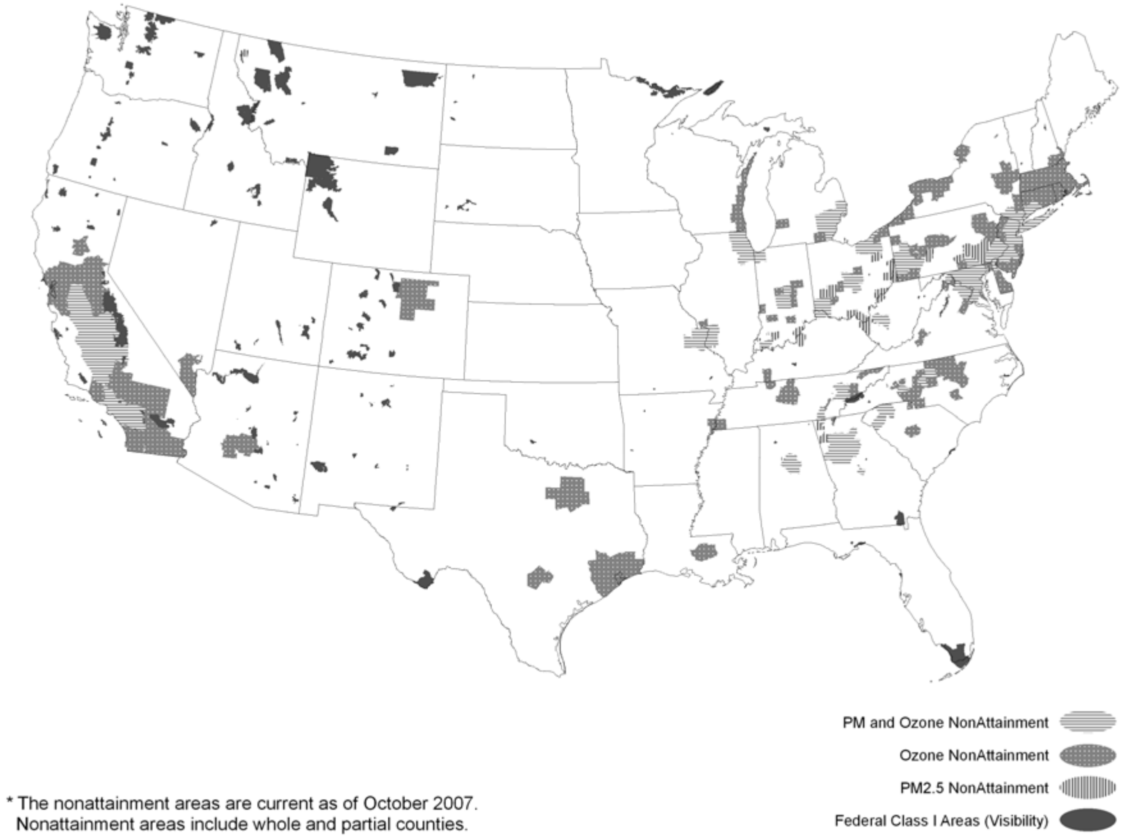
CHAPTER 2: Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources

The locomotive and marine diesel engines subject to this rulemaking generate significant emissions of particulate matter (PM) and nitrogen oxides (NO_x) that contribute to nonattainment of the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ and ozone. These engines also emit hazardous air pollutants, or air toxics, that are associated with serious adverse health effects. Emissions from locomotive and marine diesel engines also cause harm to public welfare by contributing to visibility impairment and other harmful environmental impacts across the U.S. Therefore, EPA is adopting new standards to control these emissions.

The health and environmental effects associated with these emissions are a classic example of a negative externality (an activity that imposes uncompensated costs on others). With a negative externality, an activity's social cost (the cost borne to society imposed as a result of the activity taking place) exceeds its private cost (the cost to those directly engaged in the activity). In this case, as described in this chapter, emissions from locomotives and marine diesel engines and vessels impose public health and environmental costs on society. However, these added costs to society are not reflected in the costs of those using these engines and equipment. The current market and regulatory scheme do not correct this externality because firms in the market are rewarded for minimizing their production costs, including the costs of pollution control, and do not benefit from reductions in emissions. In addition, firms that may take steps to use equipment that reduces air pollution may find themselves at a competitive disadvantage compared to firms that do not. The emission standards EPA is finalizing help address this market failure and reduce the negative externality from these emissions by providing a regulatory incentive for engine and locomotive manufacturers to produce engines and locomotives that emit fewer harmful pollutants and for railroads and vessel builders and owners to use those cleaner engines.

Today millions of Americans continue to live in areas with air quality that may endanger public health and welfare (i.e., levels not requisite to protect the public health with an adequate margin of safety). As of October 10, 2007 there are 88 million people living in 39 areas (which include all or part of 208 counties) that either do not meet the $PM_{2.5}$ NAAQS or contribute to violations in other counties. These numbers do not include the people living in areas where there is a significant future risk of failing to maintain or achieve the current or future $PM_{2.5}$ NAAQS. Currently, ozone concentrations exceeding the level of the 8-hour ozone NAAQS occur over wide geographic areas, including most of the nation's major population centers. As of October 10, 2007 there are approximately 144 million people living in 81 areas (which include all or part of 366 counties) designated as not in attainment with the 8-hour ozone NAAQS. These numbers do not include the people living in areas where there is a future risk of failing to attain or maintain the 8-hour ozone NAAQS. Figure 2-1 presents the counties currently designated as nonattainment for the $PM_{2.5}$ or 8-hour ozone NAAQS as well as mandatory class I federal areas for visibility. This figure illustrates the widespread nature of these air quality problems.



* The nonattainment areas are current as of October 2007.
Nonattainment areas include whole and partial counties.

Figure 2-1 Air Quality Problems are Widespread

Emissions from locomotive and marine diesel engines account for substantial portions of today's ambient $PM_{2.5}$ and NO_x levels (20 percent of total mobile source NO_x emissions and 25 percent of total mobile source diesel $PM_{2.5}$ emissions). Unless EPA takes action to reduce their pollution levels, the relative contribution of these engines to air quality problems will increase over time. By 2030 locomotive and marine diesel engines could constitute more than 65 percent of mobile source diesel $PM_{2.5}$ emissions and 35 percent of mobile source NO_x emissions.

Under the emission standards finalized in this action, in 2030 annual NO_x emissions will be reduced by about 800,000 tons and annual $PM_{2.5}$ emissions by about 27,000 tons**.** We estimate that the reduction in $PM_{2.5}$ will produce nationwide air quality improvements. According to air quality modeling performed in conjunction with this rule, all current $PM_{2.5}$ nonattainment areas will experience a resulting decrease in their 2030 annual $PM_{2.5}$ design values (DV). In addition, all 133 modeled mandatory class I federal areas will experience improved visibility. For the current 39 $PM_{2.5}$ nonattainment areas (annual DVs greater than $15 \mu g/m^3$) the average population-weighted modeled future-year annual $PM_{2.5}$ DVs will on *average* decrease by $0.16 \mu g/m^3$ in 2030. The *maximum* decrease for future-year annual $PM_{2.5}$ DVs over the U.S. will be $0.81 \mu g/m^3$ in 2030.

According to air quality modeling performed for this rulemaking, the locomotive and marine diesel engine emissions controls are expected to provide nationwide improvements in ozone levels. On a population-weighted basis, the average modeled future-year 8-hour ozone design values will decrease by 0.85 ppb in 2030. Within projected ozone nonattainment areas, the average decrease will be 0.62 ppb in 2030. The *maximum* decrease for future-year 8-hour ozone DVs over the U.S. will be 4.6 ppb in 2030.

While EPA has already adopted many emission control programs that are expected to reduce both ambient ozone and PM levels over the next two decades, including the Clean Air Interstate Rule (CAIR) (70 FR 25162, May 12, 2005) and the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), the additional $PM_{2.5}$ and NO_x emissions reductions from this rule will be important to a number of states efforts to attain and maintain the ozone and $PM_{2.5}$ NAAQS near term and in the decades to come.

2.1 Particulate Matter

In this section we review the health and welfare effects of $PM_{2.5}$. We also describe air quality monitoring and modeling data that indicate many areas across the country continue to be exposed to high levels of ambient $PM_{2.5}$. Emissions of hydrocarbons (HCs) and NO_x from the engines subject to this rule contribute to these PM concentrations. Information on air quality was gathered from a variety of sources, including monitored PM concentrations, air quality modeling done for this rulemaking as well as state and local air quality information.

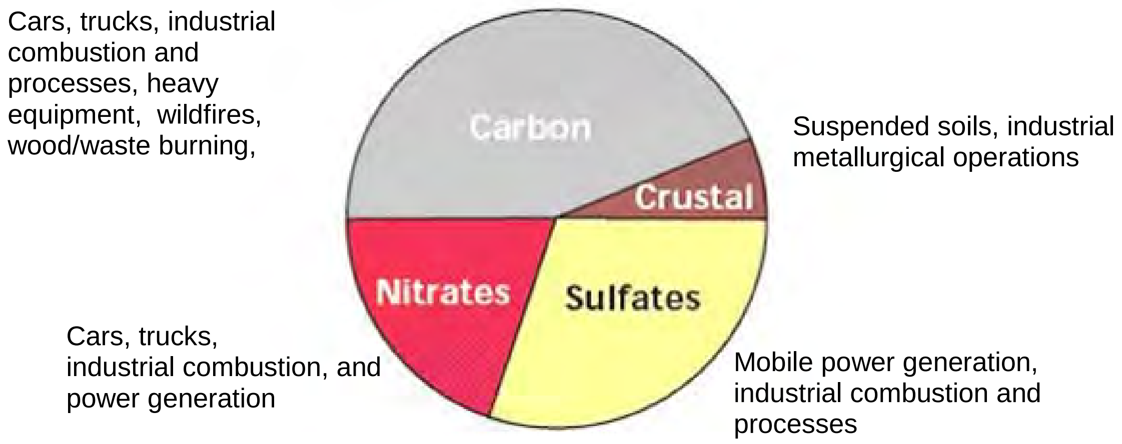
2.1.1 Science of PM Formation

Particulate matter (PM) represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM_{10} refers to particles generally less than or equal to 10 micrometers (µm) in diameter. $PM_{2.5}$ refers to fine particles, generally less than or equal to 2.5 µm in diameter. Inhalable (or “thoracic”) coarse particles refer to those particles generally greater than 2.5 µm but less than or equal to 10 µm in diameter. Ultrafine PM refers to particles less than 100 nanometers (0.1 µm) in diameter. Larger particles tend to be removed by the respiratory clearance mechanisms, whereas smaller particles are deposited deeper in the lungs.

Particles span many sizes and shapes and 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. In addition, there are also physical, non-chemical reaction mechanisms that contribute to secondary particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from a particle’s ability to shift between solid/liquid and gaseous phases, which is influenced by concentration, meteorology, and temperature.

Particles are made up of different chemical components. The major chemical components include carbonaceous materials (carbon soot and organic compounds), inorganic compounds (including, sulfate and nitrate compounds that usually include ammonium) and a mix of substances often apportioned to crustal materials such as soil and ash (Figure 2-2). The different components that make up particle pollution come from specific sources and are often formed in the atmosphere. As mentioned above, particulate matter includes both "primary" PM, which is directly emitted into the air, and "secondary" PM. Primary PM consists of carbonaceous materials emitted from cars, trucks, heavy equipment, forest fires, some industrial processes and burning waste. It also includes both combustion and process-related fine metals and larger crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations. Secondary PM forms in the atmosphere from gases. Some of these reactions require sunlight and/or water vapor. Secondary PM includes: sulfates formed from sulfur dioxide emissions from power plants and industrial facilities; nitrates formed from nitrogen oxide emissions from cars, trucks, industrial facilities, and power plants; and organic carbon formed from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

Figure 2-2 Common Sources Contributing to Fine Particle Levels



Source: The Particulate Matter Report, USEPA 454-R-04-002, Fall 2004. Carbon reflects both organic carbon and elemental carbon. Organic carbon accounts for emissions from a wide range of sources including locomotive and marine diesel engines as well as automobiles, biogenic, gas-powered off-road vehicles, and wildfires. Elemental carbon is formed from both diesel and gasoline powered sources.

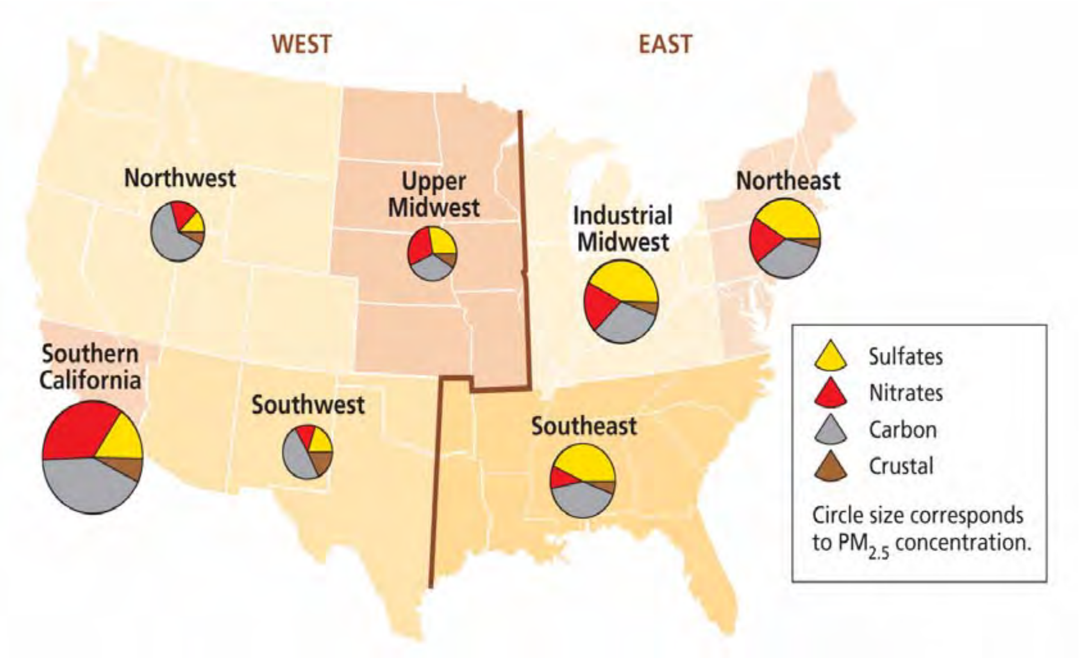
2.1.1.1 Composition of $PM_{2.5}$ in Selected Urban Areas

Note that fine particles can be transported long distances by wind and weather and can be found in the air thousands of miles from where they formed. The relative contribution of various chemical components to $PM_{2.5}$ varies by region of the country, as illustrated in Figure

2-3. Data on $PM_{2.5}$ composition are available from the EPA Speciation Trends Network and the IMPROVE Network, covering both urban and rural locations across the U.S.

These data show that carbonaceous $PM_{2.5}$ makes up the major component for $PM_{2.5}$ in both urban and rural areas in the Western U.S. Carbonaceous $PM_{2.5}$ includes both elemental and organic carbon. Nitrates formed from NO_x also play a major role in the western U.S., especially in the California area where nitrates are responsible for about a quarter of the ambient $PM_{2.5}$ concentrations. Sulfate plays a lesser role in these regions by mass, but it remains important to visibility impairment. Data for the Eastern and Central U.S. show that both sulfates and carbonaceous $PM_{2.5}$ are major contributors to ambient $PM_{2.5}$ in urban and rural areas. In some eastern areas, carbonaceous $PM_{2.5}$ is responsible for up to half of ambient $PM_{2.5}$ concentrations. Sulfate is also a major contributor to ambient $PM_{2.5}$ in the Eastern U.S. and in some areas sulfate makes greater contribution than carbonaceous $PM_{2.5}$.

Figure 2-3 Average $PM_{2.5}$ Composition in Urban areas by Region, 2003



2.1.1.2 Source Apportionment Studies of $PM_{2.5}$

Determining sources of fine particulate matter is complicated in part because the concentrations of various components are influenced by both primary emissions and secondary atmospheric reactions. As described earlier, when attempting to characterize the sources affecting $PM_{2.5}$ concentrations, it is important to note that both regional and local sources impact ambient levels. In the eastern US, regional fine particles are often dominated by secondary particles including sulfates, organics (primary and secondary) and nitrates. These are particles which form through atmospheric reactions of emitted sulfur dioxide, oxides of nitrogen and ammonia, and are transported over long distances. Conversely, local contributions to fine particles are likely dominated by directly emitted particulate matter from sources such as gasoline and diesel mobile sources, including locomotive and marine diesel engines[A], industrial facilities (e.g., iron and steel manufacturing, coke ovens, or pulp mills), and residential wood and waste burning.

Development of effective and efficient emission control strategies to lower $PM_{2.5}$ ambient concentrations can be aided by determining the relationship between the various types of emissions sources and elevated levels of $PM_{2.5}$ at ambient monitoring sites. Source apportionment analyses such as receptor modeling are useful in this regard by estimating potential fine particulate regional and local source impacts on a receptor's ambient concentrations. The goal is to apportion the mass concentrations into components attributable to the most significant source categories. Receptor modeling techniques are observation-based models which utilize measured ambient concentrations of $PM_{2.5}$ species to quantify the contribution that regional and local sources have at a given receptor which, in this case, is an ambient monitoring location.[B] These techniques may be useful in helping to characterize fine particulate source contributions to ambient $PM_{2.5}$ levels; however, there are inherent limitations including but not limited to the adequacy (e.g., vintage and representativeness) of existing source profiles in identifying source groups or specific sources, availability, completeness and representativeness of ambient datasets to fully inform these techniques, and current scientific understanding and measured data to relate tracer elements to specific sources, production processes, or activities. Additionally, commingling of similar species from different sources in one "factor" can make it difficult to relate the "factor" to a particular source. Furthermore, long-range transport of particles may alter the chemical composition of specific source emissions, making it more difficult to differentiate sources.[1]

A literature compilation summarizing source apportionment studies was conducted as part of a research and preparation program for the CAIR, which was focused on $PM_{2.5}$ transport.[2] Literature selected in this compilation represented key source apportionment research, focusing primarily on recent individual source apportionment studies in the eastern U.S. The sources identified are grouped into seven categories: secondary sulfates, mobile, secondary nitrates, biomass burning, industrial, crustal and salt, and other/not identified. Some of these studies are based on older ambient databases and more recent ambient data have shown improvement and reduced levels of ambient $PM_{2.5}$ concentrations across the U.S., especially in the East, which affects the quantitative conclusions one may draw from these studies. Notably, the relative fraction of sulfates has continued to decrease with the implementation of the acid rain program and removal of sulfur from motor vehicle fuels. More routine monitoring for specific tracer compounds that are unique to individual sources or more time-resolved measurements can lead to better separation of blended "factors" such

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[A] Note that while we believe that the mobile source sector is a substantial contributor to total $PM_{2.5}$ mass; our current mobile source inventory is likely underestimated and information on control measures is incomplete.

[B] Currently, three established receptor models are widely used for source apportionment studies: the Chemical Mass Balance (CMB) model, UNMIX and Positive Matrix Factorization (PMF). The CMB receptor model relies on measured source profiles as well as ambient species measurements to produce a source contribution estimate at the receptor location, while the PMF and UNMIX techniques decompose the ambient measurement data matrix into source profiles and contributions by utilizing the underlying relationship (i.e., correlations) between the individually measured species.

as secondary commingled sulfates and organic aerosols, the latter which are more attributed to emissions from vehicles and vegetation. Western studies have focused on sources impacting both high population areas such as Seattle, Denver, the San Joaquin Valley, Los Angeles, San Francisco as well as national parks.[3,4,5,6,7,8,9,10,11,12]

As mentioned previously, the sources of $PM_{2.5}$ can be categorized as either direct emissions or contributing to secondary formation. The results of the studies showed that approximately 20 to 60% of the fine particle mass comes from secondarily formed inorganic nitrates and sulfates depending on the area of the country, with nitrates predominantly affecting the West, sulfates in the East and a mixture of the two in the Industrial Midwest.

The precursors of secondary inorganic particles are generally gaseous pollutants such as sulfur dioxide or oxides of nitrogen, which react with ammonia in the atmosphere to form ammonium salts. Dominant sources of SO_2 include power generation facilities, which are also sources of NO_x, of which mobile sources including locomotive and marine diesel engines are also major sources. The result of recent and future reductions in precursor emissions from electrical generation utilities and mobile sources, however, will lead to a reduction in precursor contributions which would aid in limiting the production of secondary sulfates and nitrates. Also, reductions in gasoline and diesel fuel sulfur will reduce mobile source SO_2 emissions.

In addition, secondary organic carbon aerosols (SOA) also make a large contribution to the overall total $PM_{2.5}$ concentration in both the Eastern and Western United States. For many of the receptor modeling studies, the majority of organic carbon is attributed to mobile source emissions (including both gasoline and diesel). While vehicles emit organic carbon particulate, the various organic gases also emitted by these sources react in the atmosphere to form SOA which shows a correlation to the other secondarily formed aerosols due to common atmospheric reactions. As Section 2.1.1.4 of this RIA discusses, based on current data, locomotives and larger marine diesel engines which have similar engine characterizations emit a relatively large amount of organic PM. Other common sources of the organic gases which form SOA include vegetation, vehicles, and industrial volatile organic compound (VOC) and semi-volatile organic compound (SVOC) emissions. However, due to some limits on data and a lack of specific molecular markers, current receptor modeling techniques have some difficulty attributing mass to SOA. Therefore, currently available source apportionment studies may be attributing an unknown amount of SOA in ambient PM to direct emissions of mobile sources; concurrently, some secondary organic aerosol found in ambient samples may, as mentioned above, be coming from mobile sources and not be fully reflected in these assessments. Research is underway to improve estimates of the contribution of SOA to total fine particulate mass.

While gaseous precursors of $PM_{2.5}$ are important contributors, urban primary sources still influence peak local concentrations that exceed the NAAQS, even if their overall contributions are smaller. The mixture of industrial source contributions to mass vary across the nation and include emissions from heavy manufacturing such as metal processing (e.g., steel production, coke ovens, foundries), petroleum refining, and cement manufacturing, among others. Mobile source contributions from facilities like ports, rail yards, truck stops, and heavily-trafficked roads can also have strong, localized air quality impacts. Other sources of primary $PM_{2.5}$ are more seasonal in nature. One such source is biomass burning, which usually contributes more during the winter months when households burn wood for heat, but also contributes episodically during summer as a result of forest fires. Other seasonal sources of primary PM include soil, sea salt and road salting operations that occur in winter months. The extent of these primary source contributions to local $PM_{2.5}$ problems varies across the U.S. and can even vary within an urban area.

2.1.1.3 Regional and Local Source Contributions to Formation of $PM_{2.5}$

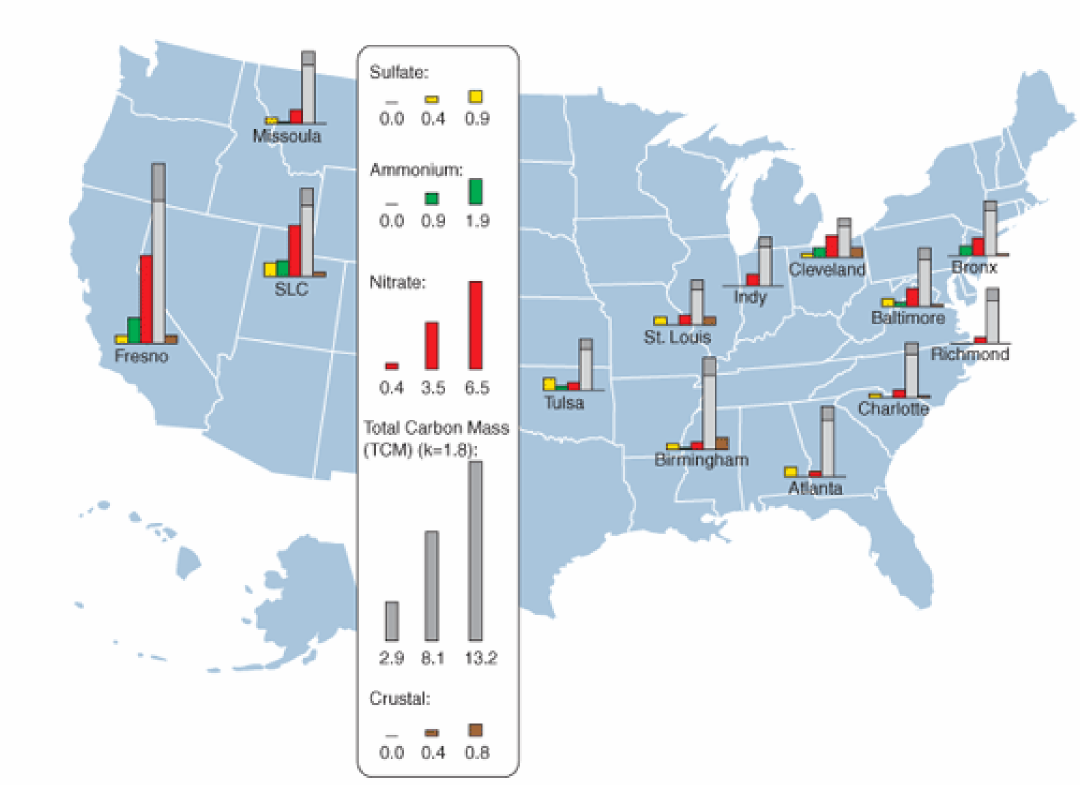
Both local and regional sources contribute to particle pollution. Figure 2-4 shows how much of the $PM_{2.5}$ mass can be attributed to local versus regional sources for 13 selected urban areas. The “urban excess” is estimated by subtracting the measured $PM_{2.5}$ species at a regional monitor location [C] (assumed to be representative of regional background) from those measured at an urban location.

As shown in Figure 2-4, total carbon mass is the main contributor to urban excess concentrations in all regions, with Fresno, CA and Birmingham, AL having the largest observed measures. Larger urban excess of nitrates is seen in the western U.S. and northern tier cities with Fresno, CA and Salt Lake City, UT having values significantly higher than all other areas across the nation. These results indicate that local sources of these pollutants are indeed contributing to the $PM_{2.5}$ air quality problem in these areas.

Urban and nearby rural $PM_{2.5}$ concentrations suggest substantial regional contributions to fine particles in the East.

[C] Regional concentrations are derived from the rural IMPROVE monitoring network Interagency Monitoring of Protected Visual Environments. See http://vista.cira.colostate.edu/improve.

Figure 2-4. Estimated "Urban Excess" of 13 Urban Areas by $PM_{2.5}$ Species Component



Note: Total Carbon Mass (TCM) is the sum of Organic Carbon (OC) and Elemental Carbon (EC). In this graph, the light grey is OC and the dark grey is EC. See: Turpin, B. and H-J, Lim, 2001: Species contributions to $PM_{2.5}$ mass concentrations: Revisiting common assumptions for estimating organic mass, Atmospheric Environment, 35, 602-610.

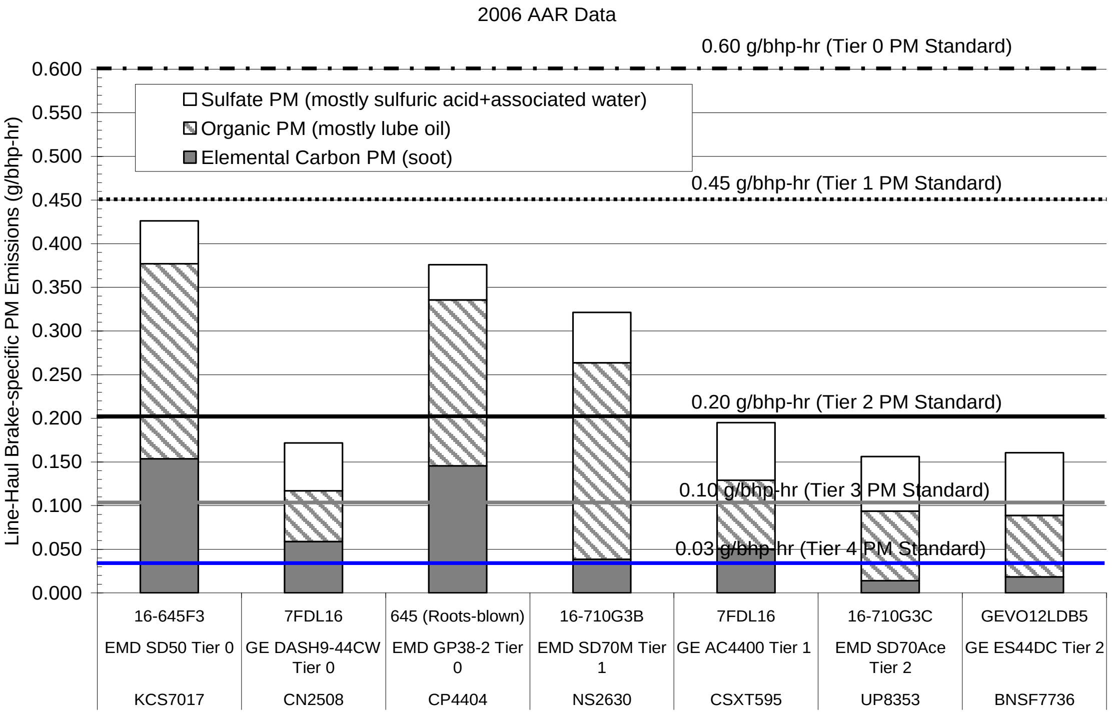
Regional pollution contributes more than half of total $PM_{2.5}$ concentrations. As expected for a predominately regional pollutant, only a modest urban excess is observed for sulfates. Rural background $PM_{2.5}$ concentrations are high in the East and are somewhat uniform over large geographic areas. These regional concentrations come from emission sources such as power plants, natural sources, and urban pollution and can be transported hundreds of miles and reflect to some extent the denser clustering of urban areas in the East as compared to the West. The local and regional contributions for the major chemical components that make up urban $PM_{2.5}$ are sulfates, carbon, and nitrates.

2.1.1.4 Composition of $PM_{2.5}$ from Locomotive and Marine Diesel Engines

Locomotive and Marine Diesel engines contribute significantly to ambient $PM_{2.5}$ levels, largely through emissions of carbonaceous $PM_{2.5}$. As discussed in the previous section, carbonaceous $PM_{2.5}$ is a major portion of ambient $PM_{2.5}$, especially in populous urban areas. For the medium speed diesel engine commonly used in locomotive and Category 2 marine applications, the majority of the total carbon PM is organic carbon. Locomotive and marine diesels also emit high levels of NO_x which react in the atmosphere to form secondary $PM_{2.5}$ (namely ammonium nitrate). Locomotive and marine diesel engines also emit SO_2 and HC which form secondary $PM_{2.5}$ (namely sulfates and organic carbonaceous $PM_{2.5}$). Figure

2-5 shows the relative contribution of elemental and organic carbon to PM emissions for seven Tier 0, Tier 1, and Tier 2 locomotives (four locomotive engines were 2-stroke while 3 locomotive engines were 4- stroke). This recent data, while limited to seven locomotives, suggest that locomotives, regardless of when they were built, tend to emit a very high level of organic carbon PM, precisely the type of carbon that appears to be responsible for a high percentage of the urban excess $PM_{2.5}$ species across the US.

Figure 2-5: PM emissions for 7 locomotives tested using 2800 ppm sulfur nonroad diesel fuel.



2.1.2 Health Effects of PM Pollution

As stated in EPA's Particulate Matter Air Quality Criteria Document (PM AQCD), available scientific findings "demonstrate well that human health outcomes are associated with ambient PM."[D] We are relying on the data and conclusions in the PM AQCD and PM Staff Paper, which reflects EPA's analysis of policy-relevant science from the PM AQCD, regarding the health effects associated with particulate matter.[13,14] We also present additional recent studies published after the cut-off date for the PM AQCD.[E15] Taken together this

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[D] Personal exposure includes contributions from many different types of particles, from many sources, and in many different environments. Total personal exposure to PM includes both ambient and nonambient components; and both components may contribute to adverse health effects.

[E] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by EPA, CASAC, and the public, as did the PM AQCD. The provisional assessment found that the "new" studies expand the scientific information and provide important insights on the information supports the conclusion that PM-related emissions such as those controlled in this action are associated with adverse health effects. Information on PM-related mortality and morbidity is presented first, followed by information on near-roadway exposure studies, marine ports and rail yard exposure studies.

2.1.2.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases (PM AQCD, p. 8-305), hospitalization and emergency department visits for cardiopulmonary diseases (PM AQCD, p. 9-93), increased respiratory symptoms (PM AQCD, p. 9-46), decreased lung function (PM AQCD Table 8-34) and physiological changes or biomarkers for cardiac changes (PM AQCD, Section 8.3.1.3.4). In addition, the PM AQCD describes a limited body of new evidence from epidemiologic studies for potential relationships between short term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality. (PM AQCD, Section 8.3.4).

Among the studies of effects from short-term exposure to $PM_{2.5}$, several specifically address the contribution of mobile sources to short-term $PM_{2.5}$ effects on daily mortality. These studies indicate that there are statistically significant associations between mortality and PM related to mobile source emissions (PM AQCD, p.8-85). The analyses incorporate source apportionment tools into daily mortality studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death indicated a relationship between mobile source $PM_{2.5}$ and mortality.[16,17] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. This study found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient PM_{10} when compared with other sources.[18] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

2.1.2.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to elevated ambient $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases and lung cancer (PM AQCD, p. 8-307), and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease (PM AQCD, pp. 8-313, 8-314). Of specific importance to this rulemaking, the PM AQCD also notes that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to the observed ambient PM-related increases in lung cancer incidence and mortality (PM AQCD, p. 8-318).

The PM AQCD and PM Staff Paper emphasize the results of two long-term studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on

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relationship between PM exposure and health effects of PM. The provisional assessment also found that “new” studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects.

several factors – the inclusion of measured PM data, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis (PM AQCD, p. 8-306, Staff Paper, p.3-18).[19,20,21] These studies indicate that there are significant associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. One analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[22]

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth (PM AQCD, Section 8.3.3.2.3). In another recent publication included in the 2006 Provisional Assessment, investigators in southern California reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and measures of atherosclerosis in the Los Angeles basin.[23] The study found significant associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease.

2.1.2.3 Roadway-Related Exposure and Health Studies

A recent body of studies reinforces the findings of these PM morbidity and mortality effects by looking at traffic-related exposures, PM measured along roadways, or time spent in traffic and adverse health effects. While many of these studies did not measure PM specifically, they include potential exhaust exposures which include mobile source PM because they employ indices such as roadway proximity or traffic volumes. One study with specific relevance to $PM_{2.5}$ health effects is a study that was done in North Carolina looking at concentrations of $PM_{2.5}$ inside police cars and corresponding physiological changes in the police personnel driving the cars. The authors report significant elevations in markers of cardiac risk associated with concentrations of $PM_{2.5}$ inside police cars on North Carolina state highways.[24] A number of studies of traffic-related pollution have shown associations between fine particles and adverse respiratory outcomes in children who live near major roadways.[25,26,27]

2.1.2.4 Marine Ports and Rail Yard Studies

Recently, new studies from the State of California provide evidence that $PM_{2.5}$ emissions within marine ports and rail yards can contribute significantly to elevated ambient concentrations near these sources[28,29] and that a substantial number of people experience exposure to fresh locomotive and marine diesel engine emissions, raising potential health concerns. Additional information on marine port and rail yard emissions and potential health effects can be found in Section 2.4 of this RIA.

2.1.3 Current $PM_{2.5}$ Levels

EPA has recently amended the NAAQS for $PM_{2.5}$ (71 FR 61144, October 17, 2006). The final PM NAAQS rule addressed revisions to the primary and secondary NAAQS for $PM_{2.5}$ to provide increased protection of public health and welfare, respectively. The primary $PM_{2.5}$ NAAQS includes a short-term (24-hour) and a long-term (annual) standard. The level of the 24-hour $PM_{2.5}$ NAAQS has been revised from 65 $\mu g/m^3$ to 35 $\mu g/m^3$ to provide increased protection against health effects associated with short-term exposures to fine particles. The current form of the 24-hour $PM_{2.5}$ standard was retained (e.g., based on the 98th percentile concentration averaged over three years). The level of the annual $PM_{2.5}$ NAAQS was retained at 15$\mu g/m^3$, continuing protection against health effects associated with long-term exposures. The current form of the annual $PM_{2.5}$ standard was retained as an annual arithmetic mean averaged over three years, however, the following two aspects of the spatial averaging criteria were narrowed: (1) the annual mean concentration at each site will now be within 10 percent of the spatially averaged annual mean, and (2) the daily values for each monitoring site pair will now yield a correlation coefficient of at least 0.9 for each calendar quarter.

With regard to the secondary standards for $PM_{2.5}$, EPA has revised these standards to be identical in all respects to the revised primary standards. Specifically, EPA has revised the current 24-hour $PM_{2.5}$ secondary standard by making it identical to the revised 24-hour $PM_{2.5}$ primary standard and retained the annual $PM_{2.5}$ secondary standard. This suite of secondary $PM_{2.5}$ standards is intended to provide protection against PM-related public welfare effects, including visibility impairment, effects on vegetation and ecosystems, and material damage and soiling.

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. In 2005, EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS based on air quality design values and a number of other factors (70 FR 943, January 5, 2005; 70 FR 19844, April 14, 2005).[F] These areas are comprised of 208 full or partial counties with a total population exceeding 88 million. The 1997 $PM_{2.5}$ nonattainment counties, areas and populations, as of October 2007, are listed in Appendix 2A to this RIA. The 1997 $PM_{2.5}$ NAAQS was recently revised and the 2006 $PM_{2.5}$ NAAQS became effective on December 18, 2006. Nonattainment areas will be designated with respect to the 2006 $PM_{2.5}$ NAAQS in early 2010. Table 2-1 provides an estimate, based on 2003-05 air quality data, of the counties violating the 2006 $PM_{2.5}$ NAAQS.

[F] The full details involved in calculating a $PM_{2.5}$ design value are given in Appendix N of 40 CFR Part 50.

Table 2-1 Counties violating the 2006 $PM_{2.5}$ NAAQS based on 2003-2005 Air Quality Data

Fine Particle Standards: Current Nonattainment Areas and Other Violated Counties		
	Number of Counties	Population[a]
1997 $PM_{2.5}$ Standards: 39 areas currently designated	208	88,394,000
2006 $PM_{2.5}$ Standards: Counties with violating monitors[b]	49	18,198,676
Total	**257**	**106,592,676**

Notes:

[a] Population numbers are from 2000 census data.

[b] The areas designated as nonattainment for the 2006 $PM_{2.5}$ NAAQS will be based on three years of air quality data. Also, the county numbers in the summary table include only the counties with monitors violating the 2006 $PM_{2.5}$ NAAQS. The monitored county violations may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

As can be seen in Figure 2-1 ambient $PM_{2.5}$ levels exceeding the 1997 $PM_{2.5}$ NAAQS are widespread throughout the country. States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most $PM_{2.5}$ nonattainment areas will be required to attain the 1997 $PM_{2.5}$ NAAQS in the 2010 to 2015 time frame and then be required to maintain the 1997 $PM_{2.5}$ NAAQS thereafter.[G] The attainment dates associated with the potential nonattainment areas based on the 2006 $PM_{2.5}$ NAAQS would likely be in the 2015 to 2020 timeframe. The emission standards being finalized in this action become effective between 2008 and 2015. Therefore, the $PM_{2.5}$ and $PM_{2.5}$ precursor inventory reductions in this action will be useful for states to attain or maintain the $PM_{2.5}$ NAAQS.

2.1.4 Projected $PM_{2.5}$ Levels

In conjunction with this rulemaking, we performed a series of $PM_{2.5}$ air quality modeling simulations for the continental U.S. The model simulations were performed for several emissions scenarios including the following: 2002 baseline projection, 2020 baseline projection, 2020 baseline projection with locomotive/marine diesel engine controls, 2030 baseline projection, and 2030 baseline projection with locomotive/marine diesel engine controls. Information on the air quality modeling methodology is contained in Section 2.3 as well as the air quality modeling technical support document (AQ TSD). In the following sections we describe projected $PM_{2.5}$ levels in the future with and without the controls being finalized in this action.

2.1.4.1 Projected $PM_{2.5}$ Levels without this Rulemaking

Even with the implementation of all current state and federal regulations, including the CAIR Rule, the NO_x SIP call, nonroad and on-road diesel rules and the Tier 2 rule, there are

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[G] The EPA finalized $PM_{2.5}$ attainment and nonattainment areas in April 2005. The EPA finalized the PM Implementation rule in November 2005 (70 FR 65984, Nov. 5, 2005).

projected to be U.S. counties violating the $PM_{2.5}$ NAAQS well into the future. The model outputs from the 2002, 2020 and 2030 baselines, combined with current air quality data, were used to identify areas expected to exceed the $PM_{2.5}$ NAAQS in the future.

The baseline air quality modeling conducted for this final rule projects that in 2020, with all current controls in effect, up to 11 counties, with a population of 24 million people, may not attain the annual standard of 15 $\mu g/m^3$. This does not account for additional areas that have air quality measurements within 10 percent of the $PM_{2.5}$ standard. These areas, although not violating the standard, will also benefit from the emissions reductions, ensuring long term maintenance of the PM NAAQS. For example, in 2020, an additional 16 million people are projected to live in 13 counties that have air quality measurements within 10 percent of the 2006 PM NAAQS. This modeling supports the conclusion that there are a substantial number of counties across the US projected to experience $PM_{2.5}$ concentrations at or above the $PM_{2.5}$ NAAQS into the future. A number of state governments and state organizations have told EPA that they need the reductions from this rule in order to be able to attain or maintain the 1997 $PM_{2.5}$ standards as well as to attain the 2006 $PM_{2.5}$ NAAQS.[30] Emission reductions from locomotive and marine diesel engines will be helpful for these counties in attaining and maintaining the $PM_{2.5}$ NAAQS.

2.1.4.2 Projected $PM_{2.5}$ Levels With this Rulemaking

The impacts of the locomotive/marine diesel engine controls were determined by comparing the model results in the future year control runs against the baseline simulations of the same year. According to air quality modeling performed for this rulemaking, the locomotive and marine diesel engine standards are expected to provide nationwide improvements in $PM_{2.5}$ levels. On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design value (DV) for all counties is expected to decrease by 0.06 $\mu g/m^3$ in 2020 and 0.12 $\mu g/m^3$ in 2030. In counties predicted to have annual $PM_{2.5}$ design values greater than 15 $\mu g/m^3$ the average decrease will be somewhat higher**:** 0.11 $\mu g/m^3$ in 2020 and 0.21 $\mu g/m^3$ in 2030. In addition, those counties that are within 10 percent of the annual $PM_{2.5}$ design value will see their average DV decrease by 0.09 $\mu g/m^3$ in 2020 and 0.18 $\mu g/m^3$ in 2030. The maximum decrease for future-year annual $PM_{2.5}$ design values will be 0.38 $\mu g/m^3$ in 2020 and 0.81 $\mu g/m^3$ in 2030. Note that for the current 39 $PM_{2.5}$ nonattainment areas the average population weighted future-year annual $PM_{2.5}$ design value will on *average* decrease by 0.08 $\mu g/m^3$ in 2020 and by 0.16 $\mu g/m^3$ in 2030.

Figure 2-6 illustrates the geographic impact of the locomotive and marine diesel engine controls on annual $PM_{2.5}$ design values in 2030. The greatest $PM_{2.5}$ reductions are projected to occur in the gulf coast region where in 2030 four counties will experience reductions in their annual $PM_{2.5}$ design values of 0.50 to 1.00 $\mu g/m^3$. The twenty counties experiencing $PM_{2.5}$ reductions between 0.25 and 0.49 $\mu g/m^3$ are geographically dispersed along the midwest, the pacific northwest, the gulf coast and southern California An additional 143 counties spread across the US will see a decrease in their projected annual $PM_{2.5}$ DV ranging from 0.10 to 0.24 $\mu g/m^3$. A complete set of maps illustrating the geographic impact of various alternatives explored as part of this rulemaking are available in the Air Quality Modeling TSD for this rulemaking.

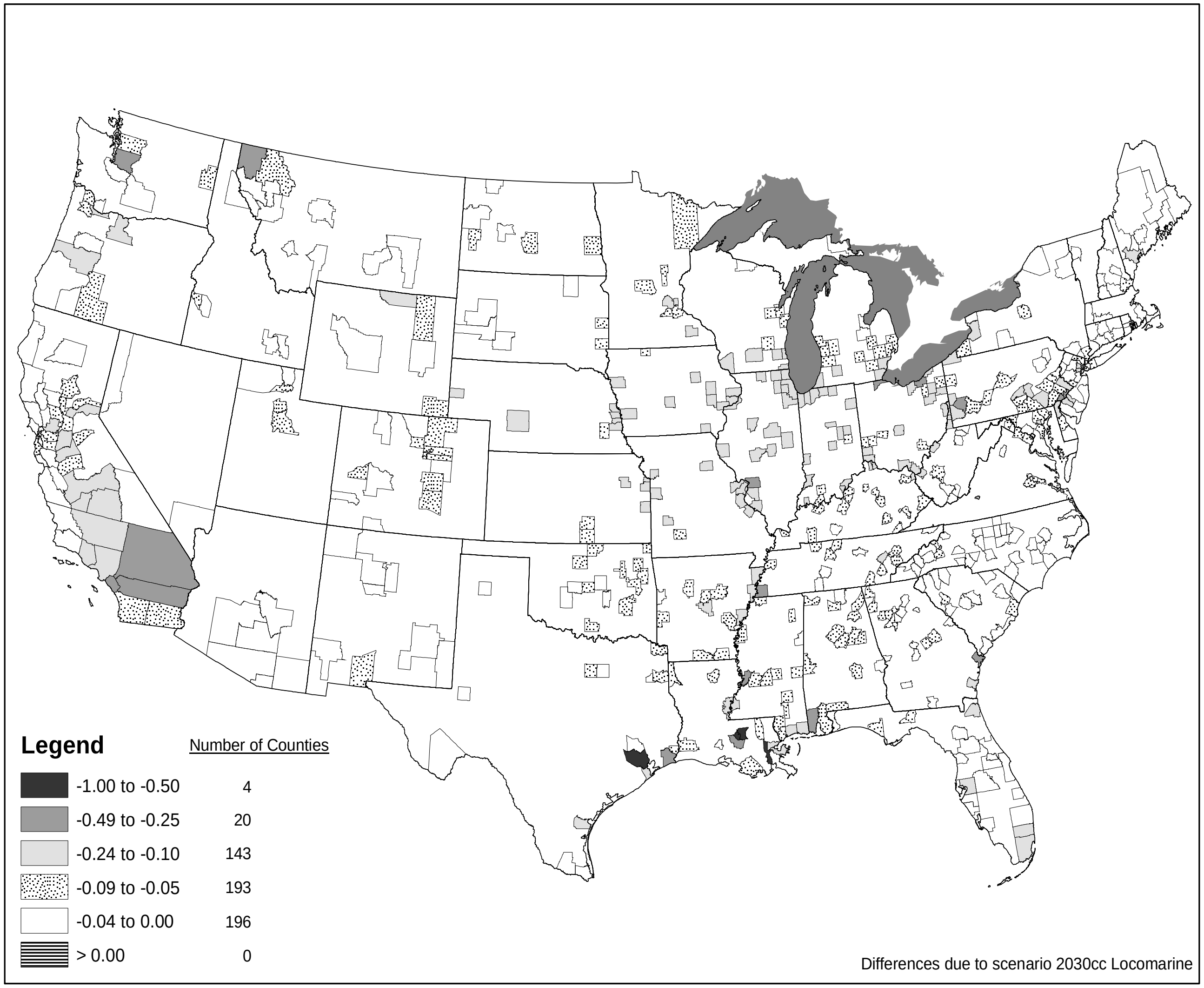

Figure 2-6 Impact of Locomotive/Marine controls on annual $PM_{2.5}$ Design Values (DV) in 2030

Table 2-2 lists the counties with projected annual $PM_{2.5}$ design values that violate or are within 10 percent of the annual $PM_{2.5}$ standard in 2020. Counties are marked with a "V" in the table if their projected design values are greater than or equal to 15.05 µg/m^3. Counties are marked with an "X" in the table if their projected annual design values are greater than or equal to 13.55 µg/m^3, but less than 15.05 µg/m^3. The counties marked "X" are not projected to violate the standard, but to be close to it, so the rule will help assure that these counties continue to meet the standard. The current design values are also presented in Table 2-2. Recall that we project future design values only for counties that have current design values, so this list is limited to those counties with ambient monitoring data sufficient to calculate current 3-year design values.

Table 2-2 Counties with 2020 Projected Annual $PM_{2.5}$Design Values in Violation or within 10 percent of the Annual $PM_{2.5}$ Standard

State	County	2000-2004 Average annual $PM_{2.5}$ DV (ug/m^3)	2020 modeling projections of annual $PM_{2.5}$ DV (ug/m^3)		2020 Population
			base	control	
Alabama	Jefferson Co	18.36	V	V	673,910
California	Fresno Co	20.02	X	X	1,012,929
California	Imperial Co	14.44	V	V	183,835
California	Kern Co	21.77	X	X	851,948
California	Kings Co	18.77	X	X	172,415
California	Los Angeles Co	23.16	X	X	10,067,663
California	Merced Co	16.47	X	X	263,184
California	Orange Co	18.27	X	X	3,690,329
California	Riverside Co	27.15	X	X	2,173,672
California	San Bernardino Co	24.63	X	X	2,302,697
California	San Diego Co	15.65	V	V	3,715,268
California	San Joaquin Co	14.84	V	V	711,938
California	Stanislaus Co	16.49	V	V	579,349
California	Tulare Co	21.33	X	X	464,651
Georgia	Fulton Co	18.29	V	V	898,342
Illinois	Cook Co	17.06	V	V	5,369,914
Illinois	Madison Co	17.27	V	V	276,838
Kentucky	Jefferson Co	16.58	V	V	717,730
Michigan	Wayne Co	19.32	X	X	1,879,876
Montana	Lincoln Co	15.85	V	V	20,078
New York	New York Co	17.16	V	V	1,560,060
Ohio	Cuyahoga Co	18.36	V	V	1,305,880
Pennsylvania	Allegheny Co	20.99	X	X	1,234,865
West Virginia	Hancock Co	17.30	V	V	30,461

2.1.5 Environmental Effects of PM Pollution

In this section we discuss public welfare effects of PM and its precursors including visibility impairment, atmospheric deposition, and materials damage and soiling.

2.1.5.1 Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[31] Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.[32] Local visibility impairment may take the form of a localized plume, a band or layer of discoloration appearing well above the terrain as a result of complex local meteorological conditions. Alternatively, local visibility impairment may manifest as an urban haze, sometimes referred to as a "brown cloud." This urban haze is largely caused by emissions from multiple sources in the urban area and is not typically attributable to only one nearby source or to long-range transport. The second type of visibility impairment, regional haze, usually results from multiple pollution sources spread over a large geographic region. Regional haze can impair visibility over large regions and across states.

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.

Fine particles are the major cause of reduced visibility in parts of the United States. To address the welfare effects of PM on visibility, EPA sets secondary $PM_{2.5}$ standards which work in conjunction with the regional haze program. The secondary (welfare-based) $PM_{2.5}$ NAAQS is equal to the suite of primary (health-based) $PM_{2.5}$ NAAQS. The regional haze rule (64 FR 35714, July 1999) was put in place to protect the visibility in mandatory class I federal areas. These areas are defined in Section 162 of the Act 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. A list of the mandatory class I federal areas is included in Appendix 2D. Visibility is impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.

Control of locomotive and marine diesel engine emissions will improve visibility across the nation. The locomotive and marine diesel engines subject to this rule either directly emit $PM_{2.5}$ or emit PM precursors which contribute to the formation of secondary $PM_{2.5}$ and thus contribute to visibility impairment. In the next sections we present current information and projected estimates about visibility impairment related to ambient $PM_{2.5}$ levels across the country and visibility impairment in mandatory class I federal areas. We conclude that visibility will continue to be impaired in the future and the emission reductions from this rule will help improve visibility conditions across the country and in mandatory class I federal areas. For more information on visibility see the PM AQCD as well as the 2005 PM Staff Paper.[33,34]

2.1.5.1.1 *Current Visibility Impairment in $PM_{2.5}$ Nonattainment Areas*

As mentioned above, the secondary $PM_{2.5}$ standards were set as equal to the suite of primary $PM_{2.5}$ standards. Almost 90 million people live in the 208 counties that are in nonattainment for the 1997 $PM_{2.5}$ NAAQS, (see Appendix 2A for the complete list of current nonattainment areas). These populations, as well as large numbers of individuals who travel to these areas can experience visibility impairment.

2.1.5.1.2 *Current Visibility Impairment at Mandatory Class I Federal Areas*

Detailed information about current and historical visibility conditions in mandatory class I federal areas is summarized in the EPA Report to Congress and the 2002 EPA Trends Report.[35,36] The conclusions draw upon the Interagency Monitoring of Protected Visual Environments (IMPROVE) network data. One of the objectives of the IMPROVE monitoring network program is to provide regional haze monitoring representing all mandatory class I federal areas where practical. The National Park Service report also describes the state of national park visibility conditions and discusses the need for improvement.[37]

The regional haze rule requires states to establish goals for each affected mandatory class I federal area that 1) improves visibility on the haziest days (20% most impaired days), 2) ensures no degradation occurs on the cleanest days (20% least impaired days), and 3) achieves natural background visibility levels by 2064. Although there have been general trends toward improved visibility, progress is still needed on the haziest days. Specifically, as discussed in the 2002 EPA Trends Report, without the effects of pollution a natural visual range in the United States is approximately 75 to 150 km in the East and 200 to 300 km in the West. In 2001, the mean visual range for the worst days was 29 km in the East and 98 km in the West.[38]

2.1.5.1.3 *Future Visibility Impairment*

Additional emission reductions will be needed from a broad set of sources, including those in this action, as part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

Modeling was used to project visibility conditions in 133 mandatory class I federal areas across the US in 2020 and 2030 as a result of the locomotive and marine diesel engine standards. The AQ modeling TSD and Section 2.3 of this RIA provide information on the modeling methodology. The results indicate that improvements in visibility will occur in all 133 mandatory class I federal areas, although these areas will continue to have annual average deciview levels above background. Table 2-3 below indicates the current monitored deciview values, the natural background levels each area is attempting to reach, and also the projected deciview values in 2020 and 2030 with and without the standards. In 2030, the greatest visibility improvement due to this rule will occur at San Gorgonio (0.24 deciview) located in San Bernadino County, California.

Table 2-3 Current (2002) and Future (2020 and 2030) Projected Visibility Conditions With and Without Locomotive and Marine Diesel Rule in Mandatory Class I Federal Areas (20% Worst Days)

Mandatory Class I Federal Area Name	State	2002 Baseline Visibility (dv)[a]	2020 Base Case (dv)	2020 Control Case (dv)	2030 Base Case (dv)	2030 Control Case (dv)	Natural Bckgrnd (dv)
Acadia NP	ME	22.89	19.79	19.77	19.86	19.81	12.43
Agua Tibia Wilderness	CA	23.50	21.23	21.14	21.16	20.94	7.64
Alpine Lake Wilderness	WA	17.84	16.77	16.71	16.72	16.60	8.43
Anaconda-Pintler Wilderness	MT	13.41	13.15	13.14	13.13	13.11	7.43
Arches NP	UT	11.24	11.14	11.11	11.05	11.03	6.43
Badlands NP	SD	17.14	15.87	15.84	15.80	15.75	8.06
Bandelier NM	NM	12.22	11.43	11.41	11.38	11.34	6.26
Big Bend NP	TX	17.30	16.15	16.13	16.18	16.15	7.16
Black Canyon of the Gunnison NM	CO	10.33	9.80	9.79	9.79	9.77	6.24
Bosque del Apache	NM	13.80	12.96	12.90	12.94	12.81	6.73
Bob Marshall Wilderness	MT	14.48	14.14	14.13	14.11	14.08	7.74
Bryce Canyon NP	UT	11.65	11.36	11.34	11.34	11.31	6.86
Bridger Wilderness	WY	11.12	10.81	10.81	10.80	10.80	6.58
Brigantine	NJ	29.01	24.88	24.85	24.99	24.91	12.24
Cabinet Mountains Wilderness	MT	14.09	13.57	13.54	13.52	13.46	7.53
Caney Creek Wilderness	AR	26.36	22.11	22.05	22.06	21.92	11.58
Canyonlands NP	UT	11.24	10.84	10.81	10.83	10.82	6.43
Caribou Wilderness	CA	14.15	13.62	13.60	13.55	13.51	7.31
Carlsbad Caverns NP	TX	17.19	15.93	15.92	15.92	15.90	6.68
Chassahowitzka	FL	26.09	21.96	21.94	21.96	21.91	11.21
Chiricahua NM	AZ	13.43	13.09	13.09	13.10	13.09	7.21
Chiricahua Wilderness	AZ	13.43	13.09	13.09	13.10	13.09	7.21
Cohutta Wilderness	GA	30.30	23.36	23.33	23.34	23.28	11.14
Crater Lake NP	OR	13.74	13.29	13.27	13.26	13.20	7.84
Craters of the Moon NM	ID	14.00	13.00	12.97	12.90	12.82	7.53
Cucamonga Wilderness	CA	19.94	17.42	17.36	17.14	17.10	7.06
Desolation Wilderness	CA	12.63	12.15	12.13	12.15	12.12	6.12
Diamond Peak Wilderness	OR	13.74	13.25	13.20	13.22	13.12	7.84
Dome Land Wilderness	CA	19.43	18.37	18.34	18.20	18.11	7.46
Dolly Sods Wilderness	WV	29.04	22.38	22.35	22.38	22.33	10.39
Eagle Cap Wilderness	OR	18.57	17.86	17.83	17.79	17.71	8.92
Eagles Nest Wilderness	CO	9.61	9.05	9.03	8.99	8.96	6.54
Emigrant Wilderness	CA	17.63	17.22	17.21	17.24	17.19	7.64
Everglades NP	FL	22.30	19.75	19.77	19.97	19.94	12.15
Fitzpatrick Wilderness	WY	11.12	10.86	10.85	10.86	10.84	6.58
Flat Tops Wilderness	CO	9.61	9.31	9.31	9.32	9.31	6.54
Galiuro Wilderness	AZ	13.43	13.08	13.07	13.11	13.09	7.21

Mandatory Class I Federal Area Name	**State**	**2002 Baseline Visibility (dv)**[a]	**2020 Base Case (dv)**	**2020 Control Case (dv)**	**2030 Base Case (dv)**	**2030 Control Case (dv)**	**Natural Bckgrnd (dv)**
Gates of the Mountains Wilderness	MT	11.29	10.92	10.91	10.89	10.87	6.45
Gearhart Mountain Wilderness	OR	13.74	13.39	13.37	13.36	13.33	7.84
Gila Wilderness	NM	13.11	12.55	12.54	12.55	12.54	6.69
Glacier Peak Wilderness	WA	13.96	13.62	13.60	13.69	13.67	8.01
Goat Rocks Wilderness	WA	12.76	12.06	12.05	12.07	12.03	8.36
Grand Canyon NP	AZ	11.66	11.13	11.09	11.15	11.08	7.14
Great Gulf Wilderness	NH	22.82	19.48	19.45	19.50	19.46	11.99
Great Sand Dunes NM	CO	12.78	12.36	12.36	12.37	12.36	6.66
Great Smoky Mountains NP	TN	30.28	23.96	23.93	23.93	23.86	11.24
Grand Teton NP	WY	11.76	11.36	11.35	11.33	11.31	6.51
Guadalupe Mountains NP	TX	17.19	15.89	15.88	15.89	15.86	6.68
Hells Canyon Wilderness	OR	18.55	17.26	17.20	17.18	17.04	8.32
Hercules-Glades Wilderness	MO	26.75	23.00	22.93	22.96	22.81	11.30
Hoover Wilderness	CA	12.87	12.73	12.72	12.75	12.74	7.91
Isle Royale NP	MI	20.74	19.15	19.10	19.16	19.04	12.37
Jarbidge Wilderness	NV	12.07	11.86	11.86	11.86	11.85	7.87
James River Face Wilderness	VA	29.12	23.43	23.34	23.43	23.26	11.13
Joshua Tree NM	CA	19.62	17.95	17.93	17.85	17.71	7.19
Joyce-Kilmer-Slickrock Wilderness	TN	30.28	23.46	23.43	23.43	23.37	11.24
Kalmiopsis Wilderness	OR	15.51	15.00	14.98	14.97	14.93	9.44
Lava Beds NM	CA	15.05	14.45	14.42	14.40	14.32	7.86
La Garita Wilderness	CO	10.33	9.90	9.89	9.89	9.88	6.24
Lassen Volcanic NP	CA	14.15	13.56	13.54	13.48	13.43	7.31
Linville Gorge Wilderness	NC	28.77	22.48	22.45	22.47	22.41	11.22
Lostwood	ND	19.57	17.73	17.70	17.67	17.60	8.00
Lye Brook Wilderness	VT	24.45	21.10	21.08	21.17	21.11	11.73
Maroon Bells-Snowmass Wilderness	CO	9.61	9.24	9.24	9.24	9.24	6.54
Mammoth Cave NP	KY	31.37	25.53	25.48	25.54	25.44	11.08
Mazatzal Wilderness	AZ	13.35	12.74	12.72	12.77	12.73	6.68
Medicine Lake	MT	17.72	16.25	16.22	16.18	16.12	7.90
Mesa Verde NP	CO	13.03	12.40	12.39	12.40	12.37	6.83
Mission Mountains Wilderness	MT	14.48	14.06	14.04	14.02	13.99	7.74
Mount Hood Wilderness	OR	14.86	14.19	14.13	14.28	14.14	8.44
Mount Jefferson Wilderness	OR	15.33	14.80	14.77	14.82	14.76	8.79

Mandatory Class I Federal Area Name	State	2002 Baseline Visibility (dv)[a]	2020 Base Case (dv)	2020 Control Case (dv)	2030 Base Case (dv)	2030 Control Case (dv)	Natural Bckgrnd (dv)
Mokelumne Wilderness	CA	12.63	12.32	12.30	12.34	12.31	6.12
Mountain Lakes Wilderness	OR	13.74	13.26	13.24	13.23	13.17	7.84
Moosehorn	ME	21.72	18.65	18.63	18.68	18.64	12.01
Mount Rainier NP	WA	18.24	17.27	17.24	17.27	17.21	8.55
Mount Washington Wilderness	OR	15.33	14.77	14.75	14.78	14.72	8.79
Mount Zirkel Wilderness	CO	10.52	10.06	10.05	10.07	10.04	6.44
North Absaroka Wilderness	WY	11.45	11.17	11.16	11.15	11.13	6.86
North Cascades NP	WA	13.96	13.58	13.57	13.68	13.67	8.01
Okefenokee	GA	27.13	23.46	23.42	23.50	23.40	11.44
Olympic NP	WA	16.74	15.85	15.82	15.95	15.89	8.44
Otter Creek Wilderness	WV	29.04	22.31	22.29	22.32	22.27	10.39
Pasayten Wilderness	WA	15.23	14.85	14.84	14.83	14.81	8.26
Pecos Wilderness	NM	10.41	10.01	10.00	10.02	10.01	6.44
Petrified Forest NP	AZ	13.21	12.90	12.83	12.87	12.75	6.49
Pine Mountain Wilderness	AZ	13.35	12.59	12.58	12.59	12.54	6.68
Pinnacles NM	CA	18.46	17.37	17.36	17.16	17.09	7.99
Point Reyes NS	CA	22.81	22.01	21.99	21.87	21.79	15.77
Presidential Range-Dry River Wilderness	NH	22.82	19.48	19.45	19.50	19.46	11.99
Rawah Wilderness	CO	10.52	10.04	10.04	10.06	10.04	6.44
Red Rock Lakes	WY	11.76	11.44	11.43	11.42	11.39	6.51
Redwood NP	CA	18.45	17.89	17.86	17.86	17.79	13.91
Roosevelt Campobello International Park	ME	21.72	18.47	18.45	18.51	18.47	12.01
Cape Romain	SC	26.48	22.77	22.74	22.77	22.71	12.12
Rocky Mountain NP	CO	13.83	13.10	13.08	13.06	13.01	7.24
Salt Creek	NM	18.03	16.61	16.59	16.58	16.52	6.81
San Gabriel Wilderness	CA	19.94	17.30	17.25	17.01	16.93	7.06
San Gorgonio Wilderness	CA	22.17	20.28	20.22	19.94	19.70	7.30
Saguaro NM	AZ	14.83	14.50	14.47	14.49	14.44	6.46
San Jacinto Wilderness	CA	22.17	19.92	19.87	19.61	19.55	7.30
St. Marks	FL	26.03	21.84	21.82	21.88	21.83	11.53
San Pedro Parks Wilderness	NM	10.17	9.53	9.52	9.53	9.52	6.08
Sawtooth Wilderness	ID	13.78	13.64	13.63	13.64	13.63	6.43
Scapegoat Wilderness	MT	14.48	14.17	14.16	14.14	14.12	7.74
Selway-Bitterroot Wilderness	MT	13.41	13.06	13.04	13.02	12.99	7.43
Seney	MI	24.16	21.77	21.72	21.78	21.66	12.65
Shenandoah NP	VA	29.31	22.83	22.80	22.83	22.76	11.35
Sierra Ancha	AZ	13.67	13.22	13.20	13.18	13.15	6.59

Mandatory Class I Federal Area Name	State	2002 Baseline Visibility (dv)[a]	2020 Base Case (dv)	2020 Control Case (dv)	2030 Base Case (dv)	2030 Control Case (dv)	Natural Bckgrnd (dv)
Wilderness							
Sipsey Wilderness	AL	29.03	23.78	23.73	23.77	23.66	10.99
South Warner Wilderness	CA	15.05	14.61	14.59	14.57	14.52	7.86
Strawberry Mountain Wilderness	OR	18.57	17.77	17.73	17.69	17.60	8.92
Swanquarter	NC	25.49	21.17	21.15	21.20	21.15	11.94
Sycamore Canyon Wilderness	AZ	15.25	14.96	14.94	14.98	14.93	6.69
Teton Wilderness	WY	11.76	11.41	11.40	11.39	11.36	6.51
Three Sisters Wilderness	OR	15.33	14.84	14.82	14.84	14.79	8.79
Thousand Lakes Wilderness	CA	14.15	13.54	13.52	13.46	13.41	7.31
Theodore Roosevelt NP	ND	17.74	16.65	16.54	16.61	16.42	7.79
UL Bend	MT	15.14	14.66	14.64	14.62	14.58	8.16
Upper Buffalo Wilderness	AR	26.27	22.41	22.35	22.34	22.19	11.57
Ventana Wilderness	CA	18.46	17.67	17.64	17.67	17.62	7.99
Voyageurs NP	MN	19.27	17.62	17.58	17.53	17.43	12.06
Washakie Wilderness	WY	11.45	11.18	11.17	11.16	11.14	6.86
West Elk Wilderness	CO	9.61	9.24	9.24	9.24	9.23	6.54
Weminuche Wilderness	CO	10.33	9.86	9.86	9.86	9.86	6.24
White Mountain Wilderness	NM	13.70	13.07	13.05	13.07	13.04	6.86
Mount Adams Wilderness	WA	12.76	12.03	12.01	12.02	11.97	8.36
Wheeler Peak Wilderness	NM	10.41	9.96	9.95	9.97	9.96	6.44
Wind Cave NP	SD	15.84	14.94	14.91	14.94	14.87	7.71
Wichita Mountains	OK	23.81	20.67	20.62	20.68	20.55	7.53
Wolf Island	GA	27.13	23.40	23.37	23.40	23.32	11.44
Yellowstone NP	WY	11.76	11.39	11.38	11.36	11.34	6.51
Yosemite NP	CA	17.63	17.16	17.14	17.15	17.11	7.64
Zion NP	UT	13.24	12.96	12.92	12.89	12.81	6.99

[a] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a "deciview", which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

2.1.5.2 Particulate Matter Deposition

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominately from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). Reflecting this fact, the PM AQCD concludes that regardless of size fractions, particles containing nitrates and sulfates have the greatest potential for widespread environmental significance, while effects are also related to other chemical constituents found in ambient PM, such as trace metals and organics. The following characterizations of the nature of these welfare effects are based on the information contained in the PM AQCD and PM Staff Paper.

2.1.5.2.1 *Deposition of Nitrates and Sulfates*

At current ambient levels, risks to vegetation from short-term exposures to dry deposited particulate nitrate or sulfate are low. However, when found in acid or acidifying deposition, such particles do have the potential to cause direct leaf injury. Specifically, the responses of forest trees to acid precipitation (rain, snow) include accelerated weathering of leaf cuticular surfaces, increased permeability of leaf surfaces to toxic materials, water, and disease agents; increased leaching of nutrients from foliage; and altered reproductive processes—all which serve to weaken trees so that they are more susceptible to other stresses (e.g., extreme weather, pests, pathogens). Acid deposition with levels of acidity associated with the leaf effects described above are currently found in some locations in the eastern U.S.[39] Even higher concentrations of acidity can be present in occult depositions (e.g., fog, mist or clouds) which more frequently impacts higher elevations. Thus, the risk of leaf injury occurring from acid deposition in some areas of the eastern U.S. is high. Nitrogen deposition has also been shown to impact ecosystems in the western U.S. A study conducted in the Columbia River Gorge National Scenic Area (CRGNSA), located along a portion of the Oregon/Washington border, indicates that lichen communities in the CRGNSA have shifted to a higher proportion of nitrophilous species and the nitrogen content of lichen tissue is elevated.[40] Lichens are sensitive indicators of nitrogen deposition effects to terrestrial ecosystems and the lichen studies in the Columbia River Gorge clearly show that ecological effects from air pollution are occurring.

Some of the most significant detrimental effects associated with excess reactive nitrogen deposition are those associated with a syndrome known as nitrogen saturation. These effects include: (1) decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) fluctuationof ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms.[41]

In the U.S. numerous forests now show severe symptoms of nitrogen saturation. These forests include: the northern hardwoods and mixed conifer forests in the Adirondack and Catskill Mountains of New York; the red spruce forests at Whitetop Mountain, Virginia, and Great Smoky Mountains National Park, North Carolina; mixed hardwood watersheds at Fernow Experimental Forest in West Virginia; American beech forests in Great Smoky Mountains National Park, Tennessee; mixed conifer forests and chaparral watersheds in southern California and the southwestern Sierra Nevada in Central California; the alpine tundra/subalpine conifer forests of the Colorado Front Range; and red alder forests in the Cascade Mountains in Washington.

Excess nutrient inputs into aquatic ecosystems (i.e. streams, rivers, lakes, estuaries or oceans) either from direct atmospheric deposition, surface runoff, or leaching from nitrogen saturated soils into ground or surface waters can contribute to conditions of severe water oxygen depletion; eutrophication and algae blooms; altered fish distributions, catches, and physiological states; loss of biodiversity; habitat degradation; and increases in the incidence of disease.

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. According to a NOAA report, more than half of the nation's estuaries have moderate to high expressions of at least one of these symptoms – an indication that eutrophication is well developed in more than half of U.S. estuaries. [42]

2.1.5.2.2 *Deposition of Heavy Metals*

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for influencing forest growth (PM AQCD, p. 4-87).[43] Investigation of trace metals near roadways and industrial facilities indicate that a substantial load of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions (PM AQCD, p. 4-75). Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment. Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline (PM AQCD, p. 4-76). This hypothesized relationship/correlation was further explored in high elevation forests in the northeastern U.S. These studies measured levels of a group of intracellular compounds found in plants that bind with metals and are produced by plants as a response to sublethal concentrations of heavy metals. These studies indicated a systematic and significant increase in concentrations of these compounds associated with the extent of tree injury. These data strongly imply that metal stress causes tree injury and contributes to forest decline in the northeastern United States (PM AQCD 4-76,77).[44] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops (PM AQCD, p. 4-75). As the fallen leaves decompose, the heavy metals are transferred into the soil.[45,46]

The environmental sources and cycling of mercury are currently of particular concern due to the bioaccumulation and biomagnification of this metal in aquatic ecosystems and the potent toxic nature of mercury in the forms in which is it ingested by people and other animals. Mercury is unusual compared with other metals in that it largely partitions into the gas phase (in elemental form), and therefore has a longer residence time in the atmosphere than a metal found predominantly in the particle phase. This property enables mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[47,48] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[49] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[50] Forty-four states have issued health advisories for the consumption of fish contaminated by mercury; however, most of these advisories are issued in areas without a mercury point source.

Elevated levels of zinc and lead have been identified in streambed sediments, and these elevated levels have been correlated with population density and motor vehicle use.[51,52] Zinc and nickel have also been identified in urban water and soils. In addition, platinum, palladium, and rhodium, metals found in the catalysts of modern motor vehicles, have been measured at elevated levels along roadsides.[53] Plant uptake of platinum has been observed at these locations.

2.1.5.2.3 *Deposition of Polycyclic Organic Matter*

Polycyclic organic matter (POM) is a byproduct of incomplete combustion and consists of organic compounds with more than one benzene ring and a boiling point greater than or equal to 100 degrees centigrade.[54] Polycyclic aromatic hydrocarbons (PAHs) are a class of POM that contains compounds which are known or suspected carcinogens.

Major sources of PAHs include mobile sources. PAHs in the environment may be present as a gas or adsorbed onto airborne particulate matter. Since the majority of PAHs are adsorbed onto particles less than 1.0 µm in diameter, long range transport is possible. However, studies have shown that PAH compounds adsorbed onto diesel exhaust particulate and exposed to ozone have half lives of 0.5 to 1.0 hours.[55]

Since PAHs are insoluble, the compounds generally are particle reactive and accumulate in sediments. Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan.[56,57] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[58,59] Sediment concentrations of PAHs are high enough in some segments of Tampa Bay to pose an environmental health threat. EPA funded a study to better characterize the sources and loading rates for PAHs into Tampa Bay.[60] PAHs that enter a water body through gas exchange likely partition into organic rich particles and can be biologically recycled, while dry deposition of aerosols containing PAHs tend to be more resistant to biological recycling.[61] Thus, dry deposition is likely the main pathway for PAH concentrations in sediments while gas/water exchange at the surface may lead to PAH distribution into the food web, leading to increased health risk concerns.

Trends in PAH deposition levels are difficult to discern because of highly variable ambient air concentrations, lack of consistency in monitoring methods, and the significant influence of local sources on deposition levels.[62] Van Metre et al. noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlate with increases in automobile use.[63]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[64] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[65]

2.1.5.2.4 *Materials Damage and Soiling*

The effects of the deposition of atmospheric pollution, including ambient PM, on materials are related to both physical damage and impaired aesthetic qualities. The deposition of PM (especially sulfates and nitrates) 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 concrete and limestone. Only chemically active fine particles or hygroscopic coarse particles contribute to these physical effects. In addition, the deposition of ambient PM can reduce the aesthetic appeal of buildings and culturally important articles through soiling. Particles consisting primarily of carbonaceous compounds cause soiling of commonly used building materials and culturally important items such as statues and works of art.

2.2 Ozone

In this section we review the health and welfare effects of ozone. We also describe the air quality monitoring and modeling data which indicate that people in many areas across the country continue to be exposed to high levels of ambient ozone and will continue to be into the future. Emissions of nitrogen oxides (NO_x) and VOCs, of which HC are the major subset, from the locomotive and marine diesel engines subject to this rule have been shown to contribute to these ozone concentrations. Information on air quality was gathered from a variety of sources, including monitored ozone concentrations, air quality modeling forecasts conducted for this rulemaking, and other state and local air quality information.

The emission reductions from this rule will assist 8-hour ozone nonattainment and maintenance areas in reaching the standard by each area’s respective attainment date, and maintaining the 8-hour ozone standard in the future. The emission reductions will also help continue to lower ambient ozone levels and reduce health impacts.

2.2.1 Science of Ozone Formation

Ground-level ozone pollution is formed by the reaction of VOCs and nitrogen oxides (NO_x) in the atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway vehicles and nonroad engines, power plants, chemical plants, refineries, makers of consumer and commercial products, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex.[66] 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 would occur on a single high-temperature day. Ozone also can be transported into an area from pollution sources found hundreds of miles upwind, 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 can be lowered by the reaction of nitric oxide 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 are 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 would not be 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 many rural 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.

2.2.2 Health Effects of Ozone Pollution

Exposure to ambient ozone contributes to a wide range of adverse health effects[H]. These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[67,68] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

[H] 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 concentration but also by the individuals breathing route and rate.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory effects. Cell-level effects such as, inflammation of lungs, have been documented as well. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. People who appear to be more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to higher ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[69, 70, 71, 72, 73, 74] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[75, 76, 77, 78, 79] Repeated exposure to sufficient concentrations of ozone can also cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses, such as emphysema and chronic bronchitis.[80, 81, 82, 83]

Children and adults who are outdoors and active during the summer months, such as construction workers, are among those most at risk of elevated ozone exposures.[84] Children and outdoor workers tend to have higher ozone exposure because they typically are active outside, working, playing and exercising, during times of day and seasons (e.g., the summer) when ozone levels are highest.[85] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported significant reductions in lung function in children who are active outdoors.[86, 87, 88, 89, 90, 91, 92, 93] Further, children are more at risk of experiencing health effects from ozone exposure than adults because their respiratory systems are still developing. These individuals (as well as people with respiratory illnesses such as asthma, especially asthmatic children) can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.[94, 95, 96, 97]

2.2.3 Current 8-Hour Ozone Levels

The locomotive and marine engine emission reductions will assist 8-hour ozone nonattainment areas in reaching the standard by each area's respective attainment date and/or assist in maintaining the 8-hour ozone standard in the future. The current ozone National Ambient Air Quality Standard (NAAQS) has an 8-hour averaging time.[I] The 8-hour ozone

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[I] EPA's review of the ozone NAAQS is underway, the proposal was published in June 2007 and the final rule is scheduled for March 2008.

NAAQS is met at an ambient air quality monitoring site when the average of the annual fourth-highest daily maximum 8-hour average ozone concentration over three years is less than or equal to 0.08 ppm. In the following section we present information on current and model-projected future 8-hour ozone levels.

A nonattainment area is defined in the CAA as an area that is violating a NAAQS or is contributing to a nearby area that is violating the NAAQS. EPA designated nonattainment areas for the 8-hour ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 8-hour Ozone NAAQS (69 FR 23858, April 30, 2004) identifies the criteria that EPA considered in making the 8-hour ozone nonattainment designations, including 2001-2003 measured data, air quality in adjacent areas, and other factors.[J]

As of October 10, 2007 there are approximately 144 million people living in 81 areas designated as nonattainment with the 8-hour ozone NAAQS. There are 366 full or partial counties that make up the 8-hour ozone nonattainment areas. These numbers do not include the people living in areas where there is a future risk of failing to maintain or attain the 8-hour ozone NAAQS. The current 8-hour ozone nonattainment areas, nonattainment counties, and populations are listed in Appendix 2C to this RIA.

States with 8-hour ozone nonattainment areas are required to take action to bring those areas into compliance in the future. The maximum attainment date assigned to an ozone nonattainment area is based on the area's classification. Most 8-hour ozone nonattainment areas will be required to attain the 8-hour ozone NAAQS in the 2007 to 2013 time frame and then be required to maintain the 8-hour ozone NAAQS thereafter.[K] We expect many of the 8-hour ozone nonattainment areas will need to adopt additional emissions reduction programs to attain and maintain the 8-hour ozone NAAQS. The expected NO_x and VOC reductions from these standards, which take effect between 2008 and 2017, will be useful to states as they seek to either attain or maintain the 8-hour ozone NAAQS.

EPA's review of the ozone NAAQS is currently underway, the proposal was published in June 2007 (72 FR 37818, July 11, 2007) and the final rule is scheduled for March 2008. If the ozone NAAQS is revised then new nonattainment areas could be designated. While EPA

[J] An ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values are determined based on three consecutive-year monitoring periods. For example, an 8-hour ozone design value is the fourth highest daily maximum 8-hour average ozone concentration measured over a three-year period at a given monitor. The full details of these determinations (including accounting for missing values and other complexities) are given in Appendices H and I of 40 CFR Part 50. Due to the precision with which the standards are expressed (0.08 parts per million (ppm) for the 8-hour), a violation of the 8-hour standard is defined as a design value greater than or equal to 0.085 ppm or 85 parts per billion (ppb). For a county, the design value is the highest design value from among all the monitors with valid design values within that county. If a county does not contain an ozone monitor, it does not have a design value. However, readers should note that ozone design values generally represent air quality across a broad area and that absence of a design value does not imply that the county is in compliance with the ozone NAAQS.

[K] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area is designated as severe and will have to attain before June 15, 2021. The South Coast Air Basin has recently applied to be redesignated as an extreme nonattainment area which will make their attainment date June 15, 2024.

is not relying on it for purposes of justifying this rule, the emission reductions from this rulemaking will also be helpful to states if EPA revises the ozone NAAQS to be more stringent.

2.2.4 Projected 8-Hour Ozone Levels

In the following sections we describe our modeling of 8-hour ozone levels in the future with and without the controls being finalized in this action.

2.2.4.1 Projected 8-Hour Ozone Levels without this Rulemaking

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001). As a result of these programs, the number of areas that continue to violate the 8-hour ozone NAAQS in the future is expected to decrease.

The baseline air quality modeling completed for this rule predicts that without additional local, regional or national controls there will continue to be a need for reductions in 8-hour ozone concentrations in some areas in the future. The determination that an area is at risk of exceeding the 8-hour ozone standard in the future was made for all areas with current design values greater than or equal to 85 ppb (or within a 10 percent margin) and with modeling evidence that concentrations at and above these levels will persist into the future.[L] Those interested in greater detail should review the air quality modeling TSD.

The baseline inventories that underlie the modeling conducted for this rulemaking include emission reductions from existing federal, state and local controls. There was no attempt to examine the prospects of areas attaining or maintaining the standard with future possible controls. The results should therefore be interpreted as indicating what counties are at risk for violating the ozone NAAQS in the future without additional federal, state or local measures that may implemented after this rulemaking is finalized. We expect many of the areas to adopt additional emission reduction programs, but we are unable to quantify or rely upon future reductions from additional programs since they have not yet been promulgated.

With reductions from programs already in place (but excluding the emission reductions from this rule), the number of counties with projected 8-hour ozone design values at or above 85 ppb in 2020 is expected to be 9 counties where 22.5 million people are projected to live. In addition, in 2020, 39 counties where 28.6 million people are projected to live, will be within 10 percent of violating the 8-hour ozone NAAQS.

As discussed in the next section, the air quality modeling conducted for this rule indicates that the almost 300,000 tons of annual NO_x reductions in 2020 will be important for ensuring that air quality in these areas meets the 8-hour ozone standard.

[L] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

2.2.4.2 Projected 8-Hour Ozone Levels with this Rulemaking

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the reductions in locomotive and marine diesel emissions finalized in this action. Specifically, we compare baseline scenarios to scenarios with controls. Our modeling indicates that the reductions from this rule will contribute to reducing ambient ozone concentrations and minimizing the risk of exposures in future years. Since some of the VOC and NO_x emission reductions from this rule go into effect during the period when some areas are still working to attain the 8-hour ozone NAAQS, the projected emission reductions will assist state and local agencies in their effort to attain the 8-hour ozone standard and help others maintain the standard. Emissions reductions from this rule will also help to counter potential ozone increases due to climate change, which are expected in many urban areas in the United States, but are not reflected in the modeling shown here.[98]

According to air quality modeling performed for this rulemaking, the locomotive and marine diesel engine standards provide improvements in ozone levels for the vast majority of areas. There are three nonattainment areas in southern California, the Los Angeles-South Coast Air Basin nonattainment area, the Riverside Co. (Coachella Valley) nonattainment area and the Los Angeles–San Bernardino (W. Mojave) nonattainment area, which will experience 8-hour ozone design value increases due to the NO_x disbenefits which occur in these VOC-limited ozone nonattainment areas. Briefly NO_x reductions can at certain times and in some areas cause ozone levels to increase slightly. Section 2.2.4.2.1 provides additional detail about NO_x disbenefits.

Despite these areas which experience ozone increases, the overall effect of this rule is positive with 573 counties (of 579 that have monitored data) experiencing at least a 0.1 ppb decrease in their 2030 ozone design values. On a population-weighted basis, the average modeled future-year 8-hour ozone design values over these counties will decrease by 0.30 ppb in 2020 and 0.85 ppb in 2030. Within areas with the highest projected 8-hour ozone design values, greater than 85 ppb, the average decrease will be 0.13 ppb in 2020 and 0.62 ppb in 2030. The *maximum* decrease for future-year design values will be 1.8 ppb in 2020 and 4.6 ppb in 2030.

Table 2-4 identifies the full list of counties projected to have design values at or above 85 ppb as well as the counties within 10 percent of violating the 8-hour ozone NAAQS in 2020. The design value for Kenosha, WI goes from being above the standard in the base case to being lower than the 8-hour ozone NAAQS with the controls being finalized in this rulemaking.

Table 2-4 Counties with 2020 8-hour Ozone Design Values in Violation or within 10 percent of the Ozone Standard in the Base and Control Cases

State	County	2000-2004 Average 8-Hour Ozone DV (ppb)[a]	2020 modeling projections of 8-Hour Ozone DV (ppb)		2020 Population
			base	control	
CA	Calaveras	91.0	V	V	58,261
CA	El Dorado	105.0	X	X	236,310
CA	Fresno	110.0	X	X	1,066,878
CA	Kern	114.3	X	X	876,131
CA	Kings	95.7	V	V	173,390
CA	Los Angeles	121.3	X	X	10,376,013
CA	Madera	91.0	V	V	173,940
CA	Merced	101.7	V	V	277,863
CA	Nevada	97.7	V	V	131,831
CA	Orange	85.3	V	V	3,900,599
CA	Placer	98.3	V	V	451,620
CA	Riverside	115.0	X	X	2,252,510
CA	Sacramento	99.0	V	V	1,640,590
CA	San Bernardino	128.7	X	X	2,424,764
CA	San Diego	92.3	V	V	3,863,460
CA	Stanislaus	95.0	V	V	607,766
CA	Tulare	105.7	X	X	477,296
CA	Tuolumne	91.0	V	V	70,570
CA	Ventura	94.7	V	V	1,023,136
CT	Fairfield	98.3	V	V	962,824
CT	New Haven	98.3	V	V	898,415
IN	Lake	88.3	V	V	509,293
LA	East Baton Rouge	87.0	V	V	522,399
MD	Harford	100.3	V	V	317,847
MI	Allegan	94.0	V	V	141,851
MI	Macomb	92.3	V	V	894,095
NJ	Camden	99.7	V	V	547,817
NJ	Gloucester	98.0	V	V	304,105
NJ	Mercer	97.7	V	V	392,236
NJ	Ocean	105.7	V	V	644,323
NY	Erie	95.7	V	V	959,145
NY	Niagara	91.7	V	V	220,989
NY	Suffolk	97.0	V	V	1,598,742
OH	Ashtabula	95.7	V	V	108,355
OH	Geauga	99.0	V	V	114,438
PA	Bucks	99.0	V	V	711,275
PA	Philadelphia	96.7	V	V	1,394,176
TX	Brazoria	94.0	V	V	322,385

State	County	2000-2004 Average 8-Hour Ozone DV (ppb)[a]	2020 modeling projections of 8-Hour Ozone DV (ppb)		2020 Population
TX	Galveston	89.7	V	V	318,966
TX	Harris	102.0	X	X	4,588,812
TX	Jefferson	91.0	V	V	272,075
TX	Montgomery	88.3	V	V	526,335
TX	Tarrant	98.7	V	V	2,137,957
WI	Kenosha	98.3	X	V	184,825
WI	Milwaukee	91.0	V	V	927,845
WI	Ozaukee	93.0	V	V	110,294
WI	Racine	91.7	V	V	212,351
WI	Sheboygan	97.0	V	V	128,777

[a] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

Table 2-5 shows the average change in future year eight-hour ozone design values. Average changes are shown for: (1) all counties with 2002 baseline design values, (2) counties with baseline design values that exceeded the standard in 2000-2004 (“violating” counties), and (3) counties that did not exceed the standard, but were within 10 percent of it in 2000-2004. This last category is intended to reflect counties that meet the standard, but will likely benefit from help in maintaining that status in the face of growth. All of these metrics show a decrease in 2020 and a larger decrease in 2030, indicating in three different ways the overall improvement in ozone air quality.

Table 2-5 Average change in projected future year 8-hour ozone design value as a result of the locomotive and marine diesel controls

Average[a]	Number of US Counties	Change in 2020 design value[b] (ppb)	Change in 2030 design value[b] (ppb)
All	579	-0.45	-1.15
All, population-weighted	579	-0.30	-0.85
Violating counties[c]	261	-0.45	-1.18
Violating counties[c], population-weighted	261	-0.27	-0.78
Counties within 10 percent of the standard[d]	477	-0.46	-1.18
Counties within 10 percent of the standard[d], population-weighted	477	-0.31	-0.86

Notes:

[a] averages are over counties with 2002 modeled design values

[b] Ozone design values are reported in parts per million (ppm) as specified in 40 CFR Part 50. Due to the scale of the design value changes in this action results have been presented in parts per billion (ppb) format.

[c] counties whose 2002 baseline design values exceeded the 8-hour ozone standard (>= 85 ppb)

[d] counties whose 2002 baseline values were less than but within 10 percent of the 8-hour ozone standard.

Figure 2.7 shows those US counties in 2030 which experience a change in their ozone design values as a result of this rule. Some of the most significant decreases will occur in the following counties: St. Mary (3.1 ppb) and Lafayette (2.6 ppb) Counties in Louisiana; Brazoria (2.9 ppb) and Jefferson (3.0 ppb) Counties in Texas; Warren County (3.2 ppb) in Mississippi; and Santa Barbara County (4.6 ppb) in California. 338 counties will see 8-hour ozone design value reductions from between 1.0 to 1.9 ppb while an estimated 190 additional counties will see design value reductions from 0.5 to 0.9 ppb. Note that 5 counties, Cook County (0.2 ppb) in Illinois; Lake County (0.1 ppb) in Indiana; and San Bernardino (0.1 ppb), Riverside (0.5 ppb) and Orange (5.5 ppb) counties in California are projected to experience increases in their ozone design values because of the NOx disbenefit that occurs in these VOC-limited areas.

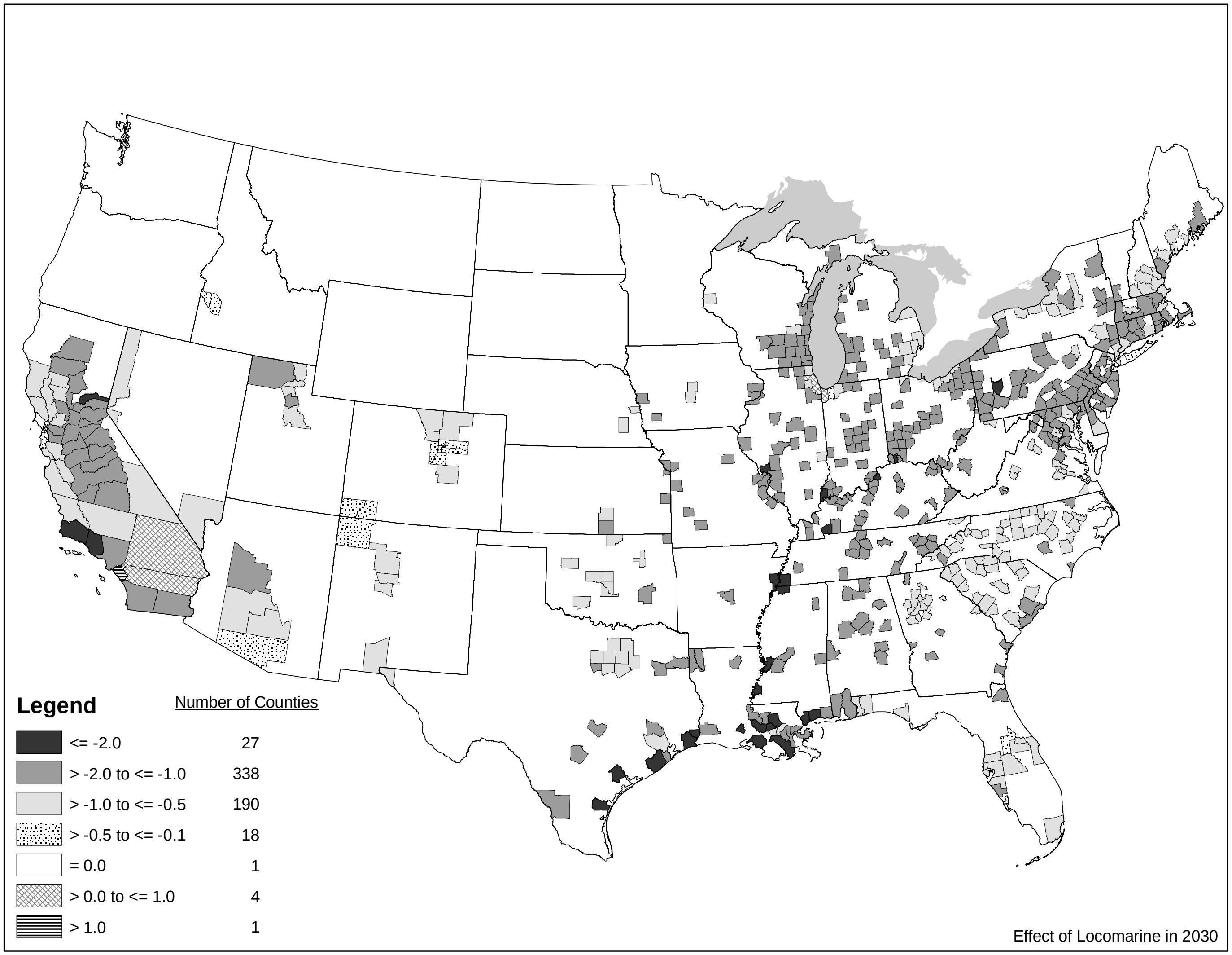

Figure 2-7 Impact of Locomotive/Marine controls on Ozone Design Values in 2030

2.2.4.2.1 *Potentially Counterproductive Impacts on Ozone Concentrations from NO_x Emissions Reductions*

While this rule reduces ozone levels generally and provides national ozone-related health benefits, this is not always the case at the local level. Due to the complex photochemistry of ozone production, NO_x emissions lead to both the formation and destruction of ozone, depending on the relative quantities of NO_x, VOC, and ozone formation catalysts such as the OH and HO_2 radicals. In areas dominated by fresh emissions of NO_x, ozone catalysts are removed via the production of nitric acid which slows the ozone formation rate. Because NO_x is generally depleted more rapidly than VOC, this effect is usually short-lived and the emitted NOx can lead to ozone formation later and further downwind. The terms “NO_x disbenefits” or “ozone disbenefits” refer to the ozone increases that result when reducing Ox emissions in localized areas. According to the NARSTO Ozone Assessment, disbenefits are generally limited to small regions within specific urban cores and are surrounded by larger regions in which NO_x control is beneficial.[99]

EPA believes that the best available approach for determining the value of a particular national emission reduction strategy is the net air quality change projected to result from a rule, evaluated on a nationwide basis for all pollutants of concern. The primary tool for assessing the net health and welfare impacts at this time is the Community Multiscale Air Quality (CMAQ) model. Model scenarios for 2020 and 2030 with and without the emission control strategies from this rule were compared to determine the expected changes in future pollutant levels resulting from this rule. A wide variety of ozone metrics were considered in assessing emissions reductions. Three of the most important are: 1) the effect of the rule on projected future-year ozone design values, 2) the effect of the rule in assisting local areas in attainment and maintenance of the NAAQS, and 3) an economic assessment of the rule benefits based on existing health studies.

When considering NOx disbenefit results for these local areas several factors related to both the model inputs and the air quality modeling should be considered. First, our future year modeling does not contain any local governmental actions which have not already been promulgated in a finalized State SIP. The inability to account for future local controls is a function of the SIP development process. EPA typically does not include local plans to reduce ozone precursors in our future baseline projections until those reductions are part of a fully promulgated State or local regulation. However, significant local controls of VOC and/or NO_x that are not reflected in the air quality modeling for this rule could modify the conclusions regarding ozone changes in some areas.

Second, due to the ozone disbenefit chemistry described above, modeling only the final rule-related NOx reductions in an area that is VOC-limited can give an inaccurate representation of future air quality. In an area such as this, marginal NOx reductions modeled independently will likely lead to ozone disbenefits. However, there is a level of NOx reduction, even in VOC-limited areas, where enough NOx will have been controlled to result in NOx-limited conditions and as a result ambient ozone concentrations will decrease.

The majority of the projected NOx disbenefits from this rule occur in Southern California, specifically Orange, Riverside and San Bernardino counties. California's South Coast Air Quality Management District (SCAQMD) includes the southern two-thirds of Los Angeles County, all of Orange County, and the western, urbanized portions of Riverside and San Bernardino counties. The SCAQMD has recently completed an air quality modeling exercise as part of their ozone attainment demonstration. This modeling indicates that with substantial NOx and VOC reductions (~90% and ~45% respectively), the entire south coast basin will be in attainment for the 8-hour ozone NAAQS by 2024.[M]

The SCAQMD attainment demonstrations for both $PM_{2.5}$ and 8-hour ozone were conducted using photochemical dispersion and meteorological modeling tools developed in response to U.S EPA modeling guidelines[100], and recommendations from air quality modeling experts. The air quality modeling has undergone scientific peer review and was made available for public review. Air Resources Board (ARB) and South Coast District staffs worked together on the modeling, including development of a gridded modeling inventory and meteorological and geological data inputs, model performance analysis, and validation of the attainment demonstrations.

It is important to note that the NOx emission reductions associated with this final locomotive and marine rule play an important role in the South Coast's demonstration of future-year ozone attainment. The SCAQMD modeling projections are based on emissions reductions from many different state and local programs, the majority of which are not yet finalized. The results of the SCAQMD attainment demonstration modeling illustrate the fact that with additional NOx and VOC controls, beyond those being finalized in this rule, ambient ozone would be reduced in Southern California.

Finally, although a VOC-heavy control strategy can be an effective means to reduce NOx disbenefits, there are reasons why NOx reductions can still be the preferred route to reducing ozone in local areas. One reason is because NOx is not only an ozone precursor but a PM precursor. Based on modeling and cost/benefit analyses completed by SCAQMD they have concluded that due to the magnitude of emissions reductions needed for ozone and PM attainment, as well as the readiness of NOx control technologies, a NOx-heavy control approach provides the most efficient path to attainment for both pollutants in California's south coast..

Historically, NO_x reductions have been very successful at reducing regional/national ozone levels. Consistent with that fact, the photochemical modeling completed for this rule indicates that the emission reductions resulting from the locomotive and marine engine rule assist in the attainment and maintenance of the ozone NAAQS at the national level. Furthermore, NO_x reductions also result in reductions in PM and its associated health and welfare effects. This rule is one important element of the overall emission reductions that States, local governments, and Tribes need to reach their clean air goals. It is expected that future local and national controls that decrease VOC, CO, and regional ozone will mitigate

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[M] Note that the NOx reductions modeled in the south coast attainment demonstration include NOx reductions that are projected to occur due to new technology that does not currently exist.

localized disbenefit. EPA continues to rely on local attainment measures to ensure no future violations of the NAAQS. Many states and environmental organizations with an interest in improved air quality have urged EPA to finalize this rule because of the significant NO_x reductions that will reduce both ozone and PM.[101] EPA believes that a balanced air quality management approach, which includes NO_x reductions from locomotive and marine engines, is needed as part of the Nation's progress toward clean air.

Another effect of ozone reduction strategies is the potential impact these reductions may have on the shielding provided by ozone from ultraviolet radiation (UV-B) derived from the sun. The majority of this shielding results from naturally occurring ozone in the stratosphere, but a variable portion of this tropospheric fraction of UV-B shielding is derived from ground level ozone. Therefore, strategies that reduce ground level ozone could, in some small measure, increase exposure to UV-B from the sun, thus potentially increasing skin cancer.

While it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Comparatively smaller changes in ground-level ozone (compared to the total ozone in the troposphere) and UV-B are not likely to measurably change long-term risks of adverse effects.

2.2.5 Environmental Effects of Ozone Pollution

There are a number of public welfare effects associated with the presence of ozone in the ambient air.[102] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

2.2.5.1 Impacts on Vegetation

The Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant. Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[103] Once sufficient levels of ozone, a highly reactive substance, (or its reaction products) reaches the interior of plant cells, it can inhibit or damage essential cellular components and functions, including enzyme activities, lipids, and cellular membranes, disrupting the plant's osmotic (i.e., water) balance and energy utilization patterns.[104,105] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[106] With fewer resources available, the plant reallocates existing resources away from root growth and storage, above ground growth or yield, and reproductive processes, toward leaf repair and maintenance. Studies have shown that plants stressed in these ways may exhibit a general loss of vigor, which can lead to secondary impacts that modify plants' responses to other environmental factors. Specifically, plants may become more sensitive to other air pollutants, more susceptible to disease, insect attack, harsh weather (e.g., drought, frost) and other environmental stresses. Furthermore, there is evidence that ozone can interfere with the formation of mycorrhiza, essential symbiotic fungi associated with the roots of most terrestrial plants, by reducing the amount of carbon available for transfer from the host to the symbiont.[107,108]

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on sensitive vegetation. Not all plants, however, are equally sensitive to ozone. Much of the variation in sensitivity between individual plants or whole species is related to the plant's ability to regulate the extent of gas exchange via leaf stomata (e.g., avoidance of O_3 uptake through closure of stomata).[109,110,111] Other resistance mechanisms may involve the intercellular production of detoxifying substances. Several biochemical substances capable of detoxifying ozone have been reported to occur in plants including the antioxidants ascorbate and glutathione. After injuries have occurred, plants may be capable of repairing the damage to a limited extent.[112]

Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants. The next few paragraphs present additional information on ozone damage to trees, ecosystems, agronomic crops and urban ornamentals.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[113,114] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts. Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[115, 116]

Because plants are at the center of the food web in many ecosystems, changes to the plant community can affect associated organisms and ecosystems (including the suitability of habitats that support threatened or endangered species and below ground organisms living in the root zone). Ozone impacts at the community and ecosystem level vary widely depending upon numerous factors, including concentration and temporal variation of tropospheric ozone, species composition, soil properties and climatic factors.[117] In most instances, responses to chronic or recurrent exposure in forested ecosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[118,119,120] It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Laboratory and field experiments have also shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the Unites States."[121] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[122, 123, 124]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[125] This is therefore a potentially costly environmental effect. However, in the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative analysis has been conducted.

2.3 Air Quality Modeling Methodology

In this section we present information on the air quality modeling, including the model domain and modeling inputs. Further discussion of the modeling methodology, including evaluations of model performance, is included in the Air Quality Modeling Technical Support Document (AQM TSD).[126]

2.3.1 Air Quality Modeling Overview

A national scale air quality modeling analysis was performed to estimate future year annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations and visibility levels. These projections were used as inputs to the calculation of expected benefits from the locomotive and marine emissions controls considered in this assessment. The 2002-based CMAQ modeling platform was used as the tool for the air quality modeling of future baseline emissions and control scenarios. It should be noted that the 2002-based modeling platform has recently been finalized and the 2001-based modeling platform was used as the tool for the air quality modeling performed for the proposal. In the next paragraph we discuss some of the differences between the 2001-based platform used for the proposal and the 2002-based platform used for this final rule.

The 2002-based modeling platform includes a number of updates and improvements to data and tools compared to the 2001-based platform that was used for the proposal modeling. For the final rule modeling we used the new 2002 National Emissions Inventory along with updated versions of the models used to project future emissions from electric generating units (EGUs) and onroad and nonroad vehicles. The proposal modeling was based on the 2001 National Emissions Inventory. The new platform also includes 2002 meteorology and more recent ambient design values which were used as the starting point for projecting future air quality. For proposal, we used meteorology for 2001 for modeling the East and 2002 for modeling the West. The updates to CMAQ between proposal and final include (1) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH; (2) improved vertical convective mixing; (3) heterogeneous reaction involving nitrate formation; (4) an updated gas-phase chemistry mechanism, Carbon Bond 2005 (CB05); and (5) an aqueous chemistry mechanism that provides a comprehensive simulation of aerosol precursor oxidants.

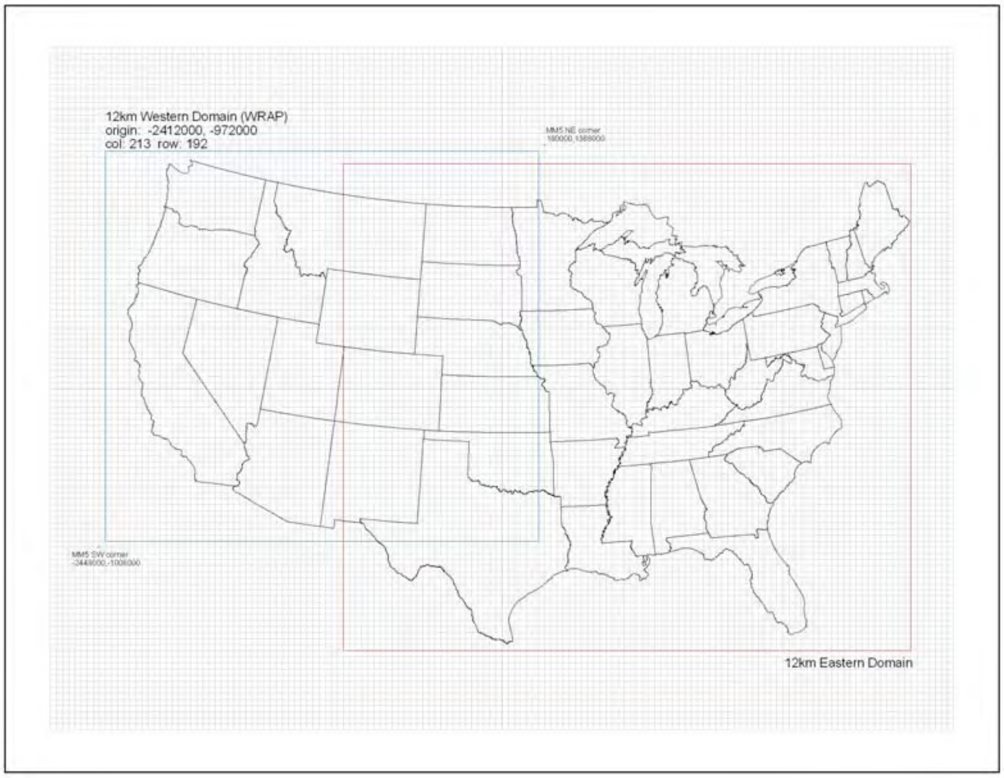
The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations and deposition over regional and urban spatial scales (e.g., over the contiguous U.S.).[127,128,129] Consideration of the different processes that affect primary (directly emitted) and secondary (formed by atmospheric processes) PM at the regional scale in different locations is fundamental to understanding and assessing the effects of pollution control measures that affect PM, ozone and deposition of pollutants to the surface. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial/boundary condition data which are inputs to this model.

The CMAQ model was peer-reviewed in 2003 for EPA as reported in "Peer Review of CMAQ Model".[130] The latest version of CMAQ (Version 4.6.1) was employed for this modeling analysis. This version reflects updates, as mentioned above, in a number of areas to improve the underlying science which include (1) use of a state-of-the science inorganic and organic aerosol module, (2) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH, (3) improved vertical convective mixing, (4) heterogeneous reaction involving nitrate formation and (5) an updated Carbon Bond 05 (CB05) gas-phase chemistry mechanism and aqueous chemistry mechanism that provides a comprehensive simulation of aerosol precursor oxidants.

2.3.2 Model Domain and Configuration

As shown in Figure 2-8 the CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico. The modeling domain is made up of a large continental U.S. 36 km grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 2-8. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

Figure 2-8. Map of the CMAQ modeling domain.



2.3.3 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from a simulation of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model[131] for the entire year of 2002. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. The meteorology for the national 36 km grid and the 12 km Eastern U.S. grid were developed by EPA and are described in more detail within the AQM TSD. The meteorology for the 12 km Western U.S. grid was developed by the Western Regional Air Partnership (WRAP) Regional Planning Organization. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.1 to derive the specific inputs to CMAQ, for example: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[132]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[133] 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). This model was run for 2002 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36 km CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

The emissions inputs used for the 2002 base year and each of the future year base cases and control scenarios are summarized in Chapter 3 of this RIA.

2.3.4 CMAQ Evaluation

An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using the 2002 data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. In summary, model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[134] The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies[135]. Overall, the performance for the 2002 modeling platform is within the range of these other applications. A detailed summary of the 2002 CMAQ model performance evaluation is available within the AQM TSD.

2.3.5 Model Simulation Scenarios

As part of our analysis for this rulemaking the CMAQ modeling system was used to calculate annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations and visibility estimates for each of the following emissions scenarios:

2002 base year

2020 base line projection

2020 base line projection with diesel marine only controls

2020 base line projection with locomotive and diesel marine controls

2030 base line projection

2030 base line projection with diesel marine only controls

2030 base line projection with locomotive and diesel marine controls

It should be noted that the emission control scenarios used in the air quality and benefits modeling are slightly different than the emission control program being finalized. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of this RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario. These refinements to the program would not significantly change the results summarized here or our conclusions drawn from this analysis.

We use the predictions from the model in a relative sense by combining the 2002 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, and visibility levels for each of the 2020 and 2030 scenarios. The ambient air quality observations are average conditions, on a site by site basis, for a period centered around the model base year (i.e., 2000-2004). After completing this process, we then calculated the effect of changes in PM, ozone and visibility air quality metrics resulting from this rulemaking on the health and welfare impact functions of the benefits analysis

The projected annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses an Federal Reference Method FRM mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the US. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[136] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the AQM TSD. The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.

2.3.6 Visibility Modeling Methodology

The modeling platform described in this section was also used to project changes in visibility. The estimate of visibility benefits was based on the projected improvement in annual average visibility at mandatory class I federal areas. There are 156 Federally mandated Class I areas which, under the Regional Haze Rule, are required to achieve natural background visibility levels by 2064. These mandatory class I federal areas are mostly national parks, national monuments, and wilderness areas. There are currently 116 Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites (representing all 156 mandatory class I federal areas) collecting ambient $PM_{2.5}$ data at mandatory class I federal areas, but not all of these sites have complete data for 2002. For this analysis, we quantified visibility improvement at the 133 mandatory class I federal areas which have complete IMPROVE ambient data for 2002 or are represented by IMPROVE monitors with complete data.[N]

Visibility impairment is quantified in extinction units. Visibility degradation is directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient (b_{ext}) and visual range. The light extinction coefficient is based on the work of Sisler, which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil.[137]

Visual range is a measure of visibility that is inversely related to the extinction coefficient. Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. Visual range (in units of kilometers) can be calculated from b_{ext} using the formula: Visual Range (km) = 3912/b_{ext} (b_{ext} units are inverse megameters [Mm^{-1}])

The future year visibility impairment was calculated using a methodology which applies modeling results in a relative sense similar to the Speciated Modeled Attainment Test (SMAT).

In calculating visibility impairment, the extinction coefficient is made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility is calculated as the percent change in the extinction coefficient for each of the PM species (on a daily average basis). The individual daily species extinction coefficients are summed to get a daily total extinction value. The daily extinction coefficients are converted to visual range and then averaged across all days. In this way, we can calculate annual average extinction and visual range at each IMPROVE site. Subtracting the annual average control case visual range from the base case visual range gives a projected improvement in visual range (in km) at each mandatory class I federal area. This serves as the visibility input for the benefits analysis (See Chapter 6).

For visibility calculations, we are continuing to use the IMPROVE program species definitions and visibility formulas which are recommended in the draft modeling guidance. Each IMPROVE site has measurements of $PM_{2.5}$ species and therefore we do not need to estimate the species fractions in the same way that we did for FRM sites (using interpolation techniques and other assumptions concerning volatilization of species).

[N] There are 100 IMPROVE sites with complete data for 2002. Many of these sites collect data that is "representative" of other nearby unmonitored mandatory class I federal areas. There are a total of 133 mandatory class I federal areas that are represented by the 100 sites. The matching of sites to monitors is taken from "Guidance for Tracking Progress Under the Regional Haze Rule".

2.4 Air Toxics

People experience elevated risk of cancer and other noncancer health effects from exposure to air toxics. Mobile sources are responsible for a significant portion of this risk. According to the National Air Toxic Assessment (NATA) for 1999, mobile sources were responsible for 44 percent of outdoor toxic emissions and almost 50 percent of the cancer risk. Benzene is the largest contributor to cancer risk of all 133 pollutants quantitatively assessed in the 1999 NATA and mobile sources were responsible for 68 percent of benzene emissions in 1999. In response, EPA has recently finalized mobile source and fuel controls that address this public health risk.[O] Although the 1999 NATA did not quantify cancer risks associated with exposure to diesel exhaust, EPA has concluded that diesel exhaust ranks with the other emissions that the 1999 NATA suggests pose the greatest relative risk.

According to the 1999 NATA, nearly the entire U.S. population was exposed to an average concentration of air toxics that has the potential for adverse noncancer respiratory health effects. This will continue to be the case in 2030, even though toxics concentrations will be lower. Mobile sources were responsible for 74 percent of the noncancer (respiratory) risk from outdoor air toxics in 1999. The majority of this risk was from exposure to acrolein. The confidence in the RfC for acrolein is medium and confidence in NATA estimates of population noncancer hazard from ambient exposure to this pollutant is low.[138,139]

The NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. These limitations and uncertainties are discussed on the 1999 NATA website.[140] Even so, this modeling framework is very useful in identifying air toxic pollutants and sources of greatest concern, setting regulatory priorities, and informing the decision making process.

The following section provides an overview of air toxics which are associated with nonroad engines, including locomotive and marine diesel engines, and provides a discussion of the health risks associated with each air toxic.

2.4.1 Diesel Exhaust PM

Locomotive and marine diesel engines emit diesel exhaust (DE), a complex mixture comprised 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 (DPM) present in diesel exhaust consists of fine particles (< 2.5µm), including a subgroup with a large number of ultrafine particles (< 0.1 µm). These particles have large surface areas which make them an excellent medium for adsorbing organics, and their small size makes them highly respirable and able to deposit deep in the lung. Diesel PM contains small quantities of numerous mutagenic and carcinogenic compounds associated with the particles (and also organic gases). In addition, while toxic trace metals emitted by locomotive and marine diesel engines

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[O] U.S. EPA (2006) Control of Hazardous Air Pollutants from Mobile Sources. 71 FR 15804; March 29, 2006.

represent a very small portion of the national emissions of metals (less than one percent) and are a small portion of diesel PM (generally much less than one percent of diesel PM), we note that several trace metals of potential toxicological significance and persistence in the environment are emitted by diesel engines. These trace metals include chromium, manganese, mercury and nickel. In addition, small amounts of dioxins have been measured in highway engine diesel exhaust, some of which may partition into the particulate phase. Dioxins are a major health concern but diesel engines are a minor contributor to overall dioxin emissions.

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).[141] Also, there are emission differences between on-road and nonroad engines because the nonroad engines are generally of older technology. After being emitted 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.

A number of health studies have been conducted regarding diesel exhaust. These include epidemiologic studies of lung cancer in groups of workers and animal studies focusing on non-cancer effects specific to diesel exhaust exposure. Diesel exhaust PM (including the associated organic compounds which are generally high molecular weight hydrocarbon types but not the more volatile gaseous hydrocarbon compounds) is generally used as a surrogate measure for diesel exhaust.

2.4.1.1 Potential Cancer Effects of Exposure to Diesel Exhaust

Exposure to diesel exhaust is of specific concern because it has been judged by EPA to pose a lung cancer hazard for humans at environmental levels of exposure.

EPA’s 2002 final “Health Assessment Document for Diesel Engine Exhaust” (the EPA Diesel HAD) classified exposure to diesel exhaust as likely to be carcinogenic to humans by inhalation at environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[142,143] In accordance with earlier EPA guidelines, exposure to diesel exhaust would similarly be classified as probably carcinogenic to humans (Group B1).[144,145] 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 US Department of Health and Human Services) have made similar classifications.[146, 147,148,149,150] The Health Effects Institute has prepared numerous studies and reports on the potential carcinogenicity of exposure to diesel exhaust.[151,152,153] In addition many animal and bioassay/genotoxic tests have been done on diesel exhaust[154,155] and case-control and cohort studies have been conducted on railroad worker exposures to diesel exhaust from railroad engines[156,157,158] in addition to studies on truck workers.[159,160,161,162] Also, there are numerous other epidemiologic studies including some studying mine workers and fire fighters.[163,164]

More specifically, the EPA Diesel HAD states that the conclusions of the document apply to diesel exhaust in use today including both onroad and nonroad engines. The EPA

Diesel HAD acknowledges that the studies were done on engines with generally older technologies and that "there have been changes in the physical and chemical composition of some DE [diesel exhaust] emissions (onroad vehicle emissions) over time, though there is no definitive information to show that the emission changes portend significant toxicological changes." In any case, the diesel technology used for locomotive and marine diesel engines typically lags that used for onroad engines which have been subject to PM standards since 1998. Thus it is reasonable to assume that the hazards identified from older technologies may be largely applicable to locomotive and marine engines.

For the Diesel HAD, EPA reviewed 22 epidemiologic studies on the subject of the carcinogenicity of exposure to diesel exhaust in various occupations, finding increased lung cancer risk, although not always statistically significant, in 8 out of 10 cohort studies and 10 out of 12 case-control studies which covered several industries, including railroad workers. Relative risk for lung cancer, associated with exposure, ranged from 1.2 to 1.5, although a few studies show relative risks as high as 2.6. Additionally, the Diesel HAD also relied on two independent meta-analyses, which examined 23 and 30 occupational studies respectively, and found statistically significant increases of 1.33 to 1.47 in smoking-adjusted relative lung cancer risk associated with diesel exhaust. These meta-analyses demonstrate the effect of pooling many studies and in this case show the positive relationship between diesel exhaust exposure and lung cancer across a variety of diesel exhaust-exposed occupations.[165,166,167]

Retrospective health studies of railroad workers have played an important part in finding that exposure to diesel exhaust is a likely to be carcinogenic to humans by inhalation at environmental levels of exposure. Key evidence of the diesel exhaust exposure linkage to lung cancer comes from two retrospective case-control studies of railroad workers. The Garshick railroad study[168] looked at more than 55,000 railroad workers post-1959 which coincided with the widespread dieselization of the railroads. The study found that the risk of lung cancer increased with increasing duration of employment, and that the youngest workers had the highest risk of dying. The second railroad study, authored by Swanson et al.[169], found statistically significant excess risks, when adjusted for age, smoking, and race, among railroad workers employed for more than 10 years and heavy truck drivers employed for more than 20 years. In addition, a 1988 industrial hygiene study documented the increased lung cancer risks associated with different railroad worker job classifications.[170] Thirty-nine job titles were originally identified and were then collapsed, for statistical analyses, into 5 categories including clerks, signal maintainers, engineers/firers, brakers/conductors/hostlers, and shop workers. The study documented that those in closest contact with diesel exhaust exhibited the highest level of lung cancer risk. Train workers (engineers/firers etc.) had the highest risk, shop workers an intermediate level, and clerks the lowest lung cancer risk.

EPA generally derives cancer unit risk estimates to calculate population risk more precisely from exposure to carcinogens. In the simplest terms, the cancer unit risk is the increased risk associated with average lifetime exposure of 1 $\mu g/m^3$. EPA concluded in the Diesel HAD that it is not currently possible to calculate a cancer unit risk for diesel exhaust due to a variety of factors that limit the current studies, such as a lack of standard exposure metric for diesel exhaust and the absence of quantitative exposure characterization in retrospective studies.

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 possible risk range by comparing a typical environmental exposure level for highway diesel sources to a selected range of occupational exposure levels. The occupationally observed risks were then proportionally scaled according to the exposure ratios to obtain an estimate of the possible environmental risk. If the occupational and environmental exposures are similar, the environmental risk would approach the risk seen in the occupational studies whereas a much higher occupational exposure indicates that the environmental risk is lower than the occupational risk.A comparison of environmental and occupational exposures showed that for certain occupations the exposures are similar to environmental exposures while, for others, they differ by a factor of about 200 or more.

A number of calculations are involved in the exploratory analysis of a possible risk range, and these can be seen in the EPA Diesel HAD. The outcome was that environmental risks from diesel exhaust exposure could range from a low of 10^{-4} to 10^{-5} to as high as 10^{-3}, reflecting the range of occupational exposures that could be associated with the relative and absolute risk levels observed in the occupational studies. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-4} or 10^{-5}, and a zero risk from diesel exhaust exposure was not ruled out.

EPA recently assessed air toxic emissions and their associated risk (the National-Scale Air Toxics Assessment or NATA for 1996 and 1999), and we concluded that diesel exhaust ranks with other emissions that the national-scale assessment suggests pose the greatest relative risk.[171,172] This national assessment estimates average population inhalation exposures to diesel PM for nonroad as well as on-highway sources. These are the sum of ambient levels in various locations weighted by the amount of time people spend in each of the locations.

In summary, even though EPA does not have a specific carcinogenic potency with which to accurately estimate the carcinogenic impact of exposure to diesel exhaust, the likely hazard to humans together with the potential for significant environmental risks leads us to conclude that diesel exhaust emissions from locomotive and marine engines present public health issues of concern to this rule.

2.4.1.2 Other Health Effects of Diesel Exhaust

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to the EPA. The Diesel HAD established an inhalation Reference Concentration (RfC) specifically based on animal studies of diesel exhaust exposure. An RfC is defined by EPA as "an estimate of a continuous inhalation exposure to the human population, including sensitive subgroups, with uncertainty spanning perhaps an order of magnitude, which is likely to be without appreciable risks of deleterious noncancer effects during a lifetime." EPA derived the RfC from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects.[173,174,175,176] The diesel RfC is based on a "no observable adverse effect" level of 144 µg/m^3 that is further reduced by applying uncertainty factors of 3 for interspecies extrapolation and 10 for human variations in sensitivity. The resulting RfC derived in the Diesel HAD is 5 µg/m^3 for diesel exhaust as measured by diesel PM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects. There is growing evidence that exposure to diesel exhaust can exacerbate these effects, but the exposure-response data is presently lacking to derive an RfC. The EPA Diesel HAD states, "With DPM [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing DE [diesel exhaust] noncancer database to identify all of the pertinent DE-caused noncancer health hazards" (p. 9-19).

While there have been relatively few human studies associated specifically with the noncancer impact of exposure to diesel PM alone, diesel PM is a component of the ambient particles studied in numerous epidemiologic studies. The conclusion that health effects associated with ambient PM in general are relevant to diesel PM is supported by studies that specifically associate observable human noncancer health effects with exposure to diesel PM. As described in the Diesel HAD, these studies identified some of the same health effects reported for ambient PM, such as respiratory symptoms (cough, labored breathing, chest tightness, wheezing), and chronic respiratory disease (cough, phlegm, chronic bronchitis and suggestive evidence for decreases in pulmonary function). Symptoms of immunological effects such as wheezing and increased allergenicity are also seen. Studies in rodents, especially rats, show the potential for human inflammatory effects in the lung and consequential lung tissue damage from chronic diesel exhaust inhalation exposure. The Diesel HAD concludes "that acute exposure to DE [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."[177] There is also evidence for an immunologic effect such as the exacerbation of allergenic responses to known allergens and asthma-like symptoms.[178,179,180]

Exposure to diesel exhaust has been shown to cause serious noncancer effects in occupational exposure studies. One recent study[181] of a small group of railroad workers and electricians found that exposure to diesel exhaust resulted in neurobehavioral impairments in one or more areas including reaction time, balance, blink reflex latency, verbal recall, and color vision confusion indices. Pulmonary function tests also showed that 10 of the 16 workers studied had airway obstruction and another group of 10 of 16 workers had chronic bronchitis, chest pain, tightness, and hyperactive airways. Finally, a variety of studies have been published subsequent to the completion of the Diesel HAD. One study, published in 2006[182] found that railroad engineers and conductors with diesel exhaust exposure from operating trains had an increased incidence of chronic obstructive pulmonary disease (COPD) mortality. The odds of COPD mortality increased with years on the job so that those who had worked more than 16 years as an engineer or conductor after 1959 had an increased risk of 1.61 (95% confidence interval, 1.12 - 2.30). EPA is assessing the significance of this study within the context of the broader literature.

The Diesel HAD briefly summarizes health effects associated with ambient PM and discusses the $PM_{2.5}$ NAAQS. There is a much more extensive body of human data, which is also mentioned earlier in the health effects discussion for $PM_{2.5}$ (Section 2.1.2 of this RIA), 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 non-cancer and premature mortality effects of $PM_{2.5}$ as a whole.

A number of recent studies have associated living near roadways with adverse health effects. A Dutch study of a population of people 55-69 years old found that there was an elevated risk of heart and lung related mortality among populations living near high traffic roads.[183] In a review of studies of the respiratory health of people living near roadways, another publication indicated that the risk of asthma and related respiratory disease appeared elevated in people living near heavy traffic.[184] These studies offer evidence that people exposed most directly to emissions from mobile sources, including diesels, face an elevated risk of illness or death.

2.4.1.3 Ambient Levels of Diesel Exhaust PM

Because diesel PM is part of overall ambient PM and cannot be easily distinguished from overall PM, we do not have direct measurements of diesel PM in the ambient air. Diesel PM concentrations are estimated here using ambient air quality modeling based on diesel PM emission inventories.

2.4.1.3.1 *Toxics Modeling and Methods*

In addition to the general ambient PM modeling conducted for this rulemaking, diesel PM concentrations were recently estimated as part of the 1999 National-Scale Air Toxics Assessment.[185] Ambient impacts of mobile source emissions were predicted using the Assessment System for Population Exposure Nationwide (ASPEN) dispersion model.

Concentrations of diesel PM were calculated at the census tract level in the 1999 NATA. The median diesel PM concentration calculated nationwide is 0.91 $\mu g/m^3$ with levels of 1.06 $\mu g/m^3$ in urban counties and 0.43 $\mu g/m^3$ in rural counties. Table 2-6 below summarizes the distribution of ambient diesel PM concentrations at the national scale. Over half of the diesel PM and diesel exhaust organic gases can be attributed to nonroad diesels. A map of median ambient concentrations is provided in Figure 2-9. Areas with high median concentrations are clustered in the Northeast, Great Lake States, California, and the Gulf Coast States, and are also distributed throughout the rest Assessment of the U.S.

Table 2-6 Distribution of Census Tract Ambient Concentrations of Diesel PM at the National Scale in 1999 NATA[a]

	Nationwide ($\mu g/m^3$)	Urban ($\mu g/m^3$)	Rural ($\mu g/m^3$)
5th Percentile	0.22	0.33	0.08
25th Percentile	0.54	0.70	0.28
Median	0.91	1.06	0.43
75th Percentile	1.41	1.56	0.62
95th Percentile	2.91	3.21	0.96
Onroad Contribution to Mean	0.43	0.49	0.20
Nonroad Contribution to Mean	0.78	0.90	0.28

[a] This table is generated from data contained in the diesel particulate matter Microsoft Access database file found in the County-Level Ambient Concentration Summaries section of the 1999 NATA webpage (http://www.epa.gov/ttn/atw/nata1999/tables.html).

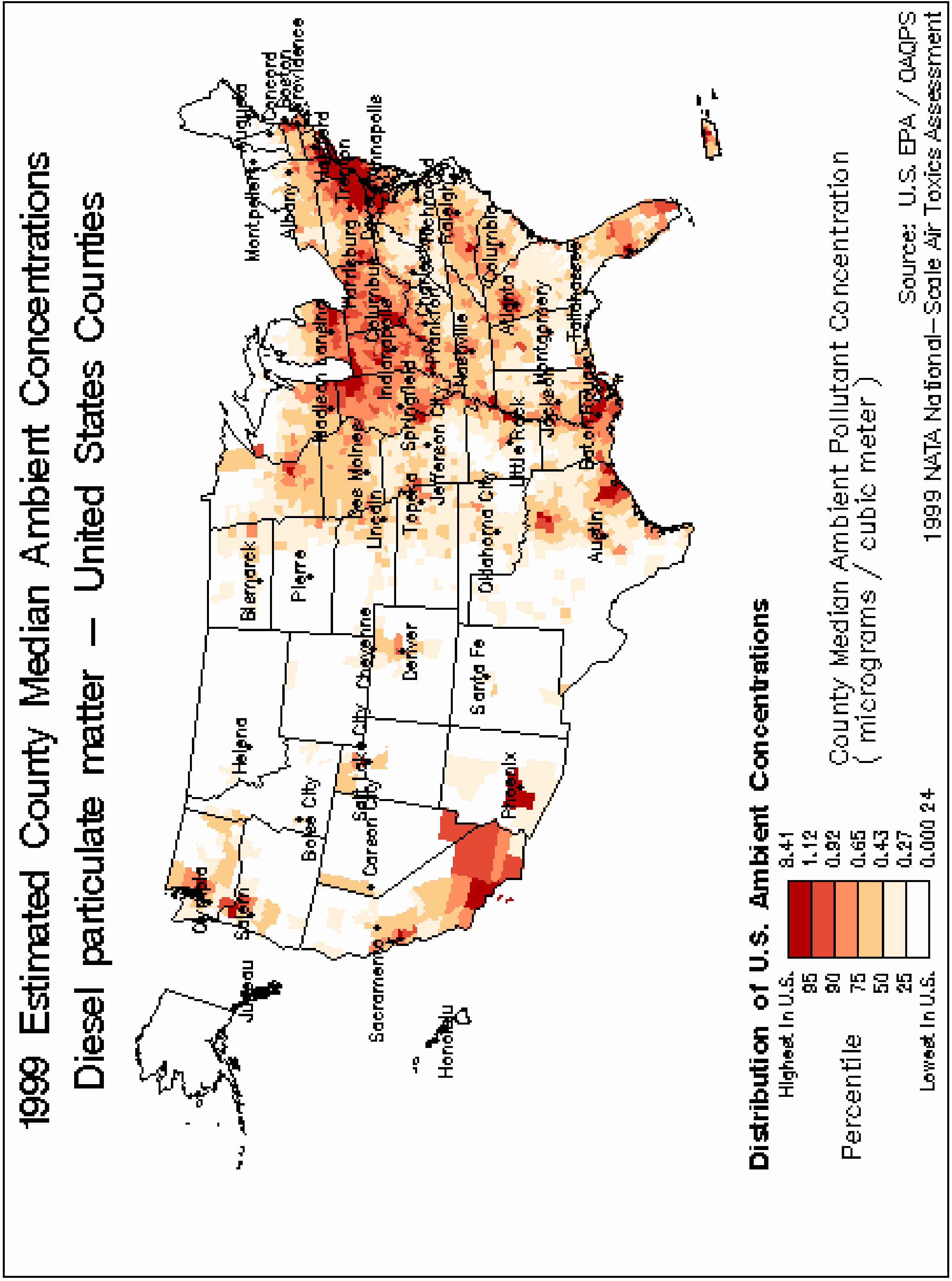


Figure 2-9 Estimated County Median Ambient Concentration of Diesel Particulate Matter

2.4.1.4 Exposure to Diesel Exhaust PM

Exposure of people to diesel exhaust depends on their various activities, the time spent in those activities, the locations where these activities occur, and the levels of diesel exhaust pollutants in those locations. The major difference between ambient levels of diesel particulate and exposure levels for diesel particulate is that exposure levels account for a person moving from location to location, the proximity to the emission source, and whether the exposure occurs in an enclosed environment.

2.4.1.4.1 *Occupational Exposures*

Occupational exposures to diesel exhaust from mobile sources, including locomotive engines and marine diesel engines, can be several orders of magnitude greater than typical exposures in the non-occupationally exposed population.

Over the years, diesel particulate exposures have been measured for a number of occupational groups resulting in a wide range of exposures from 2 to 1280 $\mu g/m^3$ for a variety of occupations. Studies have shown that miners and railroad workers typically have higher diesel exposure levels than other occupational groups studied, including firefighters, truck dock workers, and truck drivers (both short and long haul).[186] A 1988 study[187] estimated that U.S. railroad workers received an estimated occupational exposure/concentration of between 39 -191 $\mu g/m^3$ (measured as smoking adjusted respirable particles) which resulted in an equivalent environmental exposure of 8-40 $\mu g/m^3$. As discussed in the Diesel HAD, the National Institute of Occupational Safety and Health (NIOSH) has estimated a total of 1,400,000 workers are occupationally exposed to diesel exhaust from on-road and nonroad vehicles including locomotive and marine diesel engines.

2.4.1.4.2 *Elevated Concentrations and Ambient Exposures in Mobile Source-Impacted Areas*

While occupational studies indicate that those working in closest proximity to diesel exhaust experience the greatest health effects, recent studies are showing that human populations living near large diesel emission sources such as major roadways, [188] rail yards, [189] and marine ports[190] are also likely to experience greater exposure to PM and other components of diesel exhaust than the overall population, putting them at a greater health risk.

Regions immediately downwind of rail yards and marine ports may experience elevated ambient concentrations of directly-emitted $PM_{2.5}$ from diesel engines. Due to the unique nature of rail yards and marine ports, emissions from a large number of diesel engines are concentrated in a small area. Furthermore, emissions occur at or near ground level, allowing emissions of diesel engines to reach nearby receptors without fully mixing with background air.

A study conducted by the California Air Resources Board (CARB) in 2004 examined the air quality impacts of railroad operations at the J.R. Davis Rail Yard, the largest service and maintenance rail facility in the western United States.[191] The yard occupies 950 acres along a one-quarter mile wide and four mile long section of land in Roseville, CA. The study developed an emissions inventory for the facility for the year 2000 and modeled ambient concentrations of diesel PM using the ISCST3 dispersion model. The study found substantially elevated concentrations in an area 5,000 meters from the facility, with higher concentrations closer to the rail yard. Using local meteorological data, annual average contributions from the rail yard to ambient diesel PM concentrations under prevailing wind conditions were 1.74, 1.18, 0.80, and 0.25 µg/m^3 at receptors located 200, 500, 1000, and 5000 meters from the yard, respectively. Several tens of thousands of people live within the area experiencing substantial increases in annual average ambient $PM_{2.5}$ as a result of emissions from the yard. As part of an agreement between CARB and the Union Pacific Railroad and BNSF Railway, similar assessments are being prepared for 16 other large railyards. The details and results of these additional assessments can be found in their respective reports.[192]

Another study from CARB evaluated air quality impacts of diesel engine emissions within the Port of Long Beach and Los Angeles in California, one of the largest ports in the U.S.[193] Like the earlier rail yard study, the port study employed the ISCST3 dispersion model. Also using local meteorological data, annual average concentrations of diesel PM were substantially elevated over an area exceeding 200,000 acres. Because the Ports are located near heavily-populated areas, the modeling indicated that over 700,000 people lived in areas with at least 0.3 µg/m^3 of port-related diesel PM in ambient air, about 360,000 people lived in areas with at least 0.6 µg/m^3 of diesel PM, and about 50,000 people lived in areas with at least 1.5 µg/m^3 of ambient diesel PM emitted directly from the port. Figure 2-10 provides an aerial shot of the Port of Long Beach and Los Angeles in California.

Figure 2-10 Aerial Shot – Port of LA and Long Beach, California

Together these railyard and port studies highlight the substantial contribution these facilities make to ambient concentrations of diesel PM in large, densely populated areas.

The US EPA recently conducted a screening-level analysis to better understand the populations including minority, low-income, and children that are exposed to diesel particulate matter (DPM) from these facilities. The results of this study[P] are discussed here and are also available in the public docket.[194,195] In the proposal, EPA committed to finalize this study as part of an ongoing obligation to children's health and environmental justice (EJ).

This screening-level analysis focused on a representative selection of national marine ports and rail yards.[Q] Of the 47 marine ports and 37 rail yards selected, the results indicate that at least 13 million people, including a disproportionate number of low-income households, African-Americans, and Hispanics, living in the vicinity of these facilities, are being exposed to ambient DPM levels that are 2.0 μg/m^3 and 0.2 μg/m^3 above levels found in areas further from these facilities. Because those populations exposed to DPM emissions from marine ports and rail yards are more likely to be low-income and minority residents, these populations will receive a significant benefit from this rule.

With regard to children, this analysis shows that of the 13 million people living in the vicinity of the marine ports and rail yards 3.5 million are children. The age composition of the total affected population in the screening analysis matches closely with the age composition of the overall US population. However, for some individual facilities the young (0-4 years) appear to be over-represented in the affected population compared to the overall US population. Detailed results for individual harbors and rail yards are presented in the Appendices of the memorandum in the docket.

As part of this study, a computer geographic information system was used to identify the locations and boundaries of a sampling of 47 US harbor areas and 37 US rail yards and terminals, and determined the size and demographic characteristics of the populations living near these facilities. These facilities are listed in Tables 2-7 and 2-8 for harbor areas and rail yards, respectively. Figures 2-11 to 2-14 provide examples of digitized footprints of the rail yards and marine harbor areas included in this study.

[P] This type of screening-level analysis is an inexact tool and not appropriate for regulatory decision-making; it is useful in beginning to understand potential impacts and for illustrative purposes. Additionally, the emissions inventories used as inputs for the analyses are not official estimates and likely underestimate overall emissions because they are not inclusive of all emission sources at the individual ports in the sample. For example, most inventories did include emissions from ocean-going vessels (powered by Category 3 engines), as well as some commercial vessel categories, including harbor crafts, (powered by Category 1and 2 engines), cargo handling equipment, locomotives, and heavy-duty vehicles. This final rule will not address emissions from ocean-going vessels, cargo handling equipment, or heavy-duty vehicles.

[Q] The Agency selected a representative sample of the top 150 U.S. ports including coastal, inland, and Great Lake ports. In selecting a sample of rail yards the Agency identified a subset from the hundreds of rail yards operated by Class I Railroads.

Table 2-7 Marine Harbor Areas

Harbor Location
Baltimore, MD
Boston, MA
Charleston, SC
Chicago, IL
Cincinnati, OH
Cleveland, OH
Corpus Christi, TX
Detroit, MI
Duluth-Superior, MN
Freeport, TX
Gary, IN
Helena, AR
Houston, TX
Jacksonville, FL
Lake Charles, LA
Long Beach, CA
Los Angeles, CA
Louisville, KY
Miami, FL
Mobile, AL
Mount Vernon, IN
Nashville, TN
New Orleans, LA
New York, NY
Norfolk Harbor, VA
Oakland, CA
Panama City, FL
Paulsboro, NJ
Philadelphia, PA
Pittsburgh, PA

Port Arthur, TX
Port Everglades, FL
Port of Baton Rouge, LA
Port of Plaquemines, LA
Portland, ME
Portland, OR
Richmond, CA
Savannah, GA
Seattle, WA
South Louisiana, LA
St. Louis, MO
Tacoma, WA
Tampa, FL
Texas City, TX
Tulsa - Port of Catoosa, OK
Two Harbors, MN
Wilmington, NC

Table 2-8 Rail Yards and Terminals

Yard Name	Location	Railroad
Argentine	Kansas City, KS	BNSF
Avon Yard	Indianapolis, IN	CSXT
Bailey Yard	North Platte, NE	UP
Barr Yard	Chicago, IL	CSXT
Barstow Yard	Barstow, CA	BNSF
Bellevue Yard	Bellevue, OH	NS
Bensenville Yard	Bensenville, IL	CP
Blue Island Yard	Blue Island, IL	IHB
Boyles Yard	Birmingham, AL	CSXT
Buckeye Yard	Columbus, OH	CSXT
Clearing Yard	Chicago, IL	BRC
Conway Yard	Conway, PA	NS

Corwith Yard	Chicago, IL	BNSF
DeButts Yard	Chattanooga, TN	NS
Frontier Yard	Buffalo, NY	CSXT
Frontier Yard Intermodal Terminal	Buffalo, NY	CSXT
Galesburg	Galesburg, IL	BNSF
Hinkle	Hermiston, OR	UP
Inman Yard	Atlanta, GA	NS
J.R. Davis Yard	Roseville, CA	UP
Jenks Shop	North Little Rock, AR	UP
Locomotive Maintenance Facility	Alliance, NE	BNSF
Locomotive Repair Facility	Topeka, KS	BNSF
Madison Yard	East St. Louis, MO	TRRA
Moncrief Yard	Jacksonville, FL	CSXT
Philadelphia PA Railyard	Philadelphia, PA	CSXT
Pig's Eye Yard	Minneapolis, MN	CP
Proviso Yard	Chicago, IL	UP
Queensgate Yard	Cincinnati, OH	CSXT
Radnor Yard	Nashville, TN	CSXT
Rice Yard	Waycross, GA	CSXT
Schiller Park	Schiller Park, IL	CP
Selkirk Yard	Selkirk, NY	CSXT
Shaffers Crossing	Roanoke, VA	NS
Spencer Yard	Linwood, NC	NS
Stanley/Walbridge Yard	Toledo, OH	CSXT
West Colton Yard	West Colton, CA	UP

Figure 2-11 Digitized footprint of New York, NY harbor area.

Figure 2-12 Digitized footprint of Portland, OR harbor area.

Figure 2-13 Digitized footprint of Argentine Rail Yard, Kansas City, Kansas.

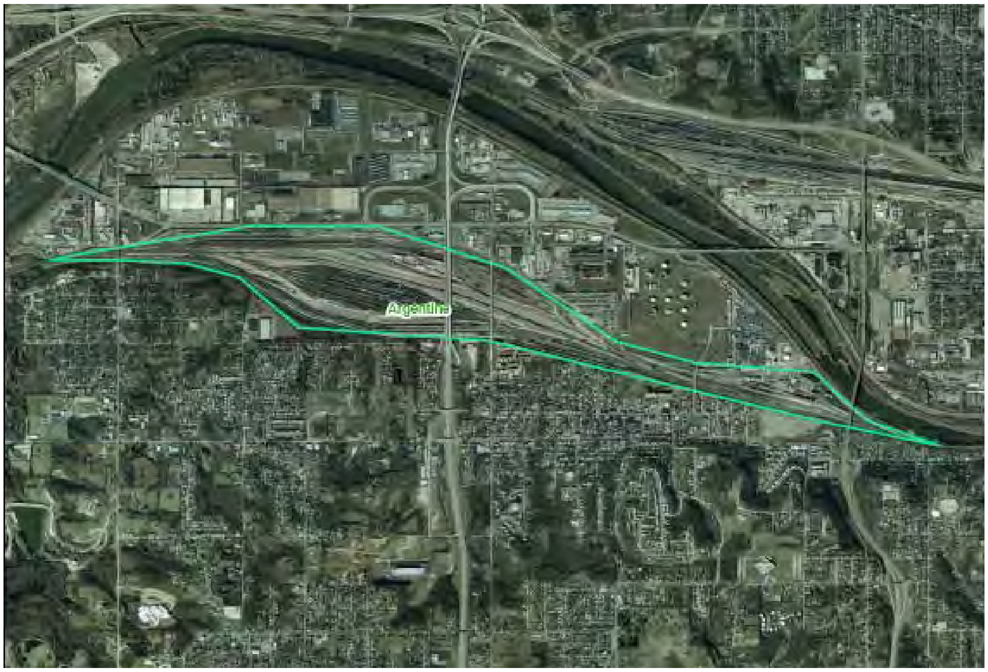
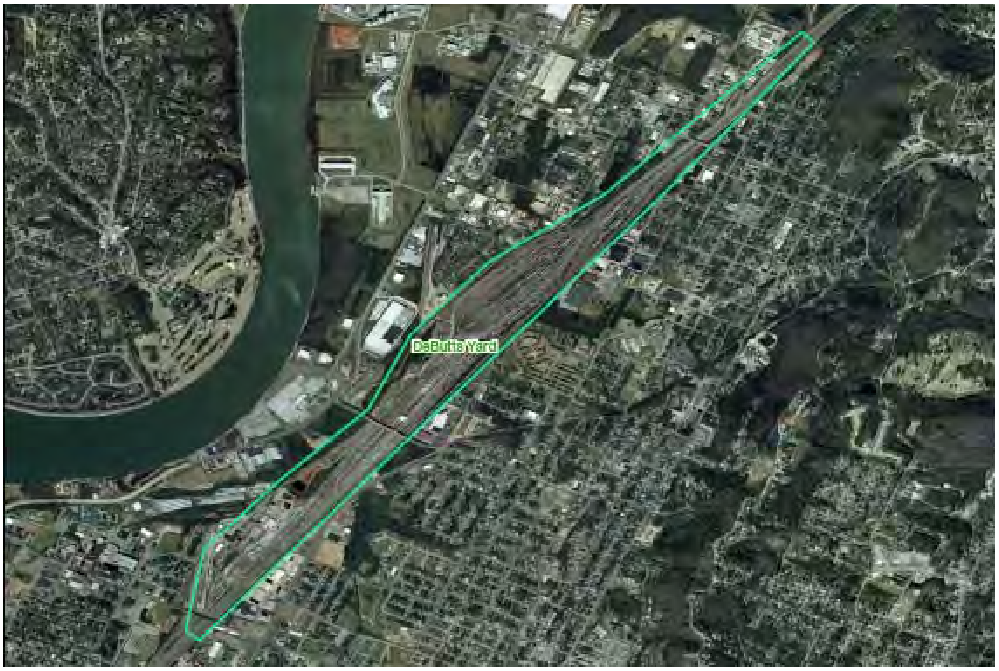


Figure 2-14. Digitized footprint of DeButts Rail Yard, Chattanooga, Tennessee.

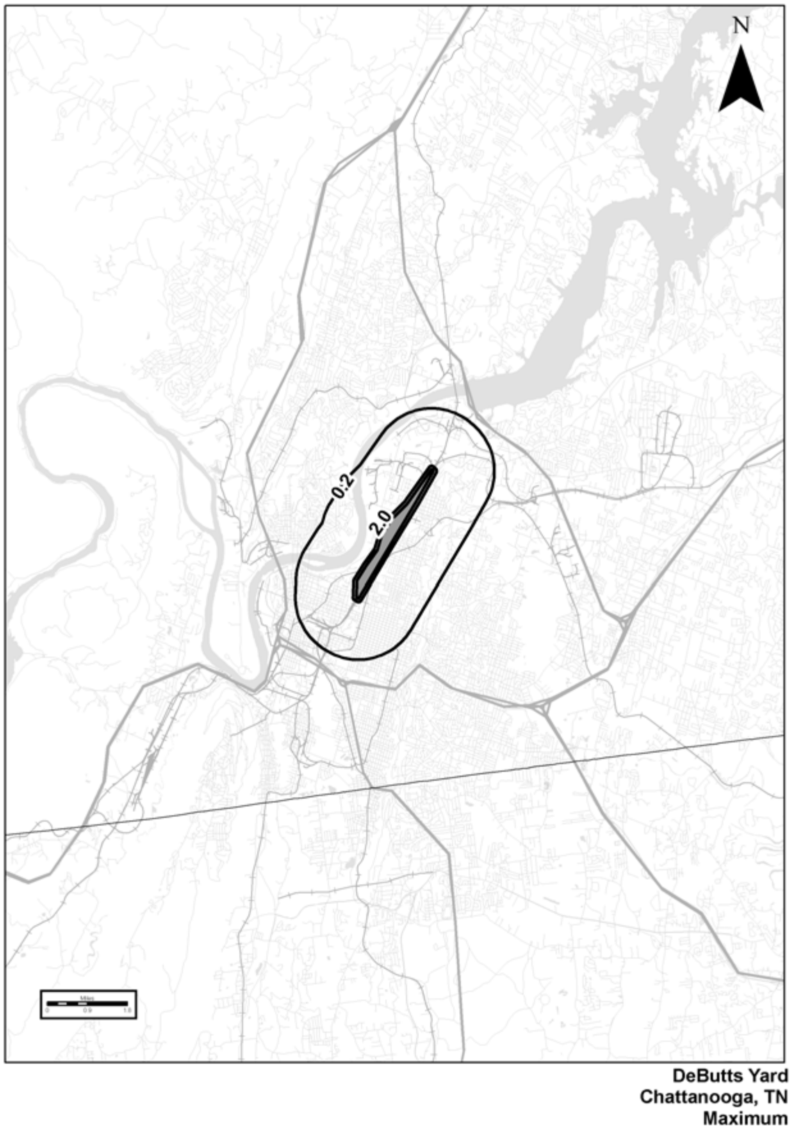


In order to better understand the populations that are living in the vicinity of rail yards and marine harbor areas and their potential exposures to DPM, DPM concentration isopleths surrounding the facilities were identified and digitized. The concentration isopleths of interest were selected to correspond to two DPM concentrations above urban background, 2.0 µg/m^3 and 0.2 µg/m^3. For marine harbor areas, the isopleths were estimated using the AERMOD air dispersion model. For rail yards and terminals, the isopleths were estimated using a process for scaling from published rail yard modeling reports. Both estimation methods are subject to important uncertainties that are discussed in the memorandum. Figures 2-15 to 2-16 provide examples of concentration isopleths surrounding the New York, NY harbor area and DeButts Rail Yard in Chattanooga, TN.

Figure 2-15 Concentration isopleths of New York, NY harbor area.

Port of New York, NY

Figure 2-16. Concentration isopleths of DeButts Rail Yard, Chattanooga, Tennessee.



The size and characteristics of populations and households that reside within the area encompassed by the two DPM concentration isopleths were determined. In addition to the total population and number of households residing within each isopleth, the demographic compositions were assessed, including age, income level, and race/ethnicity.

In summary, the population analysis suggests that for the 47 US marine ports and 37 US rail yards analyzed, at least 13 million people living in the vicinity of these facilities are being exposed to ambient DPM levels that are 2.0 µg/m^3 and 0.2 µg/m^3 above those found in areas further from these facilities.

2.4.2 Other Air Toxics—benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, POM, naphthalene

Locomotive and marine diesel engine emissions contribute to ambient levels of other air toxics known or suspected as human or animal carcinogens, or that have non-cancer health effects. Noncancer health effects can result from chronic[R], subchronic[S], or acute[T] inhalation exposures, and include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems.

These other compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. These compounds, except acetaldehyde, were identified as national or regional risk drivers in the 1999 National-Scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources. Table 2–9 provides the mobile source inventory contributions associated with these compounds.[196] The reductions in locomotive and marine diesel engine emissions in this rulemaking will help reduce exposure to these harmful substances.

Table 2-9 Mobile Source Inventory Contribution to 1999 Emissions of NATA Risk Drivers[a]

1999 NATA Risk Driver	Percent of Emissions Attributable to All Mobile Sources	Percent of Emissions Attributable to Non-road Sources
Benzene	68%	19%
1,3-Butadiene	58%	17%
Formaldehyde	47%	20%
Acrolein	25%	11%
Polycyclic organic matter (POM)[b]	5%	2%
Naphthalene	27%	6%
Diesel PM and Diesel exhaust organic gases	100%	62%

[a] This table is generated from data contained in the pollutant specific Microsoft Access database files found in the County-Level Emission Summaries section of the 1999 NATA webpage (http://www.epa.gov/ttn/atw/nata1999/tables.html).

[b] This POM inventory includes the 15 POM compounds: benzo[b]fluoranthene, benz[a]anthracene, indeno(1,2,3-c,d)pyrene, benzo[k]fluoranthene, chrysene, benzo[a]pyrene, dibenz(a,h)anthracene, anthracene, pyrene, benzo(g,h,i)perylene, fluoranthene, acenaphthylene, phenanthrene, fluorine, and acenaphthene.

[R] Chronic exposure is defined in the glossary of the Integrated Risk Information (IRIS) database (http://www.epa.gov/iris) as repeated exposure by the oral, dermal, or inhalation route for more than approximately 10 of the life span in humans (more than approximately 90 days to 2 years in typically laboratory animal species).

[S] Defined in the IRIS database as exposure to a substance spanning approximately 10 of the lifetime of an organism.

[T] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

Benzene: The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and 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.[197,198,199] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggests a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. 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.[200, 201] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[202,203] 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.[204,205, 206,207] EPA's IRIS program has not yet evaluated these new data.

1,3-Butadiene: EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[208, 209] 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; while there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 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.[210]

Formaldehyde: Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[211] EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[212,213] NCI is currently performing an update of these studies. A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[214] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoeitic cancers, but a continuing statistically significant excess in lung cancers was reported.[215]

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[216, 217,218] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde.

Based on the developments of the last decade, in 2004, the working group of the International Agency for Research on Cancer (IARC) concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals - a higher classification than previous IARC evaluations. After reviewing the currently available epidemiological evidence, the IARC (2006) characterized the human evidence for formaldehyde carcinogenicity as “sufficient,” based upon the data on nasopharyngeal cancers; the epidemiologic evidence on leukemia was characterized as “strong”.[219] EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes.

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.[220] The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[221] Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[222]

In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[223,224] Data from these studies were used by EPA to develop an inhalation reference concentration. The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

Acrolein: EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[225]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. Levels considerably lower than 1 ppm (2.3 mg/m^3) elicit subjective complaints of eye and nasal irritation and a decrease in the respiratory rate.[226,227] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein. Based on animal data, 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. This was demonstrated in mice with allergic airway-disease by comparison to non-diseased in a study of the acute respiratory irritant effects of acrolein.[228]

The Agency is currently in the process of conducting an assessment of acute exposure effects for acrolein. 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.[229]

Polycyclic Organic Matter (POM): POM is generally defined as a large class of organic compounds which have multiple benzene rings and a boiling point greater than 100 degrees Celsius. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. One of these compounds, naphthalene, is discussed separately below. Recent studies have found that maternal exposures to PAHs (a subclass of POM), 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 at age three.[230,231] EPA has not yet evaluated these recent studies.

Naphthalene: Naphthalene is found in small quantities in gasoline and diesel fuels but is primarily a product of combustion. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust and evaporative emissions from mobile sources. EPA recently released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[232] The draft reassessment recently completed external peer review.[233] Based on external peer review comments received to date, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. Once EPA evaluates public and peer reviewer comments, the document will be revised. 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.[234] 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.[235] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[236]

In addition to reducing substantial amounts of NO_x and $PM_{2.5}$ emissions from locomotive and marine diesel engines the standards being finalized today will also reduce air toxics emitted from these engines thereby helping to mitigate some of the adverse health effects associated with operation of these engines.

Appendix 2A - $PM_{2.5}$ Nonattainment

Table 2A 1997 $PM_{2.5}$ Nonattainment Areas and Populations (Data is current through October 2007 and Population Numbers are from 2000 Census Data)

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
ALABAMA				
Jackson Co	Chattanooga, AL-TN-GA	Part	16.1	1,578
Jefferson Co	Birmingham, AL	Whole	17.3	662,047
Shelby Co	Birmingham, AL	Whole	17.3	143,293
Walker Co	Birmingham, AL	Part	17.3	2,272
CALIFORNIA				
Fresno Co	San Joaquin Valley, CA	Whole	21.8	799,407
Kern Co	San Joaquin Valley, CA	Part	21.8	550,220
Kings Co	San Joaquin Valley, CA	Whole	21.8	129,461
Los Angeles Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	9,222,280
Madera Co	San Joaquin Valley, CA	Whole	21.8	123,109
Merced Co	San Joaquin Valley, CA	Whole	21.8	210,554
Orange Co	Los Angeles-South Coast Air Basin, CA	Whole	27.8	2,846,289
Riverside Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	1,194,859
San Bernardino Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	1,330,159
San Joaquin Co	San Joaquin Valley, CA	Whole	21.8	563,598
Stanislaus Co	San Joaquin Valley, CA	Whole	21.8	446,997
Tulare Co	San Joaquin Valley, CA	Whole	21.8	368,021
CONNECTICUT				
Fairfield Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	882,567
New Haven Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	824,008
DELAWARE				
New Castle Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	500,265
DISTRICT OF COLUMBIA				
Entire District	Washington, DC-MD-VA	Whole	15.8	572,059
GEORGIA				
Barrow Co	Atlanta, GA	Whole	18	46,144
Bartow Co	Atlanta, GA	Whole	18	76,019
Bibb Co	Macon, GA	Whole	15.2	153,887
Carroll Co	Atlanta, GA	Whole	18	87,268
Catoosa Co	Chattanooga, AL-TN-GA	Whole	16.1	53,282
Cherokee Co	Atlanta, GA	Whole	18	141,903

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
Clayton Co	Atlanta, GA	Whole	18	236,517
Cobb Co	Atlanta, GA	Whole	18	607,751
Coweta Co	Atlanta, GA	Whole	18	89,215
De Kalb Co	Atlanta, GA	Whole	18	665,865
Douglas Co	Atlanta, GA	Whole	18	92,174
Fayette Co	Atlanta, GA	Whole	18	91,263
Floyd Co	Rome, GA	Whole	15.6	90,565
Forsyth Co	Atlanta, GA	Whole	18	98,407
Fulton Co	Atlanta, GA	Whole	18	816,006
Gwinnett Co	Atlanta, GA	Whole	18	588,448
Hall Co	Atlanta, GA	Whole	18	139,277
Heard Co	Atlanta, GA	Part	18	170
Henry Co	Atlanta, GA	Whole	18	119,341
Monroe Co	Macon, GA	Part	15.2	950
Newton Co	Atlanta, GA	Whole	18	62,001
Paulding Co	Atlanta, GA	Whole	18	81,678
Putnam Co	Atlanta, GA	Part	18	3,088
Rockdale Co	Atlanta, GA	Whole	18	70,111
Spalding Co	Atlanta, GA	Whole	18	58,417
Walker Co	Chattanooga, AL-TN-GA	Whole	16.1	61,053
Walton Co	Atlanta, GA	Whole	18	60,687
ILLINOIS				
Cook Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	5,376,741
DuPage Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	904,161
Grundy Co	Chicago-Gary-Lake County, IL-IN	Part	17.7	6,309
Kane Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	404,119
Kendall Co	Chicago-Gary-Lake County, IL-IN	Part	17.7	28,417
Lake Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	644,356
Madison Co	St. Louis, MO-IL	Whole	17.5	258,941
Mc Henry Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	260,077
Monroe Co	St. Louis, MO-IL	Whole	17.5	27,619
Randolph Co	St. Louis, MO-IL	Part	17.5	3,627
St Clair Co	St. Louis, MO-IL	Whole	17.5	256,082
Will Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	502,266
INDIANA				

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
Clark Co	Louisville, KY-IN	Whole	16.9	96,472
Dearborn Co	Cincinnati-Hamilton, OH-KY-IN	Part	17.8	10,434
Dubois Co	Evansville, IN	Whole	16.2	39,674
Floyd Co	Louisville, KY-IN	Whole	16.9	70,823
Gibson Co	Evansville, IN	Part	16.2	3,698
Hamilton Co	Indianapolis, IN	Whole	16.7	182,740
Hendricks Co	Indianapolis, IN	Whole	16.7	104,093
Jefferson Co	Louisville, KY-IN	Part	16.9	16,770
Johnson Co	Indianapolis, IN	Whole	16.7	115,209
Lake Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	484,564
Marion Co	Indianapolis, IN	Whole	16.7	860,454
Morgan Co	Indianapolis, IN	Whole	16.7	66,689
Pike Co	Evansville, IN	Part	16.2	4,633
Porter Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	146,798
Spencer Co	Evansville, IN	Part	16.2	5,092
Vanderburgh Co	Evansville, IN	Whole	16.2	171,922
Warrick Co	Evansville, IN	Whole	16.2	52,383
KENTUCKY				
Boone Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	85,991
Boyd Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	49,752
Bullitt Co	Louisville, KY-IN	Whole	16.9	61,236
Campbell Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	88,616
Jefferson Co	Louisville, KY-IN	Whole	16.9	693,604
Kenton Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	151,464
Lawrence Co	Huntington-Ashland, WV-KY-OH	Part	17.2	1,050
MARYLAND				
Anne Arundel Co	Baltimore, MD	Whole	16.6	489,656
Baltimore (City)	Baltimore, MD	Whole	16.6	651,154
Baltimore Co	Baltimore, MD	Whole	16.6	754,292
Carroll Co	Baltimore, MD	Whole	16.6	150,897
Charles Co	Washington, DC-MD-VA	Whole	15.8	120,546
Frederick Co	Washington, DC-MD-VA	Whole	15.8	195,277
Harford Co	Baltimore, MD	Whole	16.6	218,590
Howard Co	Baltimore, MD	Whole	16.6	247,842
Montgomery Co	Washington, DC-MD-VA	Whole	15.8	873,341

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
Prince George's Co	Washington, DC-MD-VA	Whole	15.8	801,515
Washington Co	Martinsburg, WV-Hagerstown, MD	Whole	16.3	131,923
MICHIGAN				
Livingston Co	Detroit-Ann Arbor, MI	Whole	19.5	156,951
Macomb Co	Detroit-Ann Arbor, MI	Whole	19.5	788,149
Monroe Co	Detroit-Ann Arbor, MI	Whole	19.5	145,945
Oakland Co	Detroit-Ann Arbor, MI	Whole	19.5	1,194,156
St Clair Co	Detroit-Ann Arbor, MI	Whole	19.5	164,235
Washtenaw Co	Detroit-Ann Arbor, MI	Whole	19.5	322,895
Wayne Co	Detroit-Ann Arbor, MI	Whole	19.5	2,061,162
MISSOURI				
Franklin Co	St. Louis, MO-IL	Whole	17.5	93,807
Jefferson Co	St. Louis, MO-IL	Whole	17.5	198,099
St Charles Co	St. Louis, MO-IL	Whole	17.5	283,883
St Louis	St. Louis, MO-IL	Whole	17.5	348,189
St Louis Co	St. Louis, MO-IL	Whole	17.5	1,016,315
MONTANA				
Lincoln Co	Libby, MT	Part	16.2	2,626
NEW JERSEY				
Bergen Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	884,118
Burlington Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	423,394
Camden Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	508,932
Essex Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	793,633
Gloucester Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	254,673
Hudson Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	608,975
Mercer Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	350,761
Middlesex Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	750,162
Monmouth Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	615,301
Morris Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	470,212
Passaic Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	489,049
Somerset Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	297,490
Union Co	New York-N. New Jersey-	Whole	17.7	522,541

County	**Area Name**	**County NAWhole/Part**	**Design Value ($\mu g/m^3$)**	**Pop (2000)**
	Long Island, NY-NJ-CT			
New York				
Bronx Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,332,650
Kings Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	2,465,326
Nassau Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,334,544
New York Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,537,195
Orange Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	341,367
Queens Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	2,229,379
Richmond Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	443,728
Rockland Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	286,753
Suffolk Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,419,369
Westchester Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	923,459
NORTH CAROLINA				
Catawba Co	Hickory, NC	Whole	15.5	141,685
Davidson Co	Greensboro-Winston Salem-High Point, NC	Whole	15.8	147,246
Guilford Co	Greensboro-Winston Salem-High Point, NC	Whole	15.8	421,048
OHIO				
Adams Co	Huntington-Ashland, WV-KY-OH	Part	17.2	2,374
Ashtabula Co	Cleveland-Akron-Lorain, OH	Part	18.3	23,239
Belmont Co	Wheeling, WV-OH	Whole	15.7	70,226
Butler Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	332,807
Clark Co	Dayton-Springfield, OH	Whole	15.2	144,742
Clermont Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	177,977
Coshocton Co	Columbus, OH	Part	16.7	1,286
Cuyahoga Co	Cleveland-Akron-Lorain, OH	Whole	18.3	1,393,978
Delaware Co	Columbus, OH	Whole	16.7	109,989
Fairfield Co	Columbus, OH	Whole	16.7	122,759
Franklin Co	Columbus, OH	Whole	16.7	1,068,978
Gallia Co	Huntington-Ashland, WV-KY-OH	Part	17.2	3,625
Greene Co	Dayton-Springfield, OH	Whole	15.2	147,886
Hamilton Co	Cincinnati-Hamilton, OH-KY-	Whole	17.8	845,303

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
	IN			
Jefferson Co	Steubenville-Weirton, OH-WV	Whole	17.8	73,894
Lake Co	Cleveland-Akron-Lorain, OH	Whole	18.3	227,511
Lawrence Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	62,319
Licking Co	Columbus, OH	Whole	16.7	145,491
Lorain Co	Cleveland-Akron-Lorain, OH	Whole	18.3	284,664
Medina Co	Cleveland-Akron-Lorain, OH	Whole	18.3	151,095
Montgomery Co	Dayton-Springfield, OH	Whole	15.2	559,062
Portage Co	Cleveland-Akron-Lorain, OH	Whole	18.3	152,061
Scioto Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	79,195
Stark Co	Canton-Massillon, OH	Whole	17.3	378,098
Summit Co	Cleveland-Akron-Lorain, OH	Whole	18.3	542,899
Warren Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	158,383
Washington Co	Parkersburg-Marietta, WV-OH	Whole	16	63,251
PENNSYLVANIA				
Allegheny Co	Liberty-Clairton, PA	Part	21.2	21,600
Allegheny Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,260,066
Armstrong Co	Pittsburgh-Beaver Valley, PA	Part	16.9	3,691
Beaver Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	181,412
Berks Co	Reading, PA	Whole	16.4	373,638
Bucks Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	597,635
Butler Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	174,083
Cambria Co	Johnstown, PA	Whole	15.8	152,598
Chester Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	433,501
Cumberland Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	213,674
Dauphin Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	251,798
Delaware Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	550,864
Greene Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,714
Indiana Co	Johnstown, PA	Part	15.8	11,833
Lancaster Co	Lancaster, PA	Whole	17	470,658
Lawrence Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,198
Lebanon Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	120,327
Montgomery Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	750,097
Philadelphia Co	Philadelphia-Wilmington, PA-	Whole	16.2	1,517,550

County	Area Name	County NAWhole/Part	Design Value ($\mu g/m^3$)	Pop (2000)
	NJ-DE			
Washington Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	202,897
Westmoreland Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	369,993
York Co	York, PA	Whole	17	381,751
TENNESSEE				
Anderson Co	Knoxville, TN	Whole	16.4	71,330
Blount Co	Knoxville, TN	Whole	16.4	105,823
Hamilton Co	Chattanooga, AL-TN-GA	Whole	16.1	307,896
Knox Co	Knoxville, TN	Whole	16.4	382,032
Loudon Co	Knoxville, TN	Whole	16.4	39,086
Roane Co	Knoxville, TN	Part	16.4	737
VIRGINIA				
Alexandria	Washington, DC-MD-VA	Whole	15.8	128,283
Arlington Co	Washington, DC-MD-VA	Whole	15.8	189,453
Fairfax	Washington, DC-MD-VA	Whole	15.8	21,498
Fairfax Co	Washington, DC-MD-VA	Whole	15.8	969,749
Falls Church	Washington, DC-MD-VA	Whole	15.8	10,377
Loudoun Co	Washington, DC-MD-VA	Whole	15.8	169,599
Manassas	Washington, DC-MD-VA	Whole	15.8	35,135
Manassas Park	Washington, DC-MD-VA	Whole	15.8	10,290
Prince William Co	Washington, DC-MD-VA	Whole	15.8	280,813
WEST VIRGINIA				
Berkeley Co	Martinsburg, WV-Hagerstown, MD	Whole	16.3	75,905
Brooke Co	Steubenville-Weirton, OH-WV	Whole	17.8	25,447
Cabell Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	96,784
Hancock Co	Steubenville-Weirton, OH-WV	Whole	17.8	32,667
Kanawha Co	Charleston, WV	Whole	17.1	200,073
Marshall Co	Wheeling, WV-OH	Whole	15.7	35,519
Mason Co	Huntington-Ashland, WV-KY-OH	Part	17.2	2,774
Ohio Co	Wheeling, WV-OH	Whole	15.7	47,427
Pleasants Co	Parkersburg-Marietta, WV-OH	Part	16	1,675
Putnam Co	Charleston, WV	Whole	17.1	51,589
Wayne Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	42,903
Wood Co	Parkersburg-Marietta, WV-OH	Whole	16	87,986
TOTAL	**208 Counties**			88,394,361

Appendix 2B - Current 8-Hour Ozone Nonattainment Areas

Table 2B 1997 8-Hour Ozone Nonattainment Areas and Populations (Data is current through October 2007 and Population Numbers are from 2000 Census Data)

Area Name	Category/ Class	2000 Pop
Albany-Schenectady-Troy, NY	Subpart 1	923,778
Allegan Co, MI	Subpart 1	105,665
Allentown-Bethlehem-Easton, PA	Subpart 1	637,958
Amador and Calaveras Cos (Central Mtn), CA	Subpart 1	75,654
Atlanta, GA	Marginal	4,228,492
Baltimore, MD	Moderate	2,512,431
Baton Rouge, LA	Marginal	636,214
Beaumont-Port Arthur, TX	Marginal	385,090
Berkeley and Jefferson Counties, WV	Subpart 1 EAC	118,095
Boston-Lawrence-Worcester (E. MA), MA	Moderate	5,534,130
Boston-Manchester-Portsmouth(SE),NH	Moderate	696,713
Buffalo-Niagara Falls, NY	Subpart 1	1,170,111
Charlotte-Gastonia-Rock Hill, NC-SC	Moderate	1,476,564
Chattanooga, TN-GA	Subpart 1 EAC	372,264
Chicago-Gary-Lake County, IL-IN	Moderate	8,757,808
Chico, CA	Subpart 1	203,171
Cincinnati-Hamilton, OH-KY-IN	Subpart 1	1,891,518
Clearfield and Indiana Cos, PA	Subpart 1	172,987
Cleveland-Akron-Lorain, OH	Moderate	2,945,831
Columbia, SC	Subpart 1 EAC	494,518
Columbus, OH	Subpart 1	1,541,930
Dallas-Fort Worth, TX	Moderate	5,030,828
Denver-Boulder-Greeley-Ft Collins-Love., CO	Subpart 1 EAC	2,811,580
Detroit-Ann Arbor, MI	Marginal	4,932,383
Door Co, WI	Subpart 1	27,961
Erie, PA	Subpart 1	280,843
Essex Co (Whiteface Mtn), NY	Subpart 1	1,000
Fayetteville, NC	Subpart 1 EAC	302,963
Frederick Co, VA	Subpart 1 EAC	82,794
Greater Connecticut, CT	Moderate	1,543,919
Greene Co, PA	Subpart 1	40,672
Greensboro-Winston Salem-High Point, NC	Marginal EAC	1,285,879
Greenville-Spartanburg-Anderson, SC	Subpart 1 EAC	799,147
Haywood and Swain Cos (Great Smoky NP), NC	Subpart 1	288
Hickory-Morganton-Lenoir, NC	Subpart 1 EAC	309,512
Houston-Galveston-Brazoria, TX	Moderate	4,669,571
Imperial Co, CA	Marginal	142,361
Indianapolis, IN	Subpart 1	1,607,486
Jamestown, NY	Subpart 1	139,750
Jefferson Co, NY	Moderate	111,738
Johnson City-Kingsport-Bristol, TN	Subpart 1 EAC	206,611
Kern Co (Eastern Kern), CA	Subpart 1	99,251
Kewaunee Co, WI	Subpart 1	20,187
Knoxville, TN	Subpart 1	713,755
Las Vegas, NV	Subpart 1	1,348,864
Los Angeles-San Bernardino Cos(W Mojave),CA	Moderate	656,408

Area Name	Category/ Class	2000 Pop
Los Angeles South Coast Air Basin, CA	Severe 17	14,593,587
Macon, GA	Subpart 1	153,937
Manitowoc Co, WI	Subpart 1	82,887
Mariposa and Tuolumne Cos (Southern Mtn),CA	Subpart 1	71,631
Memphis, TN-AR	Marginal	948,338
Milwaukee-Racine, WI	Moderate	1,839,149
Murray Co (Chattahoochee Nat Forest), GA	Subpart 1	1,000
Nashville, TN	Subpart 1 EAC	1,097,810
Nevada Co. (Western Part), CA	Subpart 1	77,735
New York-N. New Jersey-Long Island,NY-NJ-CT	Moderate	19,634,122
Philadelphia-Wilmin-Atlantic Ci,PA-NJ-MD-DE	Moderate	7,333,475
Phoenix-Mesa, AZ	Subpart 1	3,086,045
Pittsburgh-Beaver Valley, PA	Subpart 1	2,431,087
Poughkeepsie, NY	Moderate	717,262
Providence (All RI), RI	Moderate	1,048,319
Raleigh-Durham-Chapel Hill, NC	Subpart 1	1,244,053
Riverside Co, (Coachella Valley), CA	Serious	324,750
Roanoke, VA	Subpart 1 EAC	235,932
Rochester, NY	Subpart 1	1,098,201
Sacramento Metro, CA	Serious	1,978,348
San Antonio, TX	Subpart 1 EAC	1,559,975
San Diego, CA	Subpart 1	2,813,431
San Francisco Bay Area, CA	Marginal	6,541,828
San Joaquin Valley, CA	Serious	3,191,367
Scranton-Wilkes-Barre, PA	Subpart 1	699,312
Sheboygan, WI	Moderate	112,646
Springfield (Western MA), MA	Moderate	814,967
St Louis, MO-IL	Moderate	2,504,603
State College, PA	Subpart 1	135,758
Sutter Co (Sutter Buttes), CA	Subpart 1	1
Ventura Co, CA	Moderate	753,197
Washington, DC-MD-VA	Moderate	4,452,498
Washington Co (Hagerstown), MD	Subpart 1 EAC	131,923
York, PA	Subpart 1	473,043
Youngstown-Warren-Sharon, OH-PA (PA Portion)	Subpart 1	120,293
Total (81 areas)		144,349,183

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[30] For example, see letter dated September 23, 2006 from Northeast States for Coordinated Air Use Management to Administrator Stephen L. Johnson; September 7, 2006 letter from Executive Officer of the California Air Resources Board to Acting Assistant Administrator William L. Wehrum; August 9, 2006 letter from State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials (and other organizations) to Administrator Stephen L. Johnson; January 20, 2006 letter from Executive Director, Puget Sound Clean Air Agency to Administrator Stephen L. Johnson; June 30, 2005 letter from Western Regional Air Partnership to Administrator Stephen L. Johnson.

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CHAPTER 3: Emission Inventory

This chapter presents our analysis of the emission impact of the final rule for the three source categories affected: commercial marine diesel engines, recreational marine diesel engines, and locomotives. The final control requirements include $NO_{x,}$ HC, and PM[A] emission standards for Category 1 and Category 2 commercial marine diesel engines (both above and below 37 kilowatts [kW]). New NO_x, HC, and PM emission standards would also apply to all recreational marine diesel engines and locomotives. There are no new standards for CO. In addition, there is a remanufacturing program requirement for locomotives and for selected Category 1 and Category 2 engines.

Section 3.1 describes the methodology and presents the resulting baseline and controlled inventories for commercial marine diesel engines, including the projected emission reductions from the final rule. Sections 3.2 and 3.3 present similar information for recreational marine diesel engines and locomotives, respectively. The baseline inventories represent current and future emissions with only the existing standards. The controlled inventories incorporate the new standards in the final rule. Section 3.4 follows with the total projected emission reductions from all three affected source categories. Section 3.5 and section 3.6 then describe the contribution of these source categories to national and selected local inventories, respectively. Section 3.7 concludes the chapter by describing the changes in the inputs and resulting emission inventories between the baseline and control scenarios used for the air quality modeling and the updated baseline and control scenarios in this final rule.

The inventory estimates reported in this chapter are for the 50-state geographic area. Inventories are presented for the following pollutants: particulate matter ($PM_{2.5}$ and PM_{10}), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOC), carbon monoxide (CO), and mobile source air toxics. The specific air toxics are benzene, formaldehyde, acetaldehyde, 1,3-butadiene, acrolein, napthalene, and 15 other compounds grouped together as polycyclic organic matter (POM). The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling. Inventories are provided for calendar years 2002 through 2040.

3.1 Commercial Marine Diesel Engines

This section describes the methodology and presents the resulting baseline and controlled inventories for commercial marine diesel engines, including the projected emission reductions from the final rule. Separate inventories were developed for the following commercial marine diesel engine categories: Category 1 commercial propulsion, Category 1 marine auxiliary, Category 2 commercial propulsion, less than (<) 37kW commercial propulsion, and <37kW marine auxiliary. Category 1 and 2 only include engines greater than or equal to (≥) 37kW, so it was necessary to include separate categories for those engines less than 37kW. Note that the auxiliary categories include engines used on either commercial or recreational vessels; however, given the expected small number of recreational auxiliary

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[A] PM in this document refers to PM_{10}, which are particles less than 10 microns in diameter.

engines in comparison to commercial auxiliary engines, and our inability to separate the auxiliary categories by end use, the auxiliary categories have been included in the broader commercial marine category. Category 2 marine auxiliary engines are not included here, since they are used on Category 3 ocean-going vessels that are primarily foreign-flagged and not subject to U.S. regulations. Emissions from Category 2 auxiliary engines are therefore part of the Category 3 inventories.

3.1.1 General Methodology

For the Category 1 and Category 2 commercial marine categories, inventories are estimated using spreadsheet models. Since the less than 37kW commercial marine engines are subject to existing EPA nonroad diesel regulations, emissions were estimated for this category using a special version of the NONROAD2005 model, with Source Classification Codes (SCCs) and associated inputs added for both the commercial and auxiliary engines.

The general methodology for calculating commercial marine diesel engine inventories for HC, CO, NO_x, and PM is first described. This is followed by the methodologies used to calculate fuel consumption, SO_2, VOC, $PM_{2.5}$, and air toxic inventories.

Commercial marine diesel engine inventories for HC, CO, NO_x, and PM are estimated using the equation:

Equation 3-1
$$I = (N) \times (P) \times (L) \times (A) \times (EF)$$

where each term is defined as follows:

I = the emission inventory (gram/year)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)
A = engine activity (operating hours/year)
EF = emission factor (gram/kW-hr)

Emissions are then converted and reported as short tons/year.

The average rated power, load factor, and activity inputs remain constant across all simulation years. However, populations and emission factors vary by year and age. Populations for a given base calendar year are first calculated, along with the corresponding age distribution, and then projected from that base year into the future. For most of the commercial marine diesel categories, the base year is 2002. The pollutant emission factors vary by age to account for the current and final regulations, as well as emissions deterioration. PM emission factors also have an additional adjustment to account for the in-use fuel sulfur level, which is described in more detail below.

Three variables are used to project emissions over time: the annual population growth rate, the engine median life/scrappage, and the relative deterioration rate. Collectively, these variables represent population growth, changes in the population age distribution, and emission deterioration.

Annual Population Growth Rate (percent/year). The population growth rate represents the percentage increase in the total calendar year engine population from year (n) to year (n+1). It is a compound growth rate. These growth rates vary by category. The compound growth rates are used for Category 1 and 2 engines. Since the NONROAD model uses linear growth inputs, the compound growth rates are converted to a form consistent with the NONROAD model for the less than 37kW commercial marine engines.

Engine Median Life (years) and Scrappage. The engine median life defines the length of time engines remain in service. Engines persist in the population over two median lives; during the first median life, 50 percent of the engines are scrapped, and over the second, the remaining 50 percent of the engines are scrapped. Engine median lives also vary by category. The age distribution is defined by the median life and the scrappage algorithm. For commercial marine diesel engines, the scrappage algorithm in the NONROAD model was used for all categories.[1]

Relative Deterioration Rate (percent increase in emission factor/percent median life expended). A deterioration factor can be applied to the emission factor to account for in-use deterioration. The deterioration factor varies by age and is calculated as:

Equation 3-2 $$DF = 1 + A \times \left(\frac{age}{ML} \right)$$

where each term is defined as follows:
DF = the deterioration factor for a given pollutant at a given age
A = the relative deterioration rate for a given pollutant (percent increase in emission factor/percent useful life expended)
age = the age of a specific model year group of engines in the simulation year (years)
ML = the median life of the given model year cohort (years)

A given model year cohort is represented as a fraction of the entire population. The deterioration factor adjusts the emission factor for engines in a given model year cohort in relation to the proportion of median life expended. Deterioration is linear over one median life. Following the first median life, the deteriorated emission factor is held constant over the remaining life for engines in the cohort. This is consistent with the diesel deterioration applied in the NONROAD model.[2]

Sulfur Adjustment for PM Emissions. For Tier 2 and prior engines, a sulfate adjustment is added to the PM emissions to account for differences in fuel sulfur content between the certification fuel and the episodic (calendar year) fuel, using the following equation from the NONROAD model:

Equation 3-3 $$S_{PMadj} = (FC) \times (7.1) \times (0.02247) \times \left(\frac{224}{32}\right) \times (soxdsl - soxbas) \times \left(\frac{1}{2000}\right)$$

where each term is defined as follows:
$S_{\text{PM adj}}$ = PM sulfate adjustment (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
0.02247 = fraction of fuel sulfur converted to sulfate
224/32 = grams PM sulfate/grams PM sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
soxbas = certification fuel sulfur weight fraction
2000 = conversion from lb to ton

The certification fuel sulfur term is the fuel sulfur level associated with a base emission factor in the model. If the episodic fuel sulfur level is less than the certification fuel sulfur level, the PM adjustment is negative and PM emissions will decrease.

For engines prior to Tier 2 the base fuel sulfur (soxbas) is assumed to be 3300 ppm. For Tier 2 engines less than or equal to 50 hp (37 kW) it is set at 2000 ppm, as described in the Clean Air Nonroad Diesel Rule[3], since these smaller engines are subject to the same standards as land-based diesel engines. For Tier 2 engines greater than 50 hp (37 kW) it is set at 350 ppm, based on the most recent certification data for these engines. For Tier 3 and later engines, no sulfur adjustment is applied. These engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced.

The fraction of fuel sulfur converted to sulfate is based on an analysis of nonroad engine data conducted at various fuel sulfur levels. The derivation is described in the NONROAD documentation.[4]

Estimation of fuel consumption. Annual fuel consumption is estimated using the following equation:

Equation 3-4 $$FC = \frac{(BSFC \times N \times P \times L \times A)}{(7.1 \times 454)}$$

where each term is defined as follows:
FC = fuel consumption (gallons)
BSFC = brake specific fuel consumption (g/kW-hr)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)
A = engine activity (operating hours/year)
7.1 = fuel density (lb/gal)
454 = conversion from lb to g

Estimation of SO_2 emissions. Annual SO_2 inventories are estimated using the following equation:

Equation 3-5 $$SO_2 = (FC) \times (7.1) \times (1 - 0.02247) \times \left(\frac{64}{32}\right) \times (soxdsl) \times \left(\frac{1}{2000}\right)$$

where each term is defined as follows:
SO_2 = sulfur dioxide inventory (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
(1-0.02247) = fraction of fuel sulfur converted to SO_2
64/32 = grams SO_2/grams sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
2000 = conversion from lb to ton

The calendar year fuel sulfur levels (soxdsl) were taken from the Clean Air Nonroad Diesel Rule and are reproduced in Table 3-1 below.[5]

Table 3-1 Modeled 50-State In-Use Diesel Fuel Sulfur Content for Marine Engines

Calendar Year(s)	Modeled In-Use Fuel Sulfur Content, ppm
Through 2000	2640
2001	2635
2002-2005	2637
2006	2588
2007	1332
2008-2009	435
2010	319
2011	236
2012	124
2013	44
2014	52
2015-2017	56
2018-2040	55

Estimation of VOC and $PM_{2.5}$ emissions. To estimate VOC emissions, an adjustment factor of 1.053 is applied to the HC output. Similarly, to estimate $PM_{2.5}$ emissions, an adjustment factor of 0.97 is applied to the PM_{10} output. These adjustment factors are consistent with those used in the NONROAD model[6,7] and the Clean Air Nonroad Diesel Rule.[8]

Estimation of air toxic emissions. The air toxic baseline emission inventories for this rule are based on information developed for EPA's Mobile Source Air Toxics (MSAT) final rulemaking.[9] That rule calculated air toxic emission inventories for all nonroad engines. The gaseous air toxics are correlated to VOC emissions, while POM is correlated to PM_{10} emissions. To calculate the air toxics emission inventories and reductions for this rule, the percent reductions in VOC and PM_{10} emissions will be applied to the baseline gaseous and POM air toxic inventories, respectively.

3.1.2 Baseline (Pre-Control) Inventory Development

This section describes the inputs and provides the resulting baseline inventories for commercial marine engines.

3.1.2.1 Category 1 Propulsion

The inventory inputs of base year population, average power, load factor, and activity for Category 1 commercial propulsion engines are given in Table 3-2 and Table 3-3. These inventory inputs are used to develop both baseline and control inventories. As a result, there are displacement, power density, and kilowatt subcategories, which are required to model both the current and final standards in this rule.

The current emission standards vary only by displacement (disp) category, which is expressed as liters per cylinder (L/cyl). There are four displacement categories for Category 1 engines: 1) less than 0.9 L/cyl (and power greater than or equal to 37kW), 2) greater than or equal to 0.9 L/cyl and less than 1.2 L/cyl, 3) greater than or equal to 1.2 L/cyl and less than 2.5 L/cyl, and 4) greater than or equal to 2.5 L/cyl and less than 5 L/cyl. For simplification, these will be referred to as 1) disp <0.9, 2) 0.9≤ disp <1.2, 3) 1.2≤ disp <2.5, and 4) 2.5≤ disp <5.

In order to model the final Tier 3 standards, the 2.5≤ disp <5 category is further broken out into 2.5≤ disp <3.5 and 3.5≤ disp <5 categories. The Tier 3 standards also have cut points at 75kW and 3700kW, so it was necessary to break out the disp<0.9 category into 37<kW≤75 and >75kW categories. Since there are no Category 1 engines greater than 3700kW, this cut point was not necessary to include. Finally, there are different Tier 3 standards for standard power density and high power density engines. Standard power density engines are less than 35 kW per liter (kW/L), and the high power density engines are greater than or equal to 35 kW/L. The inputs for the standard power density engines are given in Table 3-2 and the inputs for the high power density engines in Table 3-3.

The final Tier 4 standards that apply to Category 1 engines vary by the following kW categories: <600kW, 600≤kW<1000, 1000≤kW<1400, 1400≤kW<2000, 2000≤kW<3700, and ≥3700kW. As a result, these power categories were also added, with the exception of the ≥2000kW categories, since there are no Category 1 engines in this power range.

The base year populations by displacement category are generated using historical sales estimates in conjunction with the scrappage algorithm described above. Other inventory inputs that affect scrappage are load factor, activity, and median life. The historical sales estimates for calendar years 1973-2002 were obtained from Power Systems Research (PSR). These populations by displacement category were further broken out into power density and kilowatt categories using the 2002 population and engine data from PSR.

The average power estimates were population-weighted, using the 2002 engine and population data from PSR. The load factor and activity estimates were 0.45 and 943 hours per year, respectively for engines <560 kW (750 hp). These are the estimates for commercial marine propulsion engines provided by PSR. For engines >560 kW, the load factor and activity estimates used were 0.79 and 4,503 hours per year. These latter estimates were taken from the 1999 Marine Diesel FRM.[10] Higher load factors and activities were assigned to these larger engines based on information provided by the manufacturers for the previous rule, and supported by more recent discussions with the American Waterways Operators about how these larger engines typically operate.[11] This power break point is not related to the kW categories in the final standards.

Load factors for each subcategory were developed by first identifying the engines in the PSR population dataset corresponding to each subcategory. Load factors for each engine in a subcategory were assigned based on the criteria above. An average load factor for each subcategory was then obtained by weighting the individual engine load factors by population and power. A similar approach was followed to obtain activity estimates for each subcategory, with the exception that the weightings were population, power, and load factor. The average power, load factors and activities needed to be estimated using these weightings to ensure that the total inventory from this source category is correctly calculated. Note that the load factor and hours of use only varied for C1 engines in the <600 kW and 1.2<=disp<2.5 standard power density category.

The median life for all C1 propulsion engines used is 13 years, which is the estimate provided by PSR. The annual population growth rate is 1.009, which is the estimate from the Energy and Information Administration (EIA) for domestic shipping.[12]

Table 3-2 Inventory Inputs for C1 Propulsion Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 W/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	1,665	43	0.45	943	0				1,665
DISP<0.9 AND >75KW	1,102	154	0.45	943	0				1,102
0.9<=DISP<1.2	19,255	128	0.45	943	0				19,255
1.2<=DISP<2.5	23,561	294	0.51	1,905	795	781	0.79	4,503	24,356
2.5<=DISP<3.5	5,898	397	0.45	943	675	832	0.79	4,503	6,573
3.5<=DISP<5.0	205	404	0.45	943	308	748	0.79	4,503	513
TOTAL	51,687				1,777				53,464

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	1000<KW≤1400KW				>1400KW[a]				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	1,013	1,065	0.79	4,503	0				1,013
2.5<=DISP<3.5	186	1,194	0.79	4,503	0				186
3.5<=DISP<5.0	212	1,119	0.79	4,503	1,264	1,492	0.79	4,503	1,476
TOTAL	1,411				1,264				2,675

Grand Total 53,098 3,041
56,139

[a] No populations ≥2000 kW

Table 3-3 Inventory Inputs for C1 Propulsion High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	3,151	165	0.45	943	0				3,151
0.9<=DISP<1.2	21	313	0.45	943	0				21
1.2<=DISP<2.5	1,338	341	0.45	943	102	678	0.79	4,503	1,440
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	4,510				102				4,612

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	1000<KW≤1400KW				>1400KW[a]				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	214	1,176	0.79	4,503	361	1,765	0.79	4,503	575
TOTAL	214				361				575

Grand Total 4,724 463
5,187

[a] No populations ≥2000 kW

The baseline emission factors are given in Table 3-4 and Table 3-5. The emission factors are provided for three technology types: Base, Tier 1, and Tier 2. The base technology type includes all pre-control engines. Tier 1 refers to the first round of existing standards for NO_x only that began in 2000. Tier 2 refers to the second round of existing standards for $HC+NO_x$ and PM that began in 2004 to 2007, depending on the displacement category.

Table 3-4 Baseline PM_{10} and NO_x Emission Factors for C1 Propulsion Engines[a]

DISPLACEMENT CATEGORY	PM_{10} G/KW-HR			NO_X G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.54	0.54	0.23	10	9.8	5.7
0.9<=DISP<1.2	0.47	0.47	0.12	10	9.8	6.1
1.2<=DISP<2.5	0.34	0.34	0.13	10	9.8	6.0
2.5<=DISP<3.5	0.30	0.30	0.13	10	9.1	6.0
3.5<=DISP<5.0	0.30	0.30	0.13	11	9.2	6.0

[a] Deterioration is applied to the PM emission factors (EFs); see text for details. The NO_x EFs are not subject to deterioration.

Table 3-5 Baseline HC and CO Emission Factors for C1 Propulsion Engines[a]

DISPLACEMENT CATEGORY	HC G/KW-HR			CO G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.41	0.41	0.41	1.6	1.6	1.6
0.9<=DISP<1.2	0.32	0.32	0.32	1.6	1.6	0.9
1.2<=DISP<2.5	0.27	0.27	0.19	1.6	1.6	1.1
2.5<=DISP<3.5	0.27	0.27	0.19	1.6	1.6	1.1
3.5<=DISP<5.0	0.27	0.27	0.19	1.8	1.8	1.1

[a] The HC and CO emission factors (EFs) are not subject to deterioration.

The base emission factors were taken from the 1999 Marine Diesel rulemaking, and are based on emission data for uncontrolled engines.[13] For Tier 1, the NO_x emission factors were estimated using 2006 certification data. The certification data for engines using the E3 cycle[B] were sales-weighted to obtain Tier 1 NO_x emission factors for each displacement category. Since the Tier 1 standards only affect NO_x, the Tier 1 emission factors for the other pollutants are equal to the base emission factors. For Tier 2, the same 2006 certification data were used to estimate PM, NO_x, and HC emission factors.

[B] The E3 duty cycle is designated for propulsion marine diesel engines.

For C1 engines, PM is the only pollutant for which deterioration factors are applied. The relative deterioration rate (A) is 0.473, which is used for both pre-control and all regulatory tiers. As a result, the maximum PM deterioration factor is 1.473. This is consistent with the diesel deterioration assumed in the NONROAD model.[14] Not enough information is available at this time to develop deterioration factors for the other pollutants.

The certification fuel sulfur levels, which are used to estimate the PM sulfate adjustments, are 3300ppm for the Base (pre-control) technology type, and 350ppm for Tier 1 and Tier 2. The Base level was taken from the NONROAD model.[2] The Tier 1 and Tier 2 levels were estimated from reviewing the marine certification data and fuel requirements.

For calculating fuel consumption, estimates of brake specific fuel consumption (BSFC) are also required. For this analysis, a value of 213 g/kW-hr was used. This value is consistent with published estimates of BSFC and those for heavy-duty diesel engines.[15]

The resulting baseline 50-state emission inventories for Category 1 propulsion engines are given in Table 3-6.

Table 3-6 Baseline (50-State) Emissions for C1 Propulsion Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	13,328	12,928	335,561	9,488	9,010	55,303	36,201
2003	13,690	13,279	336,369	9,573	9,091	55,801	36,528
2004	13,807	13,393	332,798	9,561	9,080	55,722	36,862
2005	13,873	13,457	328,810	9,550	9,069	55,582	37,192
2006	13,872	13,456	324,900	9,540	9,060	55,450	36,827
2007	12,230	11,863	316,663	9,415	8,941	54,423	19,121
2008	10,961	10,632	308,524	9,291	8,824	53,405	6,299
2009	10,710	10,388	300,509	9,170	8,708	52,401	6,355
2010	10,304	9,995	292,651	9,051	8,595	51,414	4,705
2011	9,916	9,619	284,979	8,934	8,484	50,445	3,513
2012	9,471	9,187	277,551	8,821	8,377	49,497	1,862
2013	9,003	8,733	270,764	8,711	8,273	48,574	664
2014	8,587	8,330	264,634	8,606	8,173	47,680	799
2015	8,155	7,910	258,879	8,507	8,079	46,827	857
2016	7,718	7,487	253,538	8,415	7,992	46,023	865
2017	7,346	7,126	249,327	8,347	7,927	45,368	872
2018	7,058	6,846	246,339	8,304	7,886	44,879	879
2019	6,805	6,601	243,964	8,272	7,855	44,482	886
2020	6,632	6,433	242,764	8,269	7,852	44,301	893
2021	6,538	6,342	242,677	8,293	7,876	44,329	900
2022	6,470	6,276	242,990	8,326	7,907	44,423	907
2023	6,422	6,229	243,640	8,367	7,946	44,571	915
2024	6,388	6,197	244,563	8,414	7,990	44,760	923
2025	6,368	6,177	245,736	8,466	8,040	44,987	931
2026	6,359	6,168	247,141	8,523	8,094	45,248	939
2027	6,363	6,173	248,720	8,584	8,152	45,539	946
2028	6,381	6,190	250,474	8,649	8,214	45,861	954
2029	6,410	6,218	252,384	8,719	8,280	46,209	962
2030	6,451	6,258	254,450	8,792	8,349	46,583	970
2031	6,499	6,304	256,608	8,868	8,421	46,975	978
2032	6,552	6,356	258,851	8,946	8,495	47,385	986
2033	6,611	6,413	261,181	9,026	8,572	47,811	995
2034	6,671	6,471	263,532	9,107	8,649	48,241	1,006
2035	6,731	6,529	265,903	9,189	8,727	48,675	1,015
2036	6,791	6,588	268,297	9,272	8,805	49,114	1,023
2037	6,852	6,647	270,711	9,356	8,885	49,556	1,032
2038	6,914	6,707	273,148	9,440	8,965	50,002	1,040
2039	6,976	6,767	275,606	9,525	9,045	50,452	1,050
2040	7,039	6,828	278,086	9,610	9,127	50,906	1,059

3.1.2.2 Category 1 Auxiliary

The methodology and data sources for Category 1 marine auxiliary engines are essentially the same as those for Category 1 propulsion engines. For this source category, however, the PSR data for marine auxiliary engines and the certification data with the D2 auxiliary cycle[C] were used instead. Weighted load factor and activity values were calculated, although the load factor and hours of use only varied in the <600 kW and 1.2<=disp<2.5 standard power density category. The inventory inputs of base year population, average power, load factor, and activity for C1 auxiliary engines are given in Table 3-7 and Table 3-8. The baseline emission factors are given in Table 3-9 and Table 3-10.

For auxiliary engines, the load factor and activity estimates are 0.56 and 724 hours per year, respectively, for engines <560kW. These are the estimates for auxiliary marine engines provided by PSR. For engines >560kW, the load factor and activity estimates used are 0.65 and 2,500 hours per year, taken from the 1999 FRM.[10] The cut point of 560kW is that used for propulsion engines and is not related to the kW categories in the final standards.

The median life for all C1 auxiliary engines is 17 years, which is the estimate provided by PSR. Estimates for the annual growth rate, PM deterioration factor, certification fuel sulfur levels, and BSFC are assumed to be the same as those for C1 propulsion engines.

The resulting baseline 50-state emission inventories for Category 1 auxiliary engines are given in Table 3-11.

[C] The D2 steady-state duty cycle is designated for constant-speed engines.

Table 3-7 Inventory Inputs for C1 Auxiliary Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	9,786	44	0.56	724	0				9,786
DISP<0.9 AND >75KW	1,251	83	0.56	724	0				1,251
0.9<=DISP<1.2	11,933	109	0.56	724	0				11,933
1.2<=DISP<2.5	14,119	324	0.57	925	512	741	0.65	2,500	14,631
2.5<=DISP<3.5	785	332	0.56	724	74	882	0.65	2,500	859
3.5<=DISP<5.0	347	356	0.56	724	408	746	0.65	2,500	755
TOTAL	38,221				994				39,215

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	1000<KW≤1400				>1400KW[a]				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	14	1,194	0.65	2,500	0				14
3.5<=DISP<5.0	268	1,119	0.65	2,500	96	1,527	0.65	2,500	364
TOTAL	282				96				378

Grand Total 38,503 1,090 39,593

[a] No populations ≥2000KW

Table 3-8 Inventory Inputs for C1 Auxiliary High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	215	75	0.56	724	0				215
DISP<0.9 AND >75KW	218	141	0.56	724	0				218
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	433				0				433

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	1000<KW≤1400				>1400KW[a]				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	11	1,231	0.65	2,500	0				11
1.2<=DISP<2.5	0				39	1,531	0.65	2,500	39
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	11				39				50

Grand Total	444	39	483

[a] No populations ≥2000KW

Table 3-9 Baseline PM_{10} and NO_x Emission Factors for C1 Auxiliary Engines[a]

DISPLACEMENT CATEGORY	PM_{10} G/KW-HR			NO_X G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.84	0.84	0.23	11	9.8	5.7
0.9<=DISP<1.2	0.53	0.53	0.21	10	9.8	5.4
1.2<=DISP<2.5	0.34	0.34	0.15	10	9.8	6.1
2.5<=DISP<3.5	0.32	0.32	0.15	10	9.1	6.1
3.5<=DISP<5.0	0.30	0.30	0.15	11	9.2	6.1

[a] Deterioration is applied to the PM emission factors (EFs); see text for details. The NO_x EFs are not subject to deterioration.

Table 3-10 Baseline HC and CO Emission Factors for C1 Auxiliary Engines[a]

DISPLACEMENT CATEGORY	HC G/KW-HR			CO G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.41	0.41	0.41	2.0	2.0	1.6
0.9<=DISP<1.2	0.32	0.32	0.32	1.7	1.7	0.8
1.2<=DISP<2.5	0.27	0.27	0.21	1.5	1.5	0.9
2.5<=DISP<3.5	0.27	0.27	0.21	1.5	1.5	0.9
3.5<=DISP<5.0	0.27	0.27	0.21	1.8	1.8	0.9

[a] The HC and CO emission factors (EFs) are not subject to deterioration.

Table 3-11 Baseline (50-State) Emissions for C1 Auxiliary Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	2,714	2,632	60,641	1,767	1,678	9,624	6,553
2003	2,773	2,690	60,959	1,783	1,693	9,710	6,613
2004	2,791	2,708	60,482	1,785	1,696	9,668	6,673
2005	2,786	2,703	59,774	1,788	1,698	9,585	6,733
2006	2,769	2,686	59,073	1,791	1,700	9,503	6,667
2007	2,482	2,407	58,048	1,787	1,697	9,331	3,461
2008	2,263	2,195	57,030	1,783	1,693	9,160	1,140
2009	2,230	2,163	56,020	1,779	1,690	8,989	1,150
2010	2,170	2,105	55,022	1,776	1,686	8,820	852
2011	2,115	2,052	54,038	1,773	1,684	8,654	636
2012	2,052	1,990	53,069	1,770	1,681	8,489	337
2013	1,993	1,933	52,118	1,767	1,678	8,327	120
2014	1,952	1,893	51,185	1,765	1,676	8,167	145
2015	1,907	1,850	50,277	1,763	1,674	8,010	155
2016	1,860	1,805	49,399	1,761	1,673	7,857	157
2017	1,806	1,752	48,589	1,760	1,672	7,708	158
2018	1,746	1,693	47,849	1,759	1,671	7,563	159
2019	1,685	1,634	47,160	1,759	1,671	7,426	160
2020	1,625	1,576	46,531	1,760	1,672	7,298	162
2021	1,576	1,528	46,079	1,764	1,675	7,198	163
2022	1,543	1,497	45,840	1,771	1,681	7,134	164
2023	1,520	1,474	45,706	1,778	1,689	7,088	166
2024	1,504	1,459	45,683	1,788	1,698	7,066	167
2025	1,495	1,451	45,756	1,799	1,709	7,067	169
2026	1,489	1,445	45,875	1,811	1,720	7,077	170
2027	1,486	1,441	46,035	1,824	1,732	7,094	171
2028	1,484	1,440	46,228	1,837	1,745	7,117	173
2029	1,484	1,440	46,452	1,851	1,758	7,145	174
2030	1,486	1,441	46,703	1,865	1,771	7,178	176
2031	1,489	1,444	46,980	1,880	1,785	7,215	177
2032	1,493	1,448	47,283	1,895	1,800	7,257	179
2033	1,499	1,454	47,611	1,911	1,815	7,303	180
2034	1,506	1,461	47,962	1,927	1,830	7,353	182
2035	1,514	1,469	48,332	1,943	1,845	7,407	184
2036	1,524	1,478	48,721	1,960	1,861	7,464	185
2037	1,535	1,489	49,126	1,977	1,878	7,524	187
2038	1,547	1,501	49,553	1,995	1,894	7,588	188
2039	1,561	1,514	49,991	2,013	1,911	7,654	190
2040	1,574	1,527	50,436	2,031	1,928	7,721	192

3.1.2.3 Category 2 Propulsion

The methodology used for C2 propulsion engines is the same as that used for C1 propulsion engines, as described in section 3.1.1. For activity however, separate estimates were made for underway and idling activity, using the following equations:

Equation 3-6 Underway kW-hr = (Likely kW) x (Total Engines) x (Likely Annual Transit Days) x (Likely Load Factor) x (24 hours/day)

Equation 3-7 Idling kW-hr = (Likely kW) x (Total Engines) x (Likely Annual Idling Days) x (Minimum Load Factor) x (24 hours/day)

The Category 2 activity inputs for U.S. flag vessels by vessel type are provided in Table 3-12. These inputs were largely developed by Eastern Research Group, Inc. (ERG), under contract to EPA, with the exception of ferry vessels.[16] For ferries, a diesel fuel consumption estimate of 35,120,000 gallons for fiscal year 2004 published by the American Public Transportation Association was used, since a published value was deemed more reliable.[17] The diesel fuel gallons consumed by ferries were then converted to kW-hr using a fuel density of 7.1 lb/gallon and a brake specific fuel consumption estimate of 0.35 lb/hp-hr.

As part of its comment submittal to EPA, the American Waterways Operators (AWO) provided propulsion engine population data for towboats that can be directly compared with the estimates in this rule.[18] Table 3-13 below provides a comparison of the data submitted by AWO to that developed by ERG for towboats. The AWO data represent current populations, although the reference year was not provided. For this rule, population data for 2004 were used.

Table 3-12 Category 2 U.S. Flag Engine Activity Inputs

Vessel Type	Total C2 Engines	Utilization Rate	Equivalent C2 Engines[a]	Horsepower				Annual Transit Days			Annual Idling Days Likely	Load Factor		
				Min	Likely	Max	Total	Min	Likely	Max		Min	Likely	Max
Deep Water Cargo	92	100%	92	1,860	3,603	7,200	329,920		219		0	10%	80%	90%
Tow Boats	2,071	74%	1,533	900	2,207	7,420	3,382,781		219		0	10%	85%	90%
Ferries	218	85%	185	865	2,412	4,400	446,529	152	174	243	0	53%	68%	80%
Commercial Fishing	403	85%	342	1,000	1,924	4,313	658,293	250	271	292	81	27%	70%	80%
Great Lake	272	85%	232	518	2,505	3,600	579,847		136		0	53%	84%	84%
Coast Guard	320	100%	320	1,250	2,289	3,650	732,734	29	88	157	18	10%	80%	90%
Offshore	1,339	97%	1,303	740	2,016	7,502	2,626,265	280	299	317	66	10%	85%	87%
Research	70	100%	70	600	1,622	3,750	113,717		220		88	10%	85%	90%
Total	4,785		4,076				8,870,086	711	1,625	1,009	253			

Vessel Type	Activity (HP-HR)			Chosen Activity[b]	Reference Year(s)	Chosen Reference Year	Total U.S. Flag Activity Adjusted for 2002 Base Year	
	Underway	Idling	Total HP-HR	Total HP-HR			Total HP-HR	Total KW-HR
Deep Water Cargo	1,387,249,658	0	1,387,249,658	1,387,249,658	2004	2004	1,362,612,266	1,016,099,966
Tow Boats	15,112,911,191	0	15,112,911,191	15,112,911,191	2002-2004	2004	14,844,507,648	11,069,549,353
Ferries	1,267,998,585	0	1,267,998,585	712,434,286	2000-2004	2004	699,781,536	521,827,091
Commercial Fishing	2,995,235,100	346,591,490	3,341,826,590	3,341,826,590	2000-2004	2004	3,282,476,139	2,447,742,457
Great Lake	1,588,928,635	0	1,588,928,635	1,588,928,635	2004	2004	1,560,709,448	1,163,821,035
Coast Guard	1,238,027,096	94,962,306	1,332,989,402	1,332,989,402	2004	2004	1,309,315,665	976,356,691
Offshore	15,992,380,323	413,920,432	16,406,300,754	16,406,300,754	2005	2005	15,971,186,089	11,909,713,466
Research	510,360,006	24,016,941	534,376,948	534,376,948	2004	2004	524,886,475	391,407,845
Total	40,093,090,594	879,491,169	40,972,581,763	40,417,017,464			39,555,475,265	**29,496,517,905**

[a] Equivalent C2 Engines = (Total C2 Engines) x (Utilization Rate).

[b] Different activity used for ferries; see text.

Table 3-13 Comparison of Towboat Propulsion Engine Populations

Vessel Type	Total Propulsion Engines		Category 2 Propulsion Engines	
	ERG	AWO	ERG	AWO
Inland Towing	6,091	5,228	1,356	1,516
Coastal Towing	2,181	2,582	715	904
Total	8,272	7,810	2,071	2,420

AWO estimates that 31 percent of the towboat propulsion engines are Category 2, based on the assumption that inland towing vessels greater than 2,000 hp and coastal towing vessels greater than 3,000 hp are generally equipped with C2 engines. For the ERG analysis, a percentage of 25 percent was applied, using both vessel horsepower and hull displacement as category indicators. Applying both percentages to the AWO engine total of 7,810 engines, the range of Category 2 towboat propulsion engines is 1,952 to 2,420 engines. Since the ERG estimate falls within this range, it was retained for the final rule.

Since the reference years for the data collection varied by vessel type, it was necessary to adjust the activity estimates to the 2002 calendar year, which is the base year for this analysis. This was done by backcasting the Category 2 growth rate. The underway and idling kW-hr estimates for all vessel types were then consolidated into a single term for total kW-hr/year. For U.S. flag vessels, the total activity estimate in 2002 is 29,496,517,905 kW-hr.

The foreign-flag inputs are given in Table 3-14. All foreign-flag activity is assumed to come from off-shore vessels. These estimates were also generated by ERG. The total activity estimate is then multiplied by 0.15 to account for the fraction of time these vessels are spent in U.S. waters. The resulting foreign-flag activity in U.S. waters is estimated to be 750,291,634 kW-hr.

Table 3-14 Category 2 Foreign Flag Engine Activity Inputs

Vessel Type	Total Engines	Horsepower		Annual Transit Days	Annual Idling Days	Load Factor	Total Activity	
		Likely	Total				Total HP-HR	Total KW-HR
Deep Water Cargo Foreign	508	2,576	1,308,465	267	0	80%	6,707,716,548	5,001,994,230

Time spent in U.S. waters:	0.15
Total activity in U.S. waters:	**750,291,634 kW-hr**

The total kW-hr values for U.S. flag and foreign flag vessels were then allocated to the necessary displacement and horsepower categories, using the PSR engine data. The allocation fractions are provided in Table 3-15. For U.S. vessels, inventories were then developed by applying current and future emission factors, whereas only base (non-controlled) emission factors are used for foreign flag vessels. The same growth rate is used for each.

Table 3-15 Category 2 Activity Allocation Fractions by Displacement and Power

Displacement/kW Category	Fraction of Total Activity
5.0<=disp<15 and <600kW	0.0066
5.0<=disp<15 and 600<=kW<1000	0.0046
5.0<=disp<15 and 1000<=kW<1400	0.0191
5.0<=disp<15 and 1400<=kW<2000	0.0881
5.0<=disp<15 and 2000<=kW<3700	0.2021
5.0<=disp<15 and >=3700kW	0.2049
15.0<=disp<20.0 and <600kW	0.0000
15.0<=disp<20.0 and 600<=kW<1000	0.0000
15.0<=disp<20.0 and 1000<=kW<1400	0.0000
15.0<=disp<20.0 and 1400<=kW<2000	0.0284
15.0<=disp<20.0 and 2000<=kW<3300	0.1229
15.0<=disp<20.0 and 3300<=kW<3700	0.0000
15.0<=disp<20.0 and >=3700kW	0.3234

The activity estimates in Table 3-12 were based on estimates provided by ERG prior to release of the latest version of the report. The estimates in the latest version contain some revised inputs for deep water cargo and research vessels. Incorporating these revisions would change the total U.S. flag activity from 29,496,517,905 kW-hr to 25,665,967,253 kW-hr. ERG also provides a total activity estimate of 34,869,677,700 kW-hr, using a Monte Carlo analysis. Since the activity estimates in Table 3-12 fall between these two updated estimates, the decision was made to retain the previous activity estimates used for the NPRM.

The median life for all C2 propulsion engines is 23 years.[19] The emission factors used for all C2 propulsion engines are largely those we used for the original commercial marine rulemaking analysis.[20] The one exception to this is for Tier 1 NOx, which was updated based on an analysis of 2006 certification data. The C2 emission factors are shown in Table 3-16. Estimates for the annual growth rate, PM deterioration factor, and certification fuel sulfur levels are assumed to be the same as those for C1 propulsion engines.

Table 3-16 Baseline Emission Factors for C2 Engines (g/kW-hr)[a]

Tier	PM_{10}	NO_x	HC	CO
BASE	0.32	13.36	0.134	2.48
TIER 1	0.32	10.55	0.134	2.48
TIER 2	0.32	8.33	0.134	2.00

[a] Deterioration is applied to the PM emission factors (EFs); see text for details. The NOx, HC and CO EFs are not subject to deterioration.

The resulting baseline 50-state emission inventories for Category 2 propulsion engines are given in Table 3-17..

Table 3-17 Baseline (50-State) Emissions for C2 Propulsion Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	12,850	12,464	432,306	4,701	4,464	82,621	36,868
2003	13,112	12,719	431,973	4,743	4,504	83,364	37,193
2004	13,376	12,975	431,683	4,786	4,545	84,115	37,528
2005	13,641	13,232	431,417	4,829	4,586	84,872	37,866
2006	13,907	13,490	431,195	4,872	4,627	85,635	38,207
2007	14,174	13,748	427,380	4,916	4,669	85,621	38,550
2008	14,436	14,003	423,601	4,960	4,711	85,611	38,837
2009	14,706	14,264	419,857	5,005	4,753	85,605	39,204
2010	14,975	14,525	416,169	5,050	4,796	85,609	39,559
2011	15,245	14,787	412,537	5,096	4,839	85,621	39,920
2012	15,515	15,050	408,943	5,141	4,883	85,639	40,278
2013	15,727	15,255	405,428	5,188	4,927	85,665	39,905
2014	14,475	14,041	401,970	5,234	4,971	85,701	21,334
2015	13,635	13,226	398,593	5,281	5,016	85,746	7,888
2016	13,883	13,466	395,295	5,329	5,061	85,800	7,958
2017	13,986	13,566	392,101	5,377	5,106	85,864	6,238
2018	14,127	13,703	388,988	5,425	5,152	85,937	4,998
2019	14,228	13,801	386,000	5,474	5,199	86,020	3,277
2020	14,365	13,934	383,155	5,523	5,245	86,116	2,031
2021	14,613	14,175	380,458	5,573	5,293	86,222	2,185
2022	14,850	14,405	377,990	5,623	5,340	86,341	2,258
2023	15,059	14,607	376,313	5,674	5,388	86,475	2,279
2024	15,243	14,786	375,430	5,725	5,437	86,626	2,299
2025	15,423	14,960	374,784	5,777	5,486	86,790	2,319
2026	15,599	15,131	374,343	5,829	5,535	86,974	2,339
2027	15,772	15,299	374,086	5,881	5,585	87,178	2,359
2028	15,943	15,465	374,039	5,934	5,635	87,406	2,379
2029	16,114	15,630	374,219	5,987	5,686	87,672	2,399
2030	16,283	15,794	375,126	6,041	5,737	88,078	2,421
2031	16,451	15,957	376,727	6,096	5,789	88,623	2,442
2032	16,618	16,120	378,567	6,150	5,841	89,207	2,463
2033	16,786	16,282	380,573	6,206	5,893	89,820	2,485
2034	16,952	16,444	382,749	6,262	5,946	90,457	2,507
2035	17,119	16,605	385,076	6,318	6,000	91,119	2,529
2036	17,286	16,767	387,519	6,375	6,054	91,799	2,551
2037	17,453	16,929	390,097	6,432	6,108	92,500	2,573
2038	17,620	17,091	392,794	6,490	6,163	93,219	2,595
2039	17,787	17,253	395,609	6,549	6,219	93,956	2,618
2040	17,954	17,416	398,527	6,607	6,275	94,707	2,641

3.1.2.4 Under 37 kW Propulsion and Auxiliary

Category 1 commercial marine engines are defined as being greater than or equal to (≥) 37kW and less than (<) 5.0 liters/cylinder; however, there are commercial marine engines <37kW. The majority of these small power engines are used as auxiliary engines, although there are some propulsion engines that fall into this category. Commercial marine engines <37kW are covered under this proposal; therefore, inventories have been estimated.

Emissions were estimated using a special version of the NONROAD2005 model, with Source Classification Codes (SCCs) and associated inputs added for both the commercial and auxiliary engines. An SCC of 2280002030 was assigned to the <37kW propulsion engines, with an SCC of 2280002040 assigned to the <37kW auxiliary engines.

The inventory inputs of base year population, average power, load factor, activity, and median life are given in Table 3-18 below. These inputs were generated using the same methodology and data sources as the C1 propulsion and C1 auxiliary categories. Horsepower (hp) is used as the unit for power in the NONROAD model, so the inputs for power and emission factors are hp and g/hp-hr, respectively. The 2002 base year populations are assigned to one or more of the following hp categories in NONROAD: 0-11, 11-16, 16-25, 25-40, and 40-50. The propulsion engines all fall within the 25-40hp category, whereas there are auxiliary engines in each hp category. The average power values in the table below are population-weighted estimates.

Table 3-18 Inventory Inputs for <37kW Commercial Marine Diesel Engines

INPUTS	PROPULSION	AUXILIARY
2002 POPULATION	1,232	67,708
AVG HP	34.8	24.9
LOAD FACTOR	0.45	0.56
ACTIVITY, HOURS	943	724
MEDIAN LIFE, YEARS	13	17

The baseline emission factors are given in Table 3-19 and Table 3-20. These engines are subject to EPA nonroad diesel regulations that have established two tiers of emission standards.[21] Tier 1 phased in from 1999-2000, depending on the horsepower category, with Tier 2 phased in from 2004-2005. The "Base" entries in the tables refer to emissions from pre-controlled engines. These emission factors are used for both propulsion and auxiliary engines.

Table 3-19 Baseline PM_{10} and NO_x Emission Factors and Deterioration Factors for <37kW Commercial Marine Diesel Engines

HP RANGE	PM_{10} G/HP-HR			NO_X G/HP-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
0-11	1.00	0.45	0.38	10.00	5.23	4.39
11-16	0.90	0.27	0.19	8.50	4.44	3.63
16-25	0.90	0.27	0.19	8.50	4.44	3.63
25-50	0.80	0.34	0.23	6.90	4.73	3.71
DF ("A")	0.473	0.473	0.473	0.024	0.024	0.009

Table 3-20 Baseline HC and CO Emission Factors and Deterioration Factors for <37kW Commercial Marine Diesel Engines

HP RANGE	HC G/HP-HR			CO G/HP-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
0-11	1.50	0.76	0.68	5.00	4.11	4.11
11-16	1.70	0.44	0.21	5.00	2.16	2.16
16-25	1.70	0.44	0.21	5.00	2.16	2.16
25-50	1.80	0.28	0.54	5.00	1.53	1.53
DF ("A")	0.047	0.036	0.034	0.185	0.101	0.101

The emission factors for the base and Tier 1 technology types are consistent with those used in the NONROAD model.[22] Tier 2 emission factors were estimated using nonroad engine certification data. The deterioration factors by pollutant and technology type are also given in the tables above. The deterioration factors are those used for diesel engines in the NONROAD model.[23]

The certification fuel sulfur levels are 3300ppm for the base and Tier 1 technology type and 350ppm for Tier 2. Brake specific fuel consumption (BSFC) values were taken from the NONROAD model and are 0.408 lb/hp-hr for all hp categories.[24] The compound population growth rate is 1.009, which is the growth rate used for all commercial diesel engines. Since the NONROAD model uses linear growth inputs, the compound growth rates are converted to a form consistent with the NONROAD model for this category.

The resulting baseline 50-state emission inventories for <37kW commercial marine engines (propulsion and auxiliary combined) are given in Table 3-21.

Table 3-21 Baseline (50-State) Emissions for <37kW Commercial Marine Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	728	706	5,517	1,273	1,209	3,783	731
2003	710	689	5,448	1,222	1,161	3,680	738
2004	692	671	5,350	1,179	1,120	3,576	745
2005	671	651	5,229	1,128	1,071	3,460	752
2006	648	629	5,101	1,075	1,021	3,339	745
2007	596	578	4,973	1,022	970	3,216	387
2008	551	534	4,846	969	920	3,093	128
2009	526	511	4,719	916	870	2,970	129
2010	499	484	4,594	864	821	2,846	95
2011	472	458	4,472	813	772	2,724	71
2012	444	431	4,351	763	725	2,603	38
2013	417	404	4,234	715	679	2,484	14
2014	392	381	4,120	668	634	2,369	16
2015	368	357	4,011	624	592	2,259	18
2016	348	337	3,917	588	559	2,170	18
2017	332	322	3,846	564	535	2,109	18
2018	320	311	3,790	546	518	2,063	18
2019	310	301	3,744	531	504	2,027	18
2020	301	292	3,704	519	493	1,997	18
2021	294	285	3,675	507	482	1,972	18
2022	288	279	3,659	497	472	1,952	18
2023	284	275	3,654	491	466	1,940	19
2024	280	272	3,654	485	461	1,932	19
2025	278	269	3,658	481	457	1,926	19
2026	276	268	3,670	479	455	1,926	19
2027	275	267	3,685	478	454	1,929	19
2028	275	267	3,703	478	454	1,934	19
2029	275	267	3,723	478	454	1,942	20
2030	275	267	3,746	479	455	1,952	20
2031	276	268	3,771	481	457	1,963	20
2032	278	269	3,798	484	460	1,977	20
2033	279	271	3,828	488	463	1,992	20
2034	282	273	3,859	492	467	2,009	21
2035	284	275	3,891	496	471	2,026	21
2036	286	278	3,924	500	475	2,044	21
2037	289	280	3,958	504	479	2,061	21
2038	291	282	3,992	509	483	2,079	21
2039	294	285	4,026	513	487	2,097	21
2040	296	287	4,061	517	491	2,115	22

3.1.2.5 Commercial Marine Diesel Baseline Inventory Summary

3.1.2.5.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 3-22 thru Table 3-27 present the resulting 50-state consolidated commercial marine baseline inventories by pollutant and category, for calendar years 2002-2040.

3.1.2.5.2 Air Toxics Emissions

The baseline air toxics inventories for the consolidated commercial marine diesel engines were taken from the Mobile Source Air Toxics Rule (MSAT)[25] and are provided in Table 3-28. Inventories are provided for calendar years 1999, 2010, 2015, 2020, and 2030. The air toxics inventories were developed independently and prior to this final rule development. The purpose of presenting these inventories is to show the incidental hazardous air pollutant (HAP) reductions from this rule.

Table 3-22 Baseline (50-State) PM_{10} Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	13,328	2,714	16,041	12,850	728	29,619
2003	13,690	2,773	16,463	13,112	710	30,285
2004	13,807	2,791	16,598	13,376	692	30,666
2005	13,873	2,786	16,659	13,641	671	30,972
2006	13,872	2,769	16,641	13,907	648	31,196
2007	12,230	2,482	14,712	14,174	596	29,481
2008	10,961	2,263	13,224	14,436	551	28,211
2009	10,710	2,230	12,940	14,706	526	28,172
2010	10,304	2,170	12,474	14,975	499	27,948
2011	9,916	2,115	12,031	15,245	472	27,748
2012	9,471	2,052	11,522	15,515	444	27,482
2013	9,003	1,993	10,996	15,727	417	27,140
2014	8,587	1,952	10,539	14,475	392	25,406
2015	8,155	1,907	10,062	13,635	368	24,066
2016	7,718	1,860	9,579	13,883	348	23,809
2017	7,346	1,806	9,152	13,986	332	23,470
2018	7,058	1,746	8,804	14,127	320	23,250
2019	6,805	1,685	8,490	14,228	310	23,028
2020	6,632	1,625	8,257	14,365	301	22,923
2021	6,538	1,576	8,114	14,613	294	23,021
2022	6,470	1,543	8,013	14,850	288	23,151
2023	6,422	1,520	7,942	15,059	284	23,284
2024	6,388	1,504	7,893	15,243	280	23,416
2025	6,368	1,495	7,864	15,423	278	23,564
2026	6,359	1,489	7,849	15,599	276	23,724
2027	6,363	1,486	7,849	15,772	275	23,897
2028	6,381	1,484	7,865	15,943	275	24,083
2029	6,410	1,484	7,895	16,114	275	24,283
2030	6,451	1,486	7,937	16,283	275	24,495
2031	6,499	1,489	7,988	16,451	276	24,715
2032	6,552	1,493	8,045	16,618	278	24,941
2033	6,611	1,499	8,110	16,786	279	25,175
2034	6,671	1,506	8,177	16,952	282	25,411
2035	6,731	1,514	8,245	17,119	284	25,648
2036	6,791	1,524	8,315	17,286	286	25,887
2037	6,852	1,535	8,387	17,453	289	26,129
2038	6,914	1,547	8,461	17,620	291	26,372
2039	6,976	1,561	8,537	17,787	294	26,617
2040	7,039	1,574	8,613	17,954	296	26,864

Table 3-23 Baseline (50-State) $PM_{2.5}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	12,928	2,632	15,560	12,464	706	28,730
2003	13,279	2,690	15,969	12,719	689	29,377
2004	13,393	2,708	16,100	12,975	671	29,746
2005	13,457	2,703	16,159	13,232	651	30,042
2006	13,456	2,686	16,142	13,490	629	30,260
2007	11,863	2,407	14,270	13,748	578	28,596
2008	10,632	2,195	12,827	14,003	534	27,364
2009	10,388	2,163	12,552	14,264	511	27,327
2010	9,995	2,105	12,100	14,525	484	27,109
2011	9,619	2,052	11,670	14,787	458	26,916
2012	9,187	1,990	11,177	15,050	431	26,657
2013	8,733	1,933	10,666	15,255	404	26,326
2014	8,330	1,893	10,223	14,041	381	24,644
2015	7,910	1,850	9,760	13,226	357	23,344
2016	7,487	1,805	9,291	13,466	337	23,095
2017	7,126	1,752	8,878	13,566	322	22,766
2018	6,846	1,693	8,539	13,703	311	22,553
2019	6,601	1,634	8,235	13,801	301	22,337
2020	6,433	1,576	8,009	13,934	292	22,236
2021	6,342	1,528	7,871	14,175	285	22,330
2022	6,276	1,497	7,773	14,405	279	22,457
2023	6,229	1,474	7,703	14,607	275	22,585
2024	6,197	1,459	7,656	14,786	272	22,714
2025	6,177	1,451	7,628	14,960	269	22,857
2026	6,168	1,445	7,613	15,131	268	23,012
2027	6,173	1,441	7,614	15,299	267	23,180
2028	6,190	1,440	7,629	15,465	267	23,361
2029	6,218	1,440	7,658	15,630	267	23,555
2030	6,258	1,441	7,699	15,794	267	23,760
2031	6,304	1,444	7,748	15,957	268	23,973
2032	6,356	1,448	7,804	16,120	269	24,193
2033	6,413	1,454	7,867	16,282	271	24,420
2034	6,471	1,461	7,932	16,444	273	24,648
2035	6,529	1,469	7,998	16,605	275	24,879
2036	6,588	1,478	8,066	16,767	278	25,111
2037	6,647	1,489	8,136	16,929	280	25,345
2038	6,707	1,501	8,207	17,091	282	25,581
2039	6,767	1,514	8,281	17,253	285	25,819
2040	6,828	1,527	8,355	17,416	287	26,058

Table 3-24 Baseline (50-State) NO$_x$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	335,561	60,641	396,202	432,306	5,517	834,025
2003	336,369	60,959	397,328	431,973	5,448	834,749
2004	332,798	60,482	393,280	431,683	5,350	830,313
2005	328,810	59,774	388,583	431,417	5,229	825,229
2006	324,900	59,073	383,973	431,195	5,101	820,269
2007	316,663	58,048	374,710	427,380	4,973	807,063
2008	308,524	57,030	365,554	423,601	4,846	794,001
2009	300,509	56,020	356,529	419,857	4,719	781,105
2010	292,651	55,022	347,673	416,169	4,594	768,436
2011	284,979	54,038	339,017	412,537	4,472	756,026
2012	277,551	53,069	330,621	408,943	4,351	743,915
2013	270,764	52,118	322,882	405,428	4,234	732,544
2014	264,634	51,185	315,819	401,970	4,120	721,910
2015	258,879	50,277	309,156	398,593	4,011	711,760
2016	253,538	49,399	302,937	395,295	3,917	702,150
2017	249,327	48,589	297,916	392,101	3,846	693,862
2018	246,339	47,849	294,188	388,988	3,790	686,966
2019	243,964	47,160	291,123	386,000	3,744	680,867
2020	242,764	46,531	289,295	383,155	3,704	676,154
2021	242,677	46,079	288,756	380,458	3,675	672,889
2022	242,990	45,840	288,831	377,990	3,659	670,480
2023	243,640	45,706	289,346	376,313	3,654	669,313
2024	244,563	45,683	290,245	375,430	3,654	669,329
2025	245,736	45,756	291,492	374,784	3,658	669,934
2026	247,141	45,875	293,016	374,343	3,670	671,029
2027	248,720	46,035	294,755	374,086	3,685	672,525
2028	250,474	46,228	296,703	374,039	3,703	674,445
2029	252,384	46,452	298,836	374,219	3,723	676,778
2030	254,450	46,703	301,153	375,126	3,746	680,025
2031	256,608	46,980	303,588	376,727	3,771	684,087
2032	258,851	47,283	306,134	378,567	3,798	688,500
2033	261,181	47,611	308,792	380,573	3,828	693,193
2034	263,532	47,962	311,494	382,749	3,859	698,103
2035	265,903	48,332	314,236	385,076	3,891	703,203
2036	268,297	48,721	317,017	387,519	3,924	708,460
2037	270,711	49,126	319,838	390,097	3,958	713,892
2038	273,148	49,553	322,701	392,794	3,992	719,486
2039	275,606	49,991	325,597	395,609	4,026	725,233
2040	278,086	50,436	328,522	398,527	4,061	731,111

Table 3-25 Baseline (50-State) VOC Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	9,488	1,767	11,255	4,701	1,273	17,229
2003	9,573	1,783	11,356	4,743	1,222	17,321
2004	9,561	1,785	11,346	4,786	1,179	17,311
2005	9,550	1,788	11,338	4,829	1,128	17,295
2006	9,540	1,791	11,331	4,872	1,075	17,278
2007	9,415	1,787	11,202	4,916	1,022	17,140
2008	9,291	1,783	11,074	4,960	969	17,003
2009	9,170	1,779	10,949	5,005	916	16,870
2010	9,051	1,776	10,826	5,050	864	16,741
2011	8,934	1,773	10,707	5,096	813	16,615
2012	8,821	1,770	10,591	5,141	763	16,495
2013	8,711	1,767	10,479	5,188	715	16,381
2014	8,606	1,765	10,371	5,234	668	16,273
2015	8,507	1,763	10,270	5,281	624	16,175
2016	8,415	1,761	10,176	5,329	588	16,094
2017	8,347	1,760	10,107	5,377	564	16,048
2018	8,304	1,759	10,063	5,425	546	16,034
2019	8,272	1,759	10,031	5,474	531	16,036
2020	8,269	1,760	10,029	5,523	519	16,071
2021	8,293	1,764	10,057	5,573	507	16,137
2022	8,326	1,771	10,097	5,623	497	16,218
2023	8,367	1,778	10,145	5,674	491	16,310
2024	8,414	1,788	10,202	5,725	485	16,412
2025	8,466	1,799	10,265	5,777	481	16,523
2026	8,523	1,811	10,334	5,829	479	16,642
2027	8,584	1,824	10,408	5,881	478	16,767
2028	8,649	1,837	10,487	5,934	478	16,898
2029	8,719	1,851	10,570	5,987	478	17,035
2030	8,792	1,865	10,657	6,041	479	17,178
2031	8,868	1,880	10,748	6,096	481	17,325
2032	8,946	1,895	10,841	6,150	484	17,476
2033	9,026	1,911	10,937	6,206	488	17,631
2034	9,107	1,927	11,034	6,262	492	17,788
2035	9,189	1,943	11,133	6,318	496	17,947
2036	9,272	1,960	11,232	6,375	500	18,107
2037	9,356	1,977	11,333	6,432	504	18,269
2038	9,440	1,995	11,435	6,490	509	18,433
2039	9,525	2,013	11,537	6,549	513	18,599
2040	9,610	2,031	11,641	6,607	517	18,766

Table 3-26 Baseline (50-State) CO Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	55,303	9,624	64,927	82,621	3,783	151,331
2003	55,801	9,710	65,511	83,364	3,680	152,556
2004	55,722	9,668	65,390	84,115	3,576	153,080
2005	55,582	9,585	65,167	84,872	3,460	153,499
2006	55,450	9,503	64,954	85,635	3,339	153,928
2007	54,423	9,331	63,754	85,621	3,216	152,591
2008	53,405	9,160	62,565	85,611	3,093	151,269
2009	52,401	8,989	61,391	85,605	2,970	149,966
2010	51,414	8,820	60,235	85,609	2,846	148,690
2011	50,445	8,654	59,099	85,621	2,724	147,444
2012	49,497	8,489	57,986	85,639	2,603	146,227
2013	48,574	8,327	56,901	85,665	2,484	145,050
2014	47,680	8,167	55,847	85,701	2,369	143,917
2015	46,827	8,010	54,837	85,746	2,259	142,842
2016	46,023	7,857	53,880	85,800	2,170	141,851
2017	45,368	7,708	53,076	85,864	2,109	141,049
2018	44,879	7,563	52,443	85,937	2,063	140,443
2019	44,482	7,426	51,908	86,020	2,027	139,954
2020	44,301	7,298	51,599	86,116	1,997	139,712
2021	44,329	7,198	51,527	86,222	1,972	139,720
2022	44,423	7,134	51,557	86,341	1,952	139,851
2023	44,571	7,088	51,659	86,475	1,940	140,073
2024	44,760	7,066	51,827	86,626	1,932	140,384
2025	44,987	7,067	52,054	86,790	1,926	140,771
2026	45,248	7,077	52,325	86,974	1,926	141,226
2027	45,539	7,094	52,633	87,178	1,929	141,740
2028	45,861	7,117	52,978	87,406	1,934	142,318
2029	46,209	7,145	53,354	87,672	1,942	142,968
2030	46,583	7,178	53,761	88,078	1,952	143,791
2031	46,975	7,215	54,191	88,623	1,963	144,776
2032	47,385	7,257	54,642	89,207	1,977	145,825
2033	47,811	7,303	55,114	89,820	1,992	146,926
2034	48,241	7,353	55,595	90,457	2,009	148,060
2035	48,675	7,407	56,082	91,119	2,026	149,227
2036	49,114	7,464	56,577	91,799	2,044	150,419
2037	49,556	7,524	57,079	92,500	2,061	151,640
2038	50,002	7,588	57,589	93,219	2,079	152,887
2039	50,452	7,654	58,105	93,956	2,097	154,158
2040	50,906	7,721	58,627	94,707	2,115	155,449

Table 3-27 Baseline (50-State) SO_2 Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	36,201	6,553	42,754	36,868	731	80,353
2003	36,528	6,613	43,141	37,193	738	81,073
2004	36,862	6,673	43,535	37,528	745	81,808
2005	37,192	6,733	43,925	37,866	752	82,543
2006	36,827	6,667	43,493	38,207	745	82,445
2007	19,121	3,461	22,583	38,550	387	61,520
2008	6,299	1,140	7,440	38,837	128	46,404
2009	6,355	1,150	7,506	39,204	129	46,838
2010	4,705	852	5,557	39,559	95	45,212
2011	3,513	636	4,148	39,920	71	44,139
2012	1,862	337	2,199	40,278	38	42,515
2013	664	120	784	39,905	14	40,702
2014	799	145	943	21,334	16	22,293
2015	857	155	1,012	7,888	18	8,917
2016	865	157	1,021	7,958	18	8,997
2017	872	158	1,030	6,238	18	7,286
2018	879	159	1,038	4,998	18	6,054
2019	886	160	1,046	3,277	18	4,342
2020	893	162	1,055	2,031	18	3,104
2021	900	163	1,063	2,185	18	3,267
2022	907	164	1,072	2,258	18	3,348
2023	915	166	1,081	2,279	19	3,378
2024	923	167	1,090	2,299	19	3,408
2025	931	169	1,099	2,319	19	3,437
2026	939	170	1,109	2,339	19	3,466
2027	946	171	1,118	2,359	19	3,496
2028	954	173	1,127	2,379	19	3,526
2029	962	174	1,136	2,399	20	3,555
2030	970	176	1,146	2,421	20	3,586
2031	978	177	1,155	2,442	20	3,617
2032	986	179	1,165	2,463	20	3,649
2033	995	180	1,175	2,485	20	3,680
2034	1,006	182	1,188	2,507	21	3,716
2035	1,015	184	1,198	2,529	21	3,748
2036	1,023	185	1,208	2,551	21	3,780
2037	1,032	187	1,218	2,573	21	3,812
2038	1,040	188	1,228	2,595	21	3,845
2039	1,050	190	1,240	2,618	21	3,880
2040	1,059	192	1,251	2,641	22	3,913

Table 3-28 Air Toxics Emissions for Commercial Marine Diesel Engines (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	530	556	559	572	624
FORMALDEHYDE	3,897	4,091	4,112	4,208	4,587
ACETALDEHYDE	1,937	2,033	2,044	2,091	2,280
1,3-BUTADIENE	6	6	6	6	7
ACROLEIN	75	79	79	81	89
NAPHTHALENE	43	39	37	36	40
POM	11	10	9	9	10

3.1.3 Control Inventory Development

This section describes how the control emission inventories were developed for the commercial marine diesel categories: Category 1 propulsion, Category 1 auxiliary, Category 2 propulsion, and less than (<) 37kW. This section will only describe the modifications to the emission factors, since the other inventory inputs are unchanged.

3.1.3.1 Control Scenario(s) Modeled

For commercial marine diesel engines, there are two tiers of final PM standards and either combined HC+NO_x or NO_x and HC only standards for the control scenario that were modeled.

The final emission standards for Category 1 engines are summarized in Table 3-29 and Table 3-30. These standards apply to both propulsion and auxiliary engines. There are separate emission levels for standard and high power density engines. Standard power density engines are less than 35 kW per liter (kW/L), and the high power density engines are greater than or equal to 35 kW/L. Within these power density categories, there are also separate standards that vary by power and displacement. There are no Tier 4 standards for engines less than 600 kW. Standards are not shown in cases where there is zero engine population.

The final emission standards for Category 2 engines are summarized in Table 3-31. The standards vary by displacement and power. All Category 2 engines are considered to be standard power density engines. These engines are subject to both Tier 3 and Tier 4 emission standards.

The final emission standards for <37kW propulsion and auxilliary engines are given in Table 3-32. This category is subject to Tier 3 standards which begin in 2009.

Table 3-29 Final Standards (g/kW-hr) for C1 Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L													
	<=600KW							600<KW≤1000						
		TIER 3			TIER 4				TIER 3			TIER 4		
	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	7.5	0.30	NO TIER 4 STANDARDS				NO ENGINES IN THESE CATEGORIES						
	2014	4.7												
DISP<0.9 AND >75KW	2012	5.4	0.13											
0.9<=DISP<1.2	2013	5.4	0.12											
1.2<=DISP<2.5	2014	5.6	0.11					2014	5.6	0.11	2018	0.19	1.7	0.04
	2018		0.09											
2.5<=DISP<3.5	2013	5.6	0.11					2013	5.6	0.11	2018	0.19	1.7	0.04
	2018		0.09											
3.5<=DISP<5.0	2012	5.8	0.11					2012	5.8	0.11	2018	0.19	1.7	0.04
	2018		0.09											

DISPLACEMENT CATEGORY	<35 KW/L													
	1000<KW≤1400							1400<KW≤2000						
		TIER 3			TIER 4				TIER 3			TIER 4		
	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES							NO ENGINES IN THESE CATEGORIES						
DISP<0.9 AND >75KW														
0.9<=DISP<1.2														
1.2<=DISP<2.5	2014	5.6	0.11	2017	0.19	1.7	0.04							
2.5<=DISP<3.5	2013	5.6	0.11	2017	0.19	1.7	0.04							
3.5<=DISP<5.0	2012	5.8	0.11	2017	0.19	1.7	0.04	2012	5.8	0.11	2016	0.19	1.7	0.04

Table 3-30 Final Standards (g/kW-hr) for C1 High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L													
	<=600KW							600<KW≤1000						
		TIER 3			TIER 4				TIER 3			TIER 4		
	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	7.5	0.30	NO TIER 4 STANDARDS				NO ENGINES IN THESE CATEGORIES						
	2014	4.7												
DISP<0.9 AND >75KW	2012	5.8	0.15											
0.9<=DISP<1.2	2013	5.8	0.13											
1.2<=DISP<2.5	2014	5.8	0.12					2014	5.6	0.11	2018	0.19	1.7	0.04
2.5<=DISP<3.5	NO ENGINES							NO ENGINES IN THESE CATEGORIES						
3.5<=DISP<5.0														

DISPLACEMENT CATEGORY	≥35 KW/L													
	1000<KW≤1400							1400<KW≤2000						
		TIER 3			TIER 4				TIER 3			TIER 4		
	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM	YEAR	NO_X+HC	PM	YEAR	HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES							NO ENGINES IN THESE CATEGORIES						
DISP<0.9 AND >75KW														
0.9<=DISP<1.2	2013	5.4	0.12	2017	0.19	1.7	0.04							
1.2<=DISP<2.5	NO ENGINES IN THESE CATEGORIES							2014	5.6	0.11	2016	0.19	1.7	0.04
2.5<=DISP<3.5								NO ENGINES IN THIS CATEGORY						
3.5<=DISP<5.0	2012	5.8	0.11	2017	0.19	1.7	0.04	2012	5.8	0.11	2016	0.19	1.7	0.04

Table 3-31 Final Standards (g/kW-hr) for C2 Engines

DISPLACEMENT CATEGORY	YEAR	TIER 3		YEAR	TIER 4		
		NO_X+HC	PM		HC	NO_X	PM
5.0<=DISP<15 AND <600KW	2013	6.2	0.13				
5.0<=DISP<15 AND 600≤KW<1000	2013	6.2	0.13	2018	0.19	1.7	0.04
5.0<=DISP<15 AND 1000≤KW<1400	2013	6.2	0.13	2017	0.19	1.7	0.04
5.0<=DISP<15 AND 1400≤KW<2000	2013	6.2	0.13	2016	0.19	1.7	0.04
5.0<=DISP<15 AND 2000≤KW<3700	2013		0.13	2014	0.19	1.7	
				2016			0.04
5.0<=DISP<15 AND ≥3700KW				2014	0.19	1.7	0.12
				2017			0.05
15.0<=DISP<20.0 AND <1400KW	NO ENGINES IN THIS CATEGORY						
15.0<=DISP<20.0 AND 1400≤KW<2000	2014	7.0	0.34	2016	0.19	1.7	0.04
15.0<=DISP<20 AND 2000≤KW<3300	2014		0.34	2014	0.19	1.7	
				2016			0.04
15.0<=DISP<20.0 AND 3300≤KW<3700	NO ENGINES IN THIS CATEGORY						
15.0<=DISP<20.0 AND ≥3700KW				2014	0.19	1.7	0.25
				2017			0.05
20.0<=DISP<30.0	NO ENGINES IN THIS CATEGORY						

Table 3-32 Final Standards (g/hp-hr) for <37kW Commercial Marine Diesel Engines

HP RANGE	YEAR	TIER 3	
		NO_X+HC	PM
0-25	2009	5.6	0.30
25-50	2009	5.6	0.22
	2014	3.5	0.22

In addition to the new emission standards, Category 1 and Category 2 engines larger than 600 kW and newly manufactured after January 1, 1973 are subject to a remanufacturing program. A description of the remanufacturing program modeled is provided in Table 3-33. The remanufacturing program affects PM emissions from Category 1 engines and both NOx and PM emissions from Category 2 engines. The remanufacturing program exempts those vessel owners who earn less than $5 million per year in gross annual revenues.

Table 3-33 Description of Remanufacturing Program Modeled

Category	Power Cutoff	Calendar Year Start	Model Years	Engine Model Series	Tiers	Percent Reduction	
						NOx	PM
Category 1	>600 kW	2012	1972+	Cat 3500 DOC/MTU 149 Cummins KTA 38	Tiers 0/1/2	None	25%
Category 2	>600 kW	2008	1972+	EMD 645 EMD 710 GE (all models)	Tiers 0/1 for NOx Tiers 0/1/2 for PM	30%	25%

3.1.3.2 Category 1 Propulsion

The modeled Tier 3 and Tier 4 emission factors corresponding to the emission standards are shown in Table 3-34 and Table 3-35. These emission factors are derived by applying the appropriate relative reductions from the Tier 2 standard to the Tier 2 emission factors, using the following equations:

Equation 3-8 Tier 3 EF = (Tier 3 std/Tier 2 std) x Tier 2 EF

Equation 3-9 Tier 4 EF = (Tier 4 std/Tier 2 std) x Tier 2 EF

For NO_x, the standards used in the above equations are the combined $HC+NO_x$ standards. For HC and PM, the PM standards are used.

Once inventories were estimated using the control emission factors, the additional NOx emissions reductions of the remanufacturing program were calculated. The total NOx inventories were first separated by tier and by power category. The NOx emissions from Tier 0, Tier 1, and Tier 2 engines greater than 600 kW that are subject to the remanufacturing program were then summed for each calendar year. The following equation was then applied to those affected tons to calculate the reduced tons under the remanufacturing program:

Equation 3-10 $\textbf{Remfr Tons}_{CY} = [\textbf{Frac ctl}_{CY} \times (1-\textbf{Red}) + (1-\textbf{Frac ctl}_{CY})] \times \textbf{Tons}_{CY}$

Where:
Remfr Tons_{CY} = Tons for >600kW pre-Tier 3 engines with remanufacturing program, by calendar year
Fract ctl_{CY} = Fraction of the fleet >600kW subject to the remanufacturing program, by calendar year (from Table 3-36)
Red = Fractional reduction (0.25 from Table 3-33)
Tons = Tons for >600kW pre-Tier 3 engines, by calendar year

The fraction of the fleet subject to the remanufacturing program was estimated based on an evaluation of a random sample of inland river vessels.[26] A seven year phase-in was allowed to account for the typical rebuild cycle for these engines. The resulting fleet fractions by calendar year are provided in Table 3-36.

The remanufacture tons (Remfr Tons) was then subtracted from the Tons value to obtain the delta tons for the remanufacturing program for each calendar year. The resulting delta tons value was decreased by 12 percent to account for the small business exemption. This delta tons value was then subtracted from the total Category 1 propulsion inventory for each calendar year to obtain the resulting tons for the combined emission standard and marine remanufacturing control program.

The resulting control case 50-state emission inventories for Category 1 propulsion engines are given in Table 3-37.

Table 3-34 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Propulsion Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L											
	<=600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.14	4.08	0.08								
0.9<=DISP<1.2	2013	0.13	4.54	0.05								
1.2<=DISP<2.5	2014	0.10	4.69	0.07	2014	0.10	4.69	0.07	2018	0.04	1.30	0.03
	2018			0.061								
2.5<=DISP<3.5	2013	0.10	4.69	0.07	2013	0.10	4.69	0.07	2018	0.04	1.30	0.03
	2018			0.061								
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2012	0.10	4.81	0.07	2018	0.04	1.30	0.03
	2018			0.061								

DISPLACEMENT CATEGORY	<35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5	2014	0.10	4.69	0.07	2017	0.04	1.3	0.03								
2.5<=DISP<3.5	2013	0.10	4.69	0.07	2017	0.04	1.3	0.03								
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2017	0.04	1.3	0.03	2012	0.10	4.81	0.07	2016	0.04	1.3	0.03

Table 3-35 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Propulsion High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L											
	<=600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES				NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW	2012	0.15	4.38	0.08								
0.9<=DISP<1.2	2013	0.14	4.89	0.05								
1.2<=DISP<2.5	2014	0.11	4.81	0.08	2014	0.10	4.69	0.07	2018	0.04	1.3	0.03
2.5<=DISP<3.5	NO ENGINES				NO ENGINES IN THESE CATEGORIES							
3.5<=DISP<5.0												

DISPLACEMENT CATEGORY	≥35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5																
2.5<=DISP<3.5																
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2017	0.04	1.3	0.03	2012	0.10	4.81	0.07	2016	0.04	1.3	0.03

Table 3-36 Percent of Fleet Subject to Remanufacturing Standards*

Calendar Year	Category 1	Category 2
2008	0.0%	8.8%
2009	0.0%	17.6%
2010	0.0%	26.4%
2011	0.0%	35.2%
2012	8.5%	44.0%
2013	16.9%	52.8%
2014	25.4%	61.6%
2015	33.9%	61.6%
2016	42.3%	61.6%
2017	50.8%	61.6%
2018+	59.3%	61.6%

* Note that these percentages were based on an earlier draft analysis of Inland River Record samples. The percentages in the final analysis differ by less than two percent from those in this table.

Table 3-37 Control Case (50-State) Emissions for C1 Propulsion Engines (short tons)

YEAR	PM$_{10}$	PM$_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	13,328	12,928	335,561	9,488	9,010	55,303	36,201
2003	13,690	13,279	336,369	9,573	9,091	55,801	36,528
2004	13,807	13,393	332,798	9,561	9,080	55,722	36,862
2005	13,873	13,457	328,810	9,550	9,069	55,582	37,192
2006	13,872	13,456	324,900	9,540	9,060	55,450	36,827
2007	12,230	11,863	316,663	9,415	8,941	54,423	19,121
2008	10,961	10,632	308,524	9,291	8,824	53,405	6,299
2009	10,709	10,388	300,509	9,169	8,708	52,401	6,355
2010	10,304	9,995	292,651	9,050	8,594	51,414	4,705
2011	9,916	9,618	284,979	8,933	8,483	50,445	3,513
2012	9,274	8,996	276,209	8,708	8,270	49,497	1,862
2013	8,610	8,351	267,453	8,433	8,008	48,574	664
2014	7,949	7,710	257,691	8,042	7,637	47,680	799
2015	7,288	7,070	248,317	7,658	7,273	46,827	857
2016	6,608	6,410	236,292	7,228	6,864	46,023	865
2017	5,981	5,802	223,265	6,784	6,443	45,368	872
2018	5,422	5,259	209,717	6,334	6,015	44,879	879
2019	4,970	4,821	196,847	5,898	5,601	44,482	886
2020	4,582	4,445	185,242	5,496	5,219	44,301	893
2021	4,259	4,132	174,843	5,126	4,868	44,329	900
2022	3,956	3,837	164,971	4,772	4,532	44,423	907
2023	3,668	3,558	155,589	4,433	4,210	44,571	915
2024	3,393	3,292	146,696	4,111	3,904	44,760	923
2025	3,143	3,048	138,521	3,826	3,634	44,987	931
2026	2,922	2,834	131,195	3,589	3,408	45,248	939
2027	2,739	2,657	124,763	3,400	3,229	45,539	946
2028	2,591	2,513	119,185	3,252	3,089	45,861	954
2029	2,471	2,397	114,708	3,134	2,976	46,209	962
2030	2,387	2,315	111,660	3,049	2,896	46,583	970
2031	2,330	2,260	109,766	2,991	2,841	46,975	978
2032	2,295	2,226	108,624	2,953	2,804	47,385	986
2033	2,273	2,205	107,896	2,927	2,780	47,811	995
2034	2,258	2,190	107,443	2,911	2,764	48,241	1,006
2035	2,249	2,182	107,233	2,902	2,756	48,675	1,015
2036	2,246	2,179	107,236	2,901	2,755	49,114	1,023
2037	2,249	2,181	107,444	2,906	2,760	49,556	1,032
2038	2,256	2,188	107,834	2,919	2,772	50,002	1,040
2039	2,268	2,200	108,376	2,936	2,788	50,452	1,050
2040	2,282	2,214	109,054	2,957	2,808	50,906	1,059

3.1.3.3 Category 1 Auxiliary

The modeled Tier 3 and Tier 4 emission factors for Category 1 auxiliary engines are shown in Table 3-38 and Table 3-39. The methodology described above for Category 1 propulsion engines was used to derive these emission factors and calculate the emissions impact of the remanufacturing program.

The resulting control case 50-state emission inventories for Category 1 auxiliary engines are given in Table 3-40.

Table 3-38 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Auxiliary Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L											
	≤600KW				600<KW≤1000							
		TIER 3				TIER 3				TIER 4		
	YEAR	HC	NO$_X$	PM	YEAR	HC	NO$_X$	PM	YEAR	HC	NO$_X$	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.14	4.08	0.08								
0.9<=DISP<1.2	2013	0.13	4.02	0.08								
1.2<=DISP<2.5	2014	0.11	4.77	0.08	2014	0.11	4.77	0.08	2018	0.04	1.3	0.03
	2018			0.070								
2.5<=DISP<3.5	2013	0.11	4.77	0.08	2013	0.11	4.77	0.08	2018	0.04	1.3	0.03
	2018			0.070								
3.5<=DISP<5.0	2012	0.11	4.89	0.08	2012	0.11	4.89	0.08	2018	0.04	1.3	0.03
	2018			0.070								

DISPLACEMENT CATEGORY	<35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO$_X$	PM		HC	NO$_X$	PM		HC	NO$_X$	PM		HC	NO$_X$	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5																
2.5<=DISP<3.5	2013	0.11	4.77	0.08	2017	0.04	1.3	0.03								
3.5<=DISP<5.0	2012	0.11	4.89	0.08	2017	0.04	1.3	0.03	2012	0.11	4.89	0.08	2016	0.04	1.3	0.03

Table 3-39 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Auxiliary High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L											
	≤600KW				600<KW≤1000							
		TIER 3				TIER 3				TIER 4		
	YEAR	HC	NO_X	PM	YEAR	HC	NO_X	PM	YEAR	HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.15	4.38	0.08								
0.9<=DISP<1.2	NO ENGINES IN THESE CATEGORIES											
1.2<=DISP<2.5												
2.5<=DISP<3.5												
3.5<=DISP<5.0												

DISPLACEMENT CATEGORY	≥35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2	2013	0.13	4.02	0.08	2017	0.04	1.3	0.03								
1.2<=DISP<2.5	NO ENGINES IN THESE CATEGORIES								2014	0.11	4.77	0.08	2016	0.04	1.3	0.03
2.5<=DISP<3.5									NO ENGINES IN THESE CATEGORIES							
3.5<=DISP<5.0																

Table 3-40 Control Case (50-State) Emissions for C1 Auxiliary Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	2,714	2,632	60,641	1,767	1,678	9,624	6,553
2003	2,773	2,690	60,959	1,783	1,693	9,710	6,613
2004	2,791	2,708	60,482	1,785	1,696	9,668	6,673
2005	2,786	2,703	59,774	1,788	1,698	9,585	6,733
2006	2,769	2,686	59,073	1,791	1,700	9,503	6,667
2007	2,482	2,407	58,048	1,787	1,697	9,331	3,461
2008	2,263	2,195	57,030	1,783	1,693	9,160	1,140
2009	2,229	2,162	56,020	1,778	1,688	8,989	1,150
2010	2,169	2,104	55,022	1,773	1,684	8,820	852
2011	2,113	2,049	54,038	1,768	1,679	8,654	636
2012	2,028	1,967	52,949	1,753	1,664	8,489	337
2013	1,943	1,884	51,796	1,727	1,640	8,327	120
2014	1,862	1,806	50,317	1,677	1,593	8,167	145
2015	1,778	1,725	48,863	1,628	1,546	8,010	155
2016	1,691	1,641	47,349	1,577	1,497	7,857	157
2017	1,597	1,549	45,754	1,523	1,446	7,708	158
2018	1,490	1,445	43,895	1,463	1,389	7,563	159
2019	1,393	1,351	42,089	1,403	1,333	7,426	160
2020	1,296	1,258	40,347	1,345	1,278	7,298	162
2021	1,210	1,173	38,787	1,290	1,225	7,198	163
2022	1,138	1,104	37,444	1,239	1,176	7,134	164
2023	1,075	1,043	36,210	1,188	1,129	7,088	166
2024	1,019	988	35,096	1,141	1,083	7,066	167
2025	968	939	34,089	1,095	1,040	7,067	169
2026	919	892	33,138	1,052	999	7,077	170
2027	873	847	32,243	1,010	959	7,094	171
2028	829	804	31,399	970	921	7,117	173
2029	788	765	30,630	935	888	7,145	174
2030	752	730	29,948	905	859	7,178	176
2031	723	702	29,388	882	838	7,215	177
2032	700	679	28,939	866	823	7,257	179
2033	680	660	28,572	853	810	7,303	180
2034	664	644	28,303	843	801	7,353	182
2035	652	632	28,159	836	794	7,407	184
2036	644	625	28,117	832	790	7,464	185
2037	638	619	28,123	830	788	7,524	187
2038	635	616	28,176	829	787	7,588	188
2039	634	615	28,259	829	788	7,654	190
2040	634	615	28,367	831	789	7,721	192

3.1.3.4 Category 2 Propulsion

The modeled Tier 3 and Tier 4 emission factors for Category 2 propulsion engines are shown in Table 3-41. The methodology described above for Category 1 propulsion engines was used to derive these emission factors. The emissions impact of the remanufacturing program was calculated using Equation 3-10 and the inputs provided in Table 3-33 and Table 3-36. Similarly to Category 1, the emissions benefit of the remanufacturing program was reduced by 12 percent to account for the small business exemption.

The resulting control case 50-state emission inventories for Category 2 propulsion engines are given in Table 3-42.

Table 3-41 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C2 Engines

DISPLACEMENT CATEGORY	YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM
5.0<=DISP<15 AND <600KW	2013	0.07	5.97	0.11				
5.0<=DISP<15 AND 600≤KW<1000	2013	0.07	5.97	0.11	2018	0.02	1.3	0.03
5.0<=DISP<15 AND 1000≤KW<1400	2013	0.07	5.97	0.11	2017	0.02	1.3	0.03
5.0<=DISP<15 AND 1400≤KW<2000	2013	0.07	5.97	0.11	2016	0.02	1.3	0.03
5.0<=disp<15 AND 2000≤KW<3700	2013			0.11	2014	0.02	1.3	
					2016			0.03
5.0<=DISP<15 AND ≥3700KW					2014	0.06	1.3	0.10
					2017	0.03	1.3	0.04
15.0<=DISP<20.0 AND 1400≤KW<2000	2014	0.09	6.77	0.30	2016	0.01	1.3	0.04
15.0<=DISP<20.0 AND 2000≤kW<3300	2014			0.30	2014	0.01	1.3	
					2016			0.04
15.0<=DISP<20.0 AND >3700KW					2014	0.07	1.3	0.23
					2017	0.01	1.3	0.05

Table 3-42 Control Case (50-State) Emissions for C2 Propulsion Engines

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	12,850	12,464	432,306	4,701	4,464	82,621	36,868
2003	13,112	12,719	431,973	4,743	4,504	83,364	37,193
2004	13,376	12,975	431,683	4,786	4,545	84,115	37,528
2005	13,641	13,232	431,417	4,829	4,586	84,872	37,866
2006	13,907	13,490	431,195	4,872	4,627	85,635	38,207
2007	14,174	13,748	427,380	4,916	4,669	85,621	38,550
2008	14,164	13,739	414,725	4,960	4,711	85,611	38,837
2009	14,151	13,726	402,915	5,005	4,753	85,605	39,204
2010	14,127	13,703	391,965	5,050	4,796	85,609	39,559
2011	14,094	13,671	381,869	5,096	4,839	85,621	39,920
2012	14,051	13,630	372,614	5,141	4,883	85,639	40,278
2013	13,813	13,399	363,742	5,174	4,914	85,665	39,905
2014	12,231	11,864	345,213	5,069	4,814	85,701	21,334
2015	11,378	11,037	333,586	4,964	4,714	85,746	7,888
2016	11,293	10,954	320,992	4,846	4,602	85,800	7,817
2017	10,973	10,644	308,346	4,680	4,445	85,864	5,901
2018	10,680	10,360	295,746	4,514	4,287	85,937	4,574
2019	10,361	10,051	283,222	4,348	4,129	86,020	2,963
2020	10,067	9,765	270,832	4,182	3,972	86,116	1,888
2021	9,831	9,536	258,585	4,018	3,816	86,222	1,976
2022	9,580	9,293	246,543	3,855	3,661	86,341	1,995
2023	9,298	9,019	235,176	3,692	3,506	86,475	1,975
2024	8,990	8,720	224,475	3,530	3,352	86,626	1,954
2025	8,670	8,410	213,984	3,369	3,200	86,790	1,934
2026	8,340	8,090	203,629	3,209	3,047	86,974	1,913
2027	8,001	7,761	193,441	3,050	2,896	87,178	1,894
2028	7,653	7,424	183,404	2,891	2,746	87,406	1,874
2029	7,301	7,082	173,555	2,734	2,597	87,672	1,855
2030	6,943	6,735	164,024	2,579	2,450	88,078	1,836
2031	6,581	6,383	154,845	2,427	2,305	88,623	1,818
2032	6,216	6,030	145,870	2,276	2,162	89,207	1,800
2033	5,852	5,676	137,176	2,129	2,022	89,820	1,783
2034	5,488	5,323	128,777	1,986	1,886	90,457	1,766
2035	5,128	4,974	120,726	1,848	1,755	91,119	1,750
2036	4,795	4,651	113,237	1,718	1,632	91,799	1,735
2037	4,504	4,369	107,705	1,616	1,535	92,500	1,721
2038	4,244	4,116	104,042	1,539	1,462	93,219	1,709
2039	4,022	3,902	101,058	1,472	1,398	93,956	1,700
2040	3,864	3,748	98,614	1,420	1,349	94,707	1,699

3.1.3.5 Less than 37 kW Propulsion and Auxiliary

The modeled Tier 3 emission factors for less than (<) 37kW commercial marine diesel engines are given in Table 3-43. These emission factors apply to both propulsion and auxiliary engines. For HC, the methodology described for Category 1 propulsion engines was used. For PM, a 20 percent compliance margin was applied to the Tier 3 standard; however, if the resulting emission factor was greater than the corresponding Tier 2 emission factor, the Tier 2 value was used for Tier 3. Since the final rule does not result in NO_x control for this category, the Tier 3 NO_x emission factors were set equal to Tier 2.

Table 3-43 Control PM_{10}, NO_x, and HC Emission Factors (g/hp-hr) for <37kW Commercial Marine Diesel Engines

HP RANGE	YEAR	TIER 3		
		HC	NO_X	PM
0-11	2009	0.43	4.39	0.24
11-16	2009	0.21	3.63	0.19
	2014	0.21	2.32	0.19
16-25	2009	0.21	3.63	0.19
	2014	0.21	2.32	0.19
25-50	2009	0.41	3.71	0.18
	2014	0.41	2.32	0.18

The resulting control case 50-state emission inventories for <37kW propulsion and auxiliary engines are given in Table 3-44.

3.1.3.6 Commercial Marine Diesel Control Inventory Summary

3.1.3.6.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 3-45 thru Table 3-50 present the resulting 50-state consolidated commercial marine control case inventories for each pollutant and category, for calendar years 2002-2040.

3.1.3.6.2 Air Toxics Emissions

The control case air toxics inventories for commercial marine diesel engines are provided in Table 3-51. The gaseous air toxics are assumed to be controlled proportionately to VOC, whereas POM is controlled proportionately to PM.

Table 3-44 Control Case (50-State) Emissions for <37kW Commercial Marine Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	728	706	5,517	1,273	1,209	3,783	731
2003	710	689	5,448	1,222	1,161	3,680	738
2004	692	671	5,350	1,179	1,120	3,576	745
2005	671	651	5,229	1,128	1,071	3,460	752
2006	648	629	5,101	1,075	1,021	3,339	745
2007	596	578	4,973	1,022	970	3,216	387
2008	551	534	4,846	969	920	3,093	128
2009	524	509	4,719	911	865	2,970	129
2010	495	480	4,594	853	810	2,846	95
2011	466	452	4,472	797	757	2,724	71
2012	437	424	4,351	741	704	2,603	38
2013	409	397	4,234	688	653	2,484	14
2014	383	371	4,073	636	604	2,369	16
2015	357	346	3,917	586	556	2,259	18
2016	334	324	3,777	545	518	2,170	18
2017	317	308	3,658	515	489	2,109	18
2018	303	294	3,556	492	467	2,063	18
2019	291	282	3,462	472	448	2,027	18
2020	280	272	3,377	454	432	1,997	18
2021	271	263	3,301	438	416	1,972	18
2022	263	255	3,240	423	402	1,952	18
2023	257	249	3,188	411	390	1,940	19
2024	252	244	3,144	401	381	1,932	19
2025	248	240	3,103	393	373	1,926	19
2026	244	237	3,070	387	368	1,926	19
2027	242	235	3,042	383	364	1,929	19
2028	241	234	3,018	381	361	1,934	19
2029	240	233	2,998	379	360	1,942	20
2030	240	233	2,982	378	359	1,952	20
2031	240	233	2,978	378	359	1,963	20
2032	241	234	2,983	380	360	1,977	20
2033	242	235	2,993	381	362	1,992	20
2034	244	236	3,007	384	365	2,009	21
2035	245	238	3,022	387	367	2,026	21
2036	247	240	3,040	389	370	2,044	21
2037	249	242	3,058	392	372	2,061	21
2038	251	244	3,079	395	375	2,079	21
2039	253	246	3,100	398	378	2,097	21
2040	255	248	3,123	402	381	2,115	22

Table 3-45 Control Case (50-State) PM_{10} Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	13,328	2,714	16,041	12,850	728	29,619
2003	13,690	2,773	16,463	13,112	710	30,285
2004	13,807	2,791	16,598	13,376	692	30,666
2005	13,873	2,786	16,659	13,641	671	30,972
2006	13,872	2,769	16,641	13,907	648	31,196
2007	12,230	2,482	14,712	14,174	596	29,481
2008	10,961	2,263	13,224	14,164	551	27,938
2009	10,709	2,229	12,939	14,151	524	27,614
2010	10,304	2,169	12,472	14,127	495	27,095
2011	9,916	2,113	12,029	14,094	466	26,589
2012	9,290	2,029	11,320	14,051	437	25,808
2013	8,640	1,946	10,586	13,813	409	24,808
2014	7,990	1,866	9,856	12,231	383	22,470
2015	7,338	1,784	9,122	11,378	357	20,857
2016	6,663	1,699	8,362	11,293	334	19,989
2017	6,039	1,605	7,644	10,973	317	18,934
2018	5,480	1,499	6,979	10,680	303	17,962
2019	5,020	1,401	6,421	10,361	291	17,073
2020	4,625	1,303	5,928	10,067	280	16,275
2021	4,296	1,216	5,512	9,831	271	15,614
2022	3,986	1,144	5,130	9,580	263	14,973
2023	3,692	1,080	4,772	9,298	257	14,328
2024	3,412	1,023	4,435	8,990	252	13,677
2025	3,157	971	4,128	8,670	248	13,046
2026	2,933	922	3,855	8,340	244	12,440
2027	2,747	876	3,623	8,001	242	11,866
2028	2,597	831	3,428	7,653	241	11,323
2029	2,476	790	3,266	7,301	240	10,807
2030	2,390	754	3,144	6,943	240	10,327
2031	2,333	725	3,057	6,581	240	9,878
2032	2,297	701	2,998	6,216	241	9,455
2033	2,274	681	2,955	5,852	242	9,049
2034	2,259	665	2,923	5,488	244	8,655
2035	2,250	652	2,902	5,128	245	8,276
2036	2,246	644	2,891	4,795	247	7,933
2037	2,249	639	2,887	4,504	249	7,641
2038	2,256	636	2,892	4,244	251	7,387
2039	2,268	634	2,902	4,022	253	7,177
2040	2,282	634	2,916	3,864	255	7,035

Table 3-46 Control Case (50-State) $PM_{2.5}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	12,928	2,632	15,560	12,464	706	28,730
2003	13,279	2,690	15,969	12,719	689	29,377
2004	13,393	2,708	16,100	12,975	671	29,746
2005	13,457	2,703	16,159	13,232	651	30,042
2006	13,456	2,686	16,142	13,490	629	30,260
2007	11,863	2,407	14,270	13,748	578	28,596
2008	10,632	2,195	12,827	13,739	534	27,100
2009	10,388	2,162	12,551	13,726	509	26,785
2010	9,995	2,104	12,098	13,703	480	26,282
2011	9,618	2,049	11,668	13,671	452	25,792
2012	9,012	1,968	10,980	13,630	424	25,034
2013	8,380	1,888	10,268	13,399	397	24,064
2014	7,750	1,810	9,561	11,864	371	21,796
2015	7,118	1,731	8,848	11,037	346	20,231
2016	6,463	1,648	8,111	10,954	324	19,389
2017	5,858	1,557	7,414	10,644	308	18,366
2018	5,316	1,454	6,770	10,360	294	17,423
2019	4,869	1,359	6,228	10,051	282	16,561
2020	4,486	1,264	5,750	9,765	272	15,787
2021	4,167	1,179	5,346	9,536	263	15,145
2022	3,867	1,109	4,976	9,293	255	14,524
2023	3,582	1,048	4,629	9,019	249	13,898
2024	3,310	992	4,302	8,720	244	13,266
2025	3,062	942	4,005	8,410	240	12,654
2026	2,845	895	3,740	8,090	237	12,067
2027	2,665	850	3,514	7,761	235	11,510
2028	2,519	806	3,325	7,424	234	10,983
2029	2,402	767	3,168	7,082	233	10,483
2030	2,318	731	3,050	6,735	233	10,017
2031	2,263	703	2,966	6,383	233	9,582
2032	2,228	680	2,908	6,030	234	9,171
2033	2,206	661	2,867	5,676	235	8,778
2034	2,191	645	2,836	5,323	236	8,395
2035	2,182	633	2,815	4,974	238	8,028
2036	2,179	625	2,804	4,651	240	7,695
2037	2,181	619	2,801	4,369	242	7,411
2038	2,188	616	2,805	4,116	244	7,165
2039	2,200	615	2,815	3,902	246	6,962
2040	2,214	615	2,828	3,748	248	6,824

Table 3-47 Control Case (50-State) NO_x Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	335,561	60,641	396,202	432,306	5,517	834,025
2003	336,369	60,959	397,328	431,973	5,448	834,749
2004	332,798	60,482	393,280	431,683	5,350	830,313
2005	328,810	59,774	388,583	431,417	5,229	825,229
2006	324,900	59,073	383,973	431,195	5,101	820,269
2007	316,663	58,048	374,710	427,380	4,973	807,063
2008	308,524	57,030	365,554	414,725	4,846	785,125
2009	300,509	56,020	356,529	402,915	4,719	764,163
2010	292,651	55,022	347,673	391,965	4,594	744,232
2011	284,979	54,038	339,017	381,869	4,472	725,358
2012	276,209	52,949	329,158	372,614	4,351	706,123
2013	267,453	51,796	319,249	363,742	4,234	687,225
2014	257,691	50,317	308,007	345,213	4,073	657,294
2015	248,317	48,863	297,181	333,586	3,917	634,684
2016	236,292	47,349	283,640	320,992	3,777	608,409
2017	223,265	45,754	269,020	308,346	3,658	581,023
2018	209,717	43,895	253,612	295,746	3,556	552,914
2019	196,847	42,089	238,936	283,222	3,462	525,620
2020	185,242	40,347	225,589	270,832	3,377	499,798
2021	174,843	38,787	213,630	258,585	3,301	475,517
2022	164,971	37,444	202,415	246,543	3,240	452,197
2023	155,589	36,210	191,800	235,176	3,188	430,164
2024	146,696	35,096	181,792	224,475	3,144	409,411
2025	138,521	34,089	172,610	213,984	3,103	389,698
2026	131,195	33,138	164,333	203,629	3,070	371,033
2027	124,763	32,243	157,006	193,441	3,042	353,489
2028	119,185	31,399	150,584	183,404	3,018	337,006
2029	114,708	30,630	145,338	173,555	2,998	321,891
2030	111,660	29,948	141,608	164,024	2,982	308,614
2031	109,766	29,388	139,154	154,845	2,978	296,977
2032	108,624	28,939	137,563	145,870	2,983	286,416
2033	107,896	28,572	136,468	137,176	2,993	276,637
2034	107,443	28,303	135,746	128,777	3,007	267,530
2035	107,233	28,159	135,392	120,726	3,022	259,140
2036	107,236	28,117	135,352	113,237	3,040	251,629
2037	107,444	28,123	135,566	107,705	3,058	246,330
2038	107,834	28,176	136,009	104,042	3,079	243,131
2039	108,376	28,259	136,635	101,058	3,100	240,793
2040	109,054	28,367	137,421	98,614	3,123	239,157

Table 3-48 Control Case (50-State) VOC Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	9,488	1,767	11,255	4,701	1,273	17,229
2003	9,573	1,783	11,356	4,743	1,222	17,321
2004	9,561	1,785	11,346	4,786	1,179	17,311
2005	9,550	1,788	11,338	4,829	1,128	17,295
2006	9,540	1,791	11,331	4,872	1,075	17,278
2007	9,415	1,787	11,202	4,916	1,022	17,140
2008	9,291	1,783	11,074	4,960	969	17,003
2009	9,169	1,778	10,947	5,005	911	16,863
2010	9,050	1,773	10,823	5,050	853	16,726
2011	8,933	1,768	10,701	5,096	797	16,594
2012	8,708	1,753	10,461	5,141	741	16,344
2013	8,433	1,727	10,160	5,174	688	16,022
2014	8,042	1,677	9,719	5,069	636	15,424
2015	7,658	1,628	9,286	4,964	586	14,836
2016	7,228	1,577	8,805	4,846	545	14,196
2017	6,784	1,523	8,307	4,680	515	13,502
2018	6,334	1,463	7,796	4,514	492	12,802
2019	5,898	1,403	7,302	4,348	472	12,121
2020	5,496	1,345	6,841	4,182	454	11,478
2021	5,126	1,290	6,416	4,018	438	10,872
2022	4,772	1,239	6,010	3,855	423	10,288
2023	4,433	1,188	5,621	3,692	411	9,724
2024	4,111	1,141	5,252	3,530	401	9,183
2025	3,826	1,095	4,922	3,369	393	8,684
2026	3,589	1,052	4,640	3,209	387	8,236
2027	3,400	1,010	4,410	3,050	383	7,843
2028	3,252	970	4,223	2,891	381	7,494
2029	3,134	935	4,068	2,734	379	7,182
2030	3,049	905	3,953	2,579	378	6,911
2031	2,991	882	3,874	2,427	378	6,679
2032	2,953	866	3,819	2,276	380	6,475
2033	2,927	853	3,781	2,129	381	6,291
2034	2,911	843	3,754	1,986	384	6,124
2035	2,902	836	3,738	1,848	387	5,973
2036	2,901	832	3,733	1,718	389	5,841
2037	2,906	830	3,736	1,616	392	5,744
2038	2,919	829	3,748	1,539	395	5,682
2039	2,936	829	3,765	1,472	398	5,636
2040	2,957	831	3,787	1,420	402	5,609

Table 3-49 Control Case (50-State) CO Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	55,303	9,624	64,927	82,621	3,783	151,331
2003	55,801	9,710	65,511	83,364	3,680	152,556
2004	55,722	9,668	65,390	84,115	3,576	153,080
2005	55,582	9,585	65,167	84,872	3,460	153,499
2006	55,450	9,503	64,954	85,635	3,339	153,928
2007	54,423	9,331	63,754	85,621	3,216	152,591
2008	53,405	9,160	62,565	85,611	3,093	151,269
2009	52,401	8,989	61,391	85,605	2,970	149,966
2010	51,414	8,820	60,235	85,609	2,846	148,690
2011	50,445	8,654	59,099	85,621	2,724	147,444
2012	49,497	8,489	57,986	85,639	2,603	146,227
2013	48,574	8,327	56,901	85,665	2,484	145,050
2014	47,680	8,167	55,847	85,701	2,369	143,917
2015	46,827	8,010	54,837	85,746	2,259	142,842
2016	46,023	7,857	53,880	85,800	2,170	141,851
2017	45,368	7,708	53,076	85,864	2,109	141,049
2018	44,879	7,563	52,443	85,937	2,063	140,443
2019	44,482	7,426	51,908	86,020	2,027	139,954
2020	44,301	7,298	51,599	86,116	1,997	139,712
2021	44,329	7,198	51,527	86,222	1,972	139,720
2022	44,423	7,134	51,557	86,341	1,952	139,851
2023	44,571	7,088	51,659	86,475	1,940	140,073
2024	44,760	7,066	51,827	86,626	1,932	140,384
2025	44,987	7,067	52,054	86,790	1,926	140,771
2026	45,248	7,077	52,325	86,974	1,926	141,226
2027	45,539	7,094	52,633	87,178	1,929	141,740
2028	45,861	7,117	52,978	87,406	1,934	142,318
2029	46,209	7,145	53,354	87,672	1,942	142,968
2030	46,583	7,178	53,761	88,078	1,952	143,791
2031	46,975	7,215	54,191	88,623	1,963	144,776
2032	47,385	7,257	54,642	89,207	1,977	145,825
2033	47,811	7,303	55,114	89,820	1,992	146,926
2034	48,241	7,353	55,595	90,457	2,009	148,060
2035	48,675	7,407	56,082	91,119	2,026	149,227
2036	49,114	7,464	56,577	91,799	2,044	150,419
2037	49,556	7,524	57,079	92,500	2,061	151,640
2038	50,002	7,588	57,589	93,219	2,079	152,887
2039	50,452	7,654	58,105	93,956	2,097	154,158
2040	50,906	7,721	58,627	94,707	2,115	155,449

Table 3-50 Control Case (50-State) SO$_2$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	36,201	6,553	42,754	36,868	731	80,353
2003	36,528	6,613	43,141	37,193	738	81,073
2004	36,862	6,673	43,535	37,528	745	81,808
2005	37,192	6,733	43,925	37,866	752	82,543
2006	36,827	6,667	43,493	38,207	745	82,445
2007	19,121	3,461	22,583	38,550	387	61,520
2008	6,299	1,140	7,440	38,837	128	46,404
2009	6,355	1,150	7,506	39,204	129	46,839
2010	4,705	852	5,557	39,559	95	45,212
2011	3,513	636	4,148	39,920	71	44,139
2012	1,862	337	2,199	40,278	38	42,515
2013	664	120	784	39,905	14	40,702
2014	799	145	943	21,334	16	22,293
2015	857	155	1,012	7,888	18	8,917
2016	865	157	1,021	7,817	18	8,855
2017	872	158	1,030	5,901	18	6,949
2018	879	159	1,038	4,574	18	5,630
2019	886	160	1,046	2,963	18	4,028
2020	893	162	1,055	1,888	18	2,961
2021	900	163	1,063	1,976	18	3,058
2022	907	164	1,072	1,995	18	3,085
2023	915	166	1,081	1,975	19	3,074
2024	923	167	1,090	1,954	19	3,063
2025	931	169	1,099	1,934	19	3,052
2026	939	170	1,109	1,913	19	3,041
2027	946	171	1,118	1,894	19	3,031
2028	954	173	1,127	1,874	19	3,020
2029	962	174	1,136	1,855	20	3,010
2030	970	176	1,146	1,836	20	3,002
2031	978	177	1,155	1,818	20	2,993
2032	986	179	1,165	1,800	20	2,985
2033	995	180	1,175	1,783	20	2,978
2034	1,006	182	1,188	1,766	21	2,975
2035	1,015	184	1,198	1,750	21	2,969
2036	1,023	185	1,208	1,735	21	2,964
2037	1,032	187	1,218	1,721	21	2,961
2038	1,040	188	1,228	1,709	21	2,958
2039	1,050	190	1,240	1,700	21	2,962
2040	1,059	192	1,251	1,699	22	2,971

Table 3-51 Control Case (50-State) Air Toxic Emissions for Commercial Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	556	513	409	251
FORMALDEHYDE	4,088	3,772	3,005	1,846
ACETALDEHYDE	2,032	1,875	1,494	917
1,3-BUTADIENE	6	5	4	3
ACROLEIN	79	73	58	36
NAPHTHALENE	38	34	26	16
POM	9	8	6	4

3.1.4 Projected Commercial Marine Emission Reductions of Final Rule

The $PM_{2.5}$, NO_x, and VOC emission reductions for each category and calendar year are presented in Table 3-52 thru Table 3-54. The air toxic emission reductions by pollutant and calendar year are given in Table 3-55.

Table 3-52 Projected Commercial Marine $PM_{2.5}$ Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	264	0	264
2009	0	1	1	538	2	541
2010	0	2	2	822	4	828
2011	0	2	3	1,116	5	1,124
2012	175	22	197	1,420	6	1,623
2013	353	45	398	1,856	8	2,262
2014	580	83	662	2,177	9	2,848
2015	792	120	912	2,189	11	3,112
2016	1,023	157	1,180	2,512	13	3,706
2017	1,268	196	1,463	2,922	15	4,400
2018	1,530	240	1,770	3,343	16	5,130
2019	1,732	275	2,007	3,750	18	5,776
2020	1,947	312	2,259	4,170	20	6,448
2021	2,175	349	2,524	4,639	22	7,185
2022	2,409	387	2,797	5,112	24	7,933
2023	2,647	427	3,074	5,587	26	8,687
2024	2,887	467	3,354	6,066	28	9,447
2025	3,115	508	3,623	6,550	29	10,203
2026	3,323	550	3,873	7,041	31	10,945
2027	3,508	592	4,099	7,538	32	11,670
2028	3,671	633	4,304	8,041	33	12,378
2029	3,816	673	4,489	8,549	33	13,072
2030	3,939	710	4,649	9,059	34	13,743
2031	4,041	741	4,782	9,574	35	14,391
2032	4,128	768	4,896	10,090	35	15,022
2033	4,207	793	5,000	10,606	36	15,642
2034	4,280	816	5,096	11,121	37	16,253
2035	4,347	836	5,183	11,631	37	16,851
2036	4,409	853	5,262	12,116	38	17,416
2037	4,466	869	5,335	12,560	38	17,933
2038	4,518	884	5,402	12,975	39	18,416
2039	4,568	899	5,466	13,352	39	18,857
2040	4,614	912	5,526	13,667	40	19,233

Table 3-53 Projected Commercial Marine NO_x Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	8,876	0	8,876
2009	0	0	0	16,942	0	16,942
2010	0	0	0	24,204	0	24,204
2011	0	0	0	30,668	0	30,668
2012	1,342	121	1,463	36,330	0	37,792
2013	3,311	322	3,633	41,685	0	45,319
2014	6,944	868	7,812	56,757	47	64,616
2015	10,562	1,414	11,976	65,007	94	77,077
2016	17,246	2,051	19,297	74,303	141	93,741
2017	26,061	2,835	28,896	83,755	188	112,839
2018	36,621	3,954	40,576	93,242	235	134,052
2019	47,117	5,071	52,187	102,778	281	155,247
2020	57,522	6,184	63,705	112,324	328	176,357
2021	67,833	7,292	75,126	121,873	374	197,373
2022	78,019	8,397	86,416	131,448	420	218,283
2023	88,051	9,495	97,546	141,137	465	239,149
2024	97,867	10,586	108,453	150,954	510	259,918
2025	107,215	11,667	118,882	160,800	555	280,237
2026	115,946	12,737	128,683	170,714	599	299,996
2027	123,957	13,792	137,749	180,644	643	319,036
2028	131,290	14,829	146,119	190,636	685	337,439
2029	137,676	15,822	153,498	200,664	726	354,888
2030	142,790	16,755	159,545	211,102	764	371,411
2031	146,842	17,592	164,434	221,882	794	387,110
2032	150,228	18,343	168,571	232,697	815	402,084
2033	153,285	19,039	172,324	243,398	835	416,556
2034	156,089	19,659	175,748	253,972	852	430,573
2035	158,671	20,173	178,844	264,350	869	444,063
2036	161,061	20,604	181,665	274,282	884	456,832
2037	163,268	21,004	184,271	282,393	899	467,563
2038	165,314	21,377	186,692	288,751	913	476,356
2039	167,230	21,732	188,962	294,551	926	484,440
2040	169,033	22,069	191,102	299,914	938	491,954

Table 3-54 Projected Commercial Marine VOC Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	0	0	0
2009	0	2	2	0	5	7
2010	1	3	4	0	11	14
2011	1	5	6	0	16	22
2012	113	17	130	0	22	152
2013	279	40	319	14	27	359
2014	564	88	652	166	32	850
2015	849	135	984	318	38	1,339
2016	1,187	185	1,372	483	43	1,897
2017	1,563	237	1,800	697	49	2,546
2018	1,970	297	2,267	912	54	3,232
2019	2,374	356	2,730	1,127	59	3,915
2020	2,773	415	3,188	1,341	64	4,593
2021	3,167	474	3,640	1,555	70	5,265
2022	3,555	532	4,087	1,769	75	5,930
2023	3,934	590	4,524	1,982	79	6,586
2024	4,303	647	4,950	2,195	84	7,229
2025	4,639	704	5,343	2,407	89	7,839
2026	4,934	760	5,694	2,620	92	8,405
2027	5,184	814	5,998	2,831	95	8,924
2028	5,397	867	6,264	3,043	97	9,404
2029	5,585	917	6,501	3,253	99	9,854
2030	5,743	961	6,704	3,462	101	10,267
2031	5,876	998	6,874	3,669	103	10,646
2032	5,993	1,029	7,022	3,874	105	11,001
2033	6,099	1,058	7,157	4,076	106	11,339
2034	6,197	1,084	7,281	4,275	108	11,664
2035	6,287	1,107	7,394	4,470	109	11,974
2036	6,371	1,128	7,499	4,657	111	12,267
2037	6,449	1,147	7,596	4,816	112	12,525
2038	6,521	1,166	7,687	4,951	114	12,751
2039	6,589	1,183	7,772	5,076	115	12,963
2040	6,654	1,200	7,854	5,187	116	13,157

Table 3-55 Projected Commercial Marine Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	0	46	164	373
FORMALDEHYDE	4	341	1,203	2,742
ACETALDEHYDE	2	169	598	1,363
1,3-BUTADIENE	0	0	2	4
ACROLEIN	0	7	23	53
NAPHTHALENE	0	3	10	24
POM	0	1	3	6

3.2 Recreational Marine Diesel Engines

This section describes the methodology and presents the resulting baseline and controlled inventories for recreational marine (pleasure craft) diesel propulsion engines, including the projected emission reductions from the final rule. These engines are already subject to existing emission control standards, so the baseline inventories presented here account for those existing standards. Emissions from any diesel auxiliary engines used on recreational marine vessels are covered above in the section on engines less than 37 kW or the section on Category 1 engines, if they are over 37 kW.

3.2.1 General Methodology

The general methodology for calculating recreational marine diesel engine inventories for HC, CO, NO_x, PM_{10}, SO_2, VOC, $PM_{2.5}$, and fuel consumption uses the EPA NONROAD2005 model with inputs modified to reflect the final standards as well as updated baseline data.[27] Air toxic inventories are not generated by the NONROAD model, so those are calculated separately. NONROAD separates recreational diesel engines into two basic categories: inboard and outboard engines. NONROAD also subdivides these by power range. There are relatively few outboard diesels, and they are all in the 25 - 40 hp range.

The actual calculation methodology used by the NONROAD model is the same as described above in section 3.1.1 for all other marine diesel engines. Following is a summary of that.

Equation 3-11 $$I = (N) \times (P) \times (L) \times (A) \times (EF)$$

where each term is defined as follows:

I = the emission inventory (gram/year)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)
A = engine activity (operating hours/year)
EF = emission factor (gram/kW-hr)

Emissions are then converted and reported as short tons/year. In NONROAD the inputs are expressed in terms of horsepower (hp) instead of kW, and gram/bhp-hr instead of gram/kW-hr.

Three variables are used to project emissions over time: the engine population growth, the engine median life/scrappage, and the relative emissions deterioration rate.

Engine Population Growth. Unlike the commercial marine methodology which uses a compound population growth rate, the NONROAD model uses a linear growth assumption for recreational diesel engines, which is represented by a set of growth indexes that provide a ratio of estimation year population relative to the base year population.[28] The growth used for recreational diesel engines is 3.3 percent per year relative to a 1996 base year; i.e., each year the population grows by the same number of engines, and that number is 3.3 percent of the 1996 population.

Engine Median Life (years) and Scrappage. The engine median life defines the length of time engines remain in service. Engines persist in the population over two median lives; during the first median life, 50 percent of the engines are scrapped, and over the second, the remaining 50 percent of the engines are scrapped. Engine median lives also vary by category. The median life of both inboard and outboard engines is assumed to be 20 years, but due to the different activities used for these two categories (200 and 150 hours/year, respectively), the corresponding median life inputs for the model are 1400 and 1050 hours at full load. The age distribution is defined by the median life and the scrappage algorithm. The same basic scrappage algorithm is used for recreational and commercial marine diesel engines.[29]

Relative Deterioration Rate (percent increase in emission factor/percent median life expended). A deterioration factor can be applied to the emission factor to account for in-use deterioration. The deterioration factor varies by age and is calculated as:

Equation 3-12

$$DF = 1 + A \times \left(\frac{age}{ML} \right)$$

where each term is defined as follows:
DF = the deterioration factor for a given pollutant at a given age
A = the relative deterioration rate for a given pollutant (percent increase in emission factor/percent useful life expended)
age = the age of a specific model year group of engines in the simulation year (years)
ML = the median life of the given model year cohort (years)

A given model year cohort is represented as a fraction of the entire population. In the NONROAD model the deterioration factor adjusts the emission factor for engines in a given model year cohort in relation to the proportion of median life expended.[30] Deterioration is linear over one median life. Following the first median life, the deteriorated emission factor is held constant over the remaining life for engines in the cohort.

Sulfur Adjustment for PM Emissions. For Tier 2 and prior engines, a sulfate adjustment is added to the PM emissions to account for differences in fuel sulfur content between the certification fuel and the episodic (calendar year) fuel, using the following equation:

Equation 3-13
$$S_{PMadj} = (FC)\times(7.1)\times(0.02247)\times\left(\frac{224}{32}\right)\times(soxdsl - soxbas)\times\left(\frac{1}{2000}\right)$$

where each term is defined as follows:
$S_{\text{PM adj}}$ = PM sulfate adjustment (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
0.02247 = fraction of fuel sulfur converted to sulfate
224/32 = grams PM sulfate/grams PM sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
soxbas = certification fuel sulfur weight fraction
2000 = conversion from lb to ton

For engines prior to Tier 2 the base fuel sulfur (soxbas) is assumed to be 3300 ppm. For Tier 2 engines less than or equal to 50 hp (37 kW) it is set at 2000 ppm, as described in the Clean Air Nonroad Diesel Rule[31], since these smaller engines are subject to the same standards as land-based diesel engines. For Tier 2 engines greater than 50 hp (37 kW) it is set at 350 ppm, based on the most recent certification data for these engines. For Tier 3 and later engines, no sulfur adjustment is applied. These engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced.

The calendar year fuel sulfur levels (soxdsl) were taken from the Clean Air Nonroad Diesel Rule and are provided in Table 3-1.[32]

Estimation of air toxic emissions. The air toxic baseline emission inventories for this proposal are based on information developed for EPA's Mobile Source Air Toxics (MSAT) final rulemaking.[33] That rule calculated air toxic emission inventories for all nonroad engines. The gaseous air toxics are correlated to VOC emissions, while POM is correlated to PM_{10} emissions. To calculate the air toxics emission inventories and reductions for this proposal, the percent reductions in VOC and PM_{10} emissions will be applied to the baseline gaseous and POM air toxic inventories, respectively.

3.2.2 Baseline (Pre-Control) Inventory Development

3.2.2.1 Baseline Inventory Inputs

This section describes the NONROAD model inputs that were used to generate the baseline emission inventories for recreational marine diesel engines.

Table 3-56 and Table 3-57 list the base engine populations, average hp by power range, annual activity, load factor, and median life. These also apply to the control case, and are unchanged from the default inputs in the NONROAD model.

Table 3-56 Recreational Marine Diesel Modeling Inputs

NONROAD MODEL INPUT	RECREATIONAL MARINE DIESEL	
	INBOARD	OUTBOARD
POPULATION (year 2000)	291,387*	9,819
HP AVERAGE	*	32.25
ACTIVITY HRS/YEAR	200	150
LOAD FACTOR	0.35	0.35
MEDIAN LIFE (hrs at full load)	1400	1050
MEDIAN LIFE (years)	20	20
* See TABLE 3-57 for breakout by individual power ranges.		

Table 3-57 Recreational Marine Inboard Diesel Population

POWER RANGE	DIESEL REC MARINE INBOARD	
MIN < HP <= MAX	HP AVG	POPULATION
0 – 11	9.736	9,126
11 – 16	14.92	4,478
16 – 25	21.41	9,908
25 – 40	31.2	5,421
40 – 50	42.4	1,002
50 – 75	56.19	8,784
75 – 100	94.22	7,397
100 - 175	144.9	60,632
175 - 300	223.1	99,703
300 - 600	387.1	73,546
600 - 750	677	2,902
750 - 1000	876.5	5,502
1000 - 1200	1154	448
1200 - 2000	1369	1,573
2000 - 3000	2294	964
TOTAL		291,387

The baseline emission factors are given in Table 3-58 and Table 3-59. "Zero Hour" emission factors represent the emissions from new engines that have been broken in, but before any significant deterioration occurs. The Deterioration Factor is used to calculate how emissions change as the engine and emission control system deteriorate over time, as explained above in Equation 3-2. Engines under 50 hp are subject to EPA nonroad diesel regulations that have established two tiers of emission standards.[34] Tier 1 phased in from 1999-2000, depending on the hp category, and Tier 2 phased in from 2004-2005. Engines above 50 hp are subject to separate standards (shown in the Tier 2 column) that take effect in

2008-2012, depending on hp category. The "Base" entries in the tables refer to emissions from pre-controlled engines. All these emission factors are used for both inboard and outboard diesel engines, although the outboards are all under 50 hp.

The emission factors for the base and Tier 1 technology types are unchanged from what has been in the NONROAD model.[35] Tier 2 emission factors were updated from those in the NONROAD model using all the nonroad engine certification data available in mid-2006. The deterioration factors by pollutant and technology type are also given in the tables above, and they are unchanged from what has been in the NONROAD model.[36]

The certification fuel sulfur levels are 3300ppm for the base and Tier 1 technology type and 350ppm for Tier 2. Brake Specific Fuel Consumption (BSFC) values in the NONROAD model are 0.408 lb/hp-hr for all hp categories.[37]

Table 3-58 Baseline PM_{10} and NO_x Zero Hour Emission Factors and Deterioration Factors for Recreational Marine Diesel Engines

HP RANGE	PM_{10} G/HP-HR			NO_X G/HP-HR		
	BASE	TIER1	TIER2	BASE	TIER1	TIER2
0-11	1.00	0.45	0.38	10.00	5.23	4.39
11-16	0.90	0.27	0.19	8.50	4.44	3.63
16-25	0.90	0.27	0.19	8.50	4.44	3.63
25-50	0.80	0.34	0.23	6.90	4.73	3.71
50-75	0.16	0.16	0.13	6.67	6.67	3.82
75-100	0.16	0.16	0.13	6.67	6.67	3.82
100-175	0.16	0.16	0.13	6.67	6.67	3.82
175-300	0.16	0.16	0.090	6.67	6.67	4.46
300-600	0.16	0.16	0.082	6.67	6.67	4.42
600-750	0.16	0.16	0.082	6.67	6.67	4.42
750-1200	0.16	0.16	0.082	6.67	6.67	4.42
>1200	0.16	0.16	0.082	6.67	6.67	4.42
DF ("A")	0.473	0.473	0.473	0.024	0.024	0.009

Table 3-59 Baseline HC and CO Zero Hour Emission Factors and Deterioration Factors for Recreational Marine Diesel Engines

HP RANGE	HC G/HP-HR			CO G/HP-HR		
	BASE	TIER1	TIER2	BASE	TIER1	TIER2
0-11	1.50	0.76	0.68	5.00	4.11	4.11
11-16	1.70	0.44	0.21	5.00	2.16	2.16
16-25	1.70	0.44	0.21	5.00	2.16	2.16
25-50	1.80	0.28	0.54	5.00	1.53	1.53
50-75	0.22	0.22	0.20	0.95	0.95	0.95
75-100	0.22	0.22	0.20	0.95	0.95	0.95
100-175	0.22	0.22	0.20	0.95	0.95	0.95
175-300	0.22	0.22	0.25	0.95	0.95	0.95
300-600	0.22	0.22	0.33	0.95	0.95	0.95
600-750	0.22	0.22	0.33	0.95	0.95	0.95
750-1200	0.22	0.22	0.33	0.95	0.95	0.95
>1200	0.22	0.22	0.33	0.95	0.95	0.95
DF ("A")	0.047	0.047	0.034	0.185	0.101	0.101

3.2.2.2 Recreational Marine Diesel Baseline Inventory

3.2.2.2.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 3-60 shows the baseline 50-state emission inventories for recreational marine diesel engines (inboard and outboard combined) resulting from the baseline model inputs presented above.

3.2.2.2.2 Air Toxics Emissions

The baseline air toxics inventories for recreational marine diesel engines were taken from the final MSAT rule[38] and are summarized in Table 3-61. Inventories are provided for calendar year 1999, and are projected for 2010, 2015, 2020, and 2030.

Table 3-60 Baseline (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

YEAR	PM$_{10}$	PM2.5	NO$_X$	VOC	HC	CO	SO$_2$
2002	1,130	1,096	40,437	1,540	1,462	6,467	5,145
2003	1,161	1,126	41,572	1,578	1,499	6,642	5,290
2004	1,192	1,156	42,704	1,618	1,536	6,816	5,436
2005	1,223	1,186	43,835	1,656	1,573	6,989	5,582
2006	1,247	1,210	44,089	1,720	1,633	7,161	5,621
2007	1,054	1,023	44,307	1,783	1,693	7,331	2,967
2008	915	888	44,513	1,846	1,753	7,499	993
2009	937	909	44,648	1,912	1,816	7,665	1,017
2010	935	907	44,772	1,979	1,879	7,829	764
2011	938	910	44,880	2,045	1,942	7,991	578
2012	934	906	44,977	2,112	2,006	8,150	311
2013	935	907	45,064	2,179	2,069	8,308	113
2014	952	924	45,139	2,246	2,133	8,464	136
2015	969	940	45,208	2,313	2,196	8,618	150
2016	984	954	45,270	2,380	2,260	8,771	153
2017	998	968	45,327	2,448	2,325	8,922	156
2018	1,011	981	45,378	2,516	2,389	9,073	156
2019	1,024	994	45,427	2,584	2,454	9,223	159
2020	1,037	1,006	45,477	2,653	2,520	9,374	162
2021	1,050	1,019	45,531	2,723	2,586	9,525	165
2022	1,063	1,031	45,586	2,793	2,652	9,675	168
2023	1,075	1,043	45,649	2,862	2,718	9,825	171
2024	1,087	1,054	45,729	2,932	2,784	9,975	174
2025	1,099	1,066	45,842	3,000	2,849	10,124	177
2026	1,112	1,079	46,114	3,064	2,910	10,279	180
2027	1,127	1,093	46,549	3,124	2,967	10,439	183
2028	1,143	1,108	47,030	3,184	3,023	10,601	186
2029	1,159	1,124	47,551	3,242	3,079	10,765	189
2030	1,175	1,140	48,102	3,299	3,133	10,930	192
2031	1,192	1,156	48,671	3,356	3,187	11,095	195
2032	1,208	1,172	49,257	3,412	3,240	11,262	199
2033	1,226	1,189	49,861	3,468	3,294	11,429	202
2034	1,243	1,205	50,477	3,524	3,346	11,596	205
2035	1,260	1,222	51,106	3,579	3,399	11,765	208
2036	1,278	1,239	51,748	3,634	3,451	11,933	211
2037	1,295	1,256	52,399	3,689	3,503	12,102	214
2038	1,313	1,274	53,062	3,744	3,555	12,272	217
2039	1,331	1,291	53,735	3,798	3,607	12,442	220
2040	1,349	1,308	54,417	3,852	3,659	12,613	223

Table 3-61 Baseline Air Toxics Emissions for Recreational Marine Diesel Engines (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	30	34	34	34	35
FORMALDEHYDE	176	199	197	195	201
ACETALDEHYDE	79	89	88	87	90
1,3-BUTADIENE	3	3	3	3	3
ACROLEIN	5	5	5	5	5
NAPHTHALENE	0	0	0	0	0
POM	1	0	0	0	0

3.2.3 Control Inventory Development

3.2.3.1 Control Scenario(s) Modeled

Table 3-62 shows the control case exhaust emission standards that were modeled for recreational marine diesel engines.

Table 3-62 Modeled Standards (g/hp-hr) for Recreational Marine Diesel Engines

HP RANGE	TIER 3		
	YEAR	NO_X+HC	PM
0-25	2009	5.6	0.30
25-100	2009	5.6	0.22
	2014	3.5	0.22
100-175	2012	4.3	0.11
175-300	2013	4.3	0.10
300-750	2014	4.3	0.09
750-1200	2013	4.3	0.09
>1200	2012	4.3	0.08

3.2.3.2 Control Inventory Inputs

Table 3-63 shows the NONROAD model emission factor inputs that were used to generate the control case emission inventories for recreational marine diesel engines. These emission factors were applied to engines beginning with the model years shown in Table 3-62. No sulfur adjustment is applied to the Tier 3 PM calculations, since these engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced

All other modeling inputs are the same as shown above for the base case inventory development. Table 3-56 and Table 3-57 list the base engine populations, average hp by power range, annual activity, load factor, and median life. These are unchanged from the default inputs in the NONROAD model.

Table 3-63 Control Emission Factors for Recreational Marine Diesel Engines

	TIER 3 EMISSION FACTORS G/HP-HR			
HP RANGE	PM_{10}	NO_X	HC	CO
0-11	0.24	4.39	0.43	4.11
11-16	0.19	3.63	0.21	2.16
16-25	0.19	3.63	0.21	2.16
25-50	0.18	3.71	0.41	1.53
	0.18	2.32	0.41	1.53
50-75	0.13	3.82	0.2	0.95
	0.13	2.39	0.2	0.95
75-100	0.13	3.82	0.2	0.95
	0.13	2.39	0.2	0.95
100-175	0.088	3.34	0.13	0.95
175-300	0.08	3.9	0.22	0.95
300-600	0.072	3.98	0.29	0.95
600-750	0.072	3.98	0.29	0.95
750-1200	0.072	3.98	0.29	0.95
>1200	0.064	3.98	0.29	0.95
DF ("A")	0.473	0.009	0.034	0.101

3.2.3.3 Recreational Marine Diesel Control Inventory

3.2.3.3.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

The control case 50-state emission inventories for recreational marine diesel engines (inboard and outboard combined) resulting from the control case model inputs presented above are shown in Table 3-64.

3.2.3.3.2 Air Toxics Emissions

The control case air toxics inventories for recreational marine diesel engines are provided in Table 3-65. Gaseous air toxics and POM are reduced proportionately to VOC and $PM_{2.5}$, respectively.

Table 3-64 Control Case (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

YEAR	PM$_{10}$	PM$_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	1,130	1,096	40,437	1,540	1,462	6,467	5,145
2003	1,161	1,126	41,572	1,578	1,499	6,642	5,290
2004	1,192	1,156	42,704	1,618	1,536	6,816	5,436
2005	1,223	1,186	43,835	1,656	1,573	6,989	5,582
2006	1,247	1,210	44,089	1,720	1,633	7,161	5,621
2007	1,054	1,023	44,307	1,783	1,693	7,331	2,967
2008	915	888	44,513	1,846	1,753	7,499	993
2009	937	909	44,649	1,912	1,816	7,665	1,017
2010	935	907	44,772	1,978	1,878	7,829	764
2011	938	910	44,880	2,044	1,941	7,991	578
2012	931	903	44,938	2,104	1,998	8,150	311
2013	929	901	44,889	2,159	2,051	8,308	113
2014	943	915	44,724	2,206	2,095	8,464	136
2015	956	927	44,551	2,252	2,139	8,618	150
2016	966	937	44,368	2,298	2,183	8,771	153
2017	976	947	44,178	2,345	2,227	8,922	156
2018	986	956	43,982	2,391	2,271	9,073	156
2019	994	965	43,780	2,438	2,316	9,223	159
2020	1,003	973	43,579	2,486	2,361	9,374	162
2021	1,011	981	43,380	2,534	2,406	9,525	165
2022	1,018	988	43,181	2,582	2,452	9,675	168
2023	1,025	995	42,989	2,629	2,497	9,825	171
2024	1,032	1,001	42,814	2,676	2,542	9,975	174
2025	1,038	1,007	42,672	2,723	2,586	10,124	177
2026	1,046	1,015	42,688	2,765	2,626	10,279	180
2027	1,056	1,024	42,868	2,803	2,662	10,439	183
2028	1,065	1,033	43,096	2,840	2,697	10,601	186
2029	1,075	1,043	43,364	2,877	2,732	10,765	189
2030	1,086	1,053	43,665	2,913	2,766	10,930	192
2031	1,097	1,064	43,989	2,948	2,800	11,095	196
2032	1,108	1,075	44,343	2,985	2,835	11,262	199
2033	1,121	1,088	44,741	3,024	2,872	11,429	202
2034	1,135	1,101	45,189	3,065	2,911	11,596	205
2035	1,149	1,114	45,672	3,108	2,952	11,765	208
2036	1,163	1,128	46,177	3,151	2,993	11,933	211
2037	1,178	1,143	46,697	3,195	3,034	12,102	214
2038	1,193	1,157	47,234	3,239	3,076	12,272	217
2039	1,208	1,172	47,785	3,282	3,117	12,442	220
2040	1,223	1,187	48,347	3,326	3,159	12,613	223

Table 3-65 Control Case Air Toxic Emissions for Recreational Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	34	33	31	31
FORMALDEHYDE	198	192	182	178
ACETALDEHYDE	89	86	82	80
1,3-BUTADIENE	3	3	3	3
ACROLEIN	5	5	5	5
NAPHTHALENE	0	0	0	0
POM	0	0	0	0

3.2.4 Projected Recreational Marine Emission Reductions of Final Rule

The $PM_{2.5}$, NO_x, and VOC emission reductions by calendar year are shown in Table 3-66. The air toxic emission reductions by pollutant and calendar year are given in Table 3-67.

Table 3-66 Projected Recreational Marine Emission Reductions (short tons)

YEAR	PM $_{2.5}$	NO_X	VOC
2008	0	0	0
2009	0	0	1
2010	0	0	1
2011	1	0	2
2012	3	39	8
2013	5	174	20
2014	9	415	40
2015	13	657	61
2016	17	902	82
2017	21	1,148	103
2018	25	1,397	124
2019	29	1,647	146
2020	34	1,898	167
2021	38	2,151	189
2022	43	2,405	211
2023	48	2,659	233
2024	53	2,915	255
2025	59	3,171	277
2026	64	3,426	299
2027	70	3,681	321
2028	75	3,935	343
2029	81	4,187	365
2030	86	4,437	386
2031	92	4,682	407
2032	97	4,915	427
2033	101	5,120	444
2034	105	5,288	459
2035	108	5,434	471
2036	111	5,570	483
2037	114	5,702	494
2038	116	5,828	505
2039	119	5,951	516
2040	122	6,070	526

Table 3-67 Projected Air Toxic Reductions from Recreational Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	0	1	2	4
FORMALDEHYDE	0	5	12	24
ACETALDEHYDE	0	2	6	11
1,3-BUTADIENE	0	0	0	0
ACROLEIN	0	0	0	1
NAPHTHALENE	0	0	0	0
POM	0	0	0	0

3.3 Locomotives

3.3.1 General Methodology

Given the quality of the data available, it was possible to develop more detailed estimates of fleet composition and emission rates. As described in this chapter, detailed data on fuel consumption, fleet size, and fleet composition were available from industry sources. Load factors and emission factors were developed in the previous rulemaking. However, usage and scrappage rates had to be assumed based on less detailed information. These assumptions were made available to the railroads and the rest of the public in the NPRM, and we received no information to contradict them. It is important to note that the overall analysis is much less sensitive to these assumptions than to the estimates of fuel consumption and emission factors.

Locomotive emissions were calculated based on estimated current and projected fuel consumption rates. Emissions were calculated separately for the following locomotive categories:

- Large Railroad Line-Haul Locomotives
- Large Railroad Switching (including Class III Switch railroads owned by Class I railroads)
- Other Line-Haul Locomotives (such as local railroads)
- Other Switch/Terminal Locomotives
- Passenger/Commuter Locomotives

We used the following approach for all categories, except for the small railroads (see 3.3.2.3). For each calendar year, locomotives were tracked separately by model year and then the activity was summed (in terms of work, fuel, and emissions) for all model years in the fleet. Seven basic steps were used to determine emissions in any calendar year:

1. Start with the fleet from the previous calendar year.
2. Determine which model years would be due to be remanufactured or scrapped.
3. Update the fleet to remove locomotives that would be scrapped.
4. Determine the amount of work that would be done by the remaining locomotives from the previous year's fleet.
5. Determine the number of freshly manufactured (i.e., brand new) locomotives that would be purchased, and add them to the fleet.
6. Determine the total amount of work that would be done by all the locomotives in the fleet.
7. Determine total emissions from the work and brake-specific emission factors.

3.3.1.1 Base Fleet

As is described later, the base fleet was estimated for 2005 from a variety of industry sources. A new base fleet is calculated for each subsequent calendar year based on the scrappage rates and sales. The base fleet is a sum of multiple model years that are described by the number of locomotives in the fleet, the average work that has been accumulated since the last time it was remanufactured (in megawatt-hours or MW-hr), the average horsepower, and the Tier of standards to which they are certified.

3.3.1.2 Useful Life

In this analysis, all locomotives are assumed to be either remanufactured or scrapped when they reach or exceed their useful life. The useful life in MW-hrs is set equal to the rated horsepower of the locomotive multiplied by 7.5. Thus a 4000 horsepower locomotive would have a useful life of 30,000 MW-hrs. Annual accumulation of MW-hrs is projected based on the assumed rated horsepower of the locomotive and the relative use rate (which is a function of locomotive age). At the end of this second step, the projected fleet is adjusted to reflect a year's worth of use beyond the previous base fleet.

3.3.1.3 Scrappage

For each future calendar year, there will generally be some locomotive model years that will be projected to have reached the end of their current useful life. For example, we estimate that there will be 243 line-haul freight locomotives in use in 2010 that:

- Were originally manufactured in model year 1986.
- Will be accumulating about 2000 MW-hrs per year.
- Will reach the end of their useful lives during 2011.

According to our scrappage curve, we estimate that 15 of these locomotives will be scrapped in 2011. The remaining 228 are projected to be remanufactured. We perform this analysis for each model year, then update that fleet to remove locomotives that would be scrapped and change the emission levels for locomotives that are remanufactured to new standards.

3.3.1.4 Work Done by Old Fleet

Once the existing fleet is adjusted for each new calendar year, we determine the amount of work that would be done by the remaining locomotives from the previous year's fleet. First we calculate the amount of work done by each model year's fleet as follows:

Equation 3-14 $$W_i = (H) \times (LF) \times (N_i) \times (P_i) \times (RUF_i)$$

W_i = Combined annual work output for all locomotives remaining in the fleet that were originally manufactured in model year i.

H = Number of hours per year that a newly manufactured locomotive is projected to be used (approximately 4000 to 5000 hrs/yr).

L = Typical average load factor.

N_i = Number of locomotives remaining in the fleet that were originally manufactured in model year i.

P_i = Average rated power of locomotives remaining in the fleet that were originally manufactured in model year i.

RUF_i = Relative use factor for locomotives remaining in the fleet that were originally manufactured in model year i.

The total work done by the remaining fleet (W_r) is calculated by summing the work done by each model year (W_i).

3.3.1.5 New Sales

Sales of freshly manufactured locomotives are projected for each calendar year after the remaining fleet has been analyzed. These newly manufactured locomotives are added to the remaining locomotives to comprise a new total fleet. The number is calculated based on the amount of fuel that is projected to be used in that calendar year:

Equation 3-15 $$New\,Sales = (Total\ Fuel / BSFC - W_r) / H / LF / P$$

Where BSFC is the estimated brake specific fuel consumption rate (Gal/MW-hr)

3.3.1.6 Total Work

The total amount of work that would be done by all the locomotives in the fleet is calculated for each calendar year by summing the work projected to be done by the newly manufactured locomotives and the work projected to be done by the remaining locomotives. The total work is calculated separately for each tier of locomotives.

3.3.1.7 Emissions

Emissions are determined from the work calculated in section 3.3.1.6 (converted to hp-hrs) and brake-specific emission factors:

Equation 3-16 $$\mathit{Total\ Emissions} = (\mathit{Total\ Work}) \times (\mathit{Emission\ Factor})$$

The emission factors used are the estimated average in-use emissions for each tier of standards, which are shown in Table 3-68 and Table 3-69. They take into account deterioration of emissions throughout the useful life, production variations, and the compliance margins that manufacturers incorporate into their designs. For this analysis, we are generally assuming that average in-use emission levels will be 10 percent below the applicable standards.

Table 3-68 Baseline Line-Haul Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.32	0.48	13.0	1.28
TIER 0	0.32	0.48	8.60	1.28
TIER 1	0.32	0.47	6.70	1.28
TIER2	0.18	0.26	4.95	1.28

Table 3-69 Baseline Switch Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.44	1.01	17.4	1.83
TIER 0	0.44	1.01	12.6	1.83
TIER 1	0.43	1.01	9.9	1.83
TIER 2	0.19	0.51	7.3	1.83

These PM_{10} emission factors reflect the emission rates expected from locomotives operating on current in-use fuel with sulfur levels at 3000 ppm. The emission inventories described in this chapter, however, account for the reductions in sulfate particulate expected to result from using lower sulfur fuels after 2007. We estimate that the PM_{10} emission rate for locomotives operating on nominally 500 ppm sulfur fuel will be 0.05 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3000 ppm sulfur fuel. Similarly we estimate that the PM_{10} emission rate for locomotives operating on nominally 15 ppm sulfur fuel will be 0.06 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3000 ppm sulfur fuel. This is higher than the estimates used for the NPRM because they are based on newer data.

To estimate VOC emissions, an adjustment factor of 1.053 is applied to the HC output.[39] Similarly, to estimate $PM_{2.5}$ emissions, an adjustment factor of 0.97 is applied to the PM_{10} output.[40] These adjustment factors are the same as those used for marine engines.

3.3.2 Baseline (Pre-Control) Inventory Development

In developing the baseline inventory, we collected fuel consumption estimates from the regulated industries, including publicly available estimates for Class I and commuter railroads. We used the same estimated average in-use emission factors and load factors as we used in the previous rulemaking.

We are using a projection by the Energy Information Administration (EIA) that locomotive fuel consumption will grow 1.6 percent annually.[41] We are assuming that this fuel growth applies equally across all categories of locomotives and is directly proportional to engine work performed by the fleet.

Table 3-70 Summary of Locomotive Emission Analysis Inputs

	Large Line-Haul	Large Switch	Small Line-Haul	Small Switch	Passenger/ Commuter
2005 FUEL CONSUMPTION (GAL/YR)	3.981 BILLION	315 MILLION	34 MILLION	34 MILLION	142 MILLION
HOURS USED PER YEAR WHEN NEW	4350	4450	NA	NA	3900
YEARS AFTER WHICH USAGE BEGINS TO DECLINE	8	50	NA	NA	20
HOURS PER YEAR AT END OF LIFE	1740 @ 40 YRS	3115 @ 70 YRS	NA	NA	2340@30YRS
AGE AFTER WHICH SCRAPPAGE BEGINS	20	50	NA	NA	20
AGE AFTER WHICH NO LOCOMOTIVES REMAIN IN FLEET	40	70	NA	NA	30
LOAD FACTOR (AVG HP/RATED HP)	0.275	0.100	0.275	0.100	0.275
AVG HP-HR/GAL	20.8	15.2	18.2	15.2	20.8

3.3.2.1 Large Line-Haul

The large line-haul category includes line-haul freight locomotives that are fully subject to the standards being final. Class III locomotives that are owned and operated by railroads that qualify as small businesses are addressed separately, as described in 3.3.2.3. The large line-haul analysis is based primarily on data collected for Class I and Class II railroads. However, as described in 3.3.2.3, the total fuel includes one-third of the estimated Class III fuel use to account for those Class III railroads that do not qualify as small businesses. The estimate of current Class I total fuel use came from the AAR Railroad Facts booklet. The estimate of Class II railroad fuel consumption is based on the survey information provided by the American Shortline Railroad Association for Class II and Class III railroads. These results had to be adjusted upward to correct for a response rate of approximately 85 percent. The combined total for Class I and Class II railroads was reduced by 7 percent to reflect fuel used in switching rather than line-haul operation.[42]

The fleet composition for all large railroads was estimated based on a contractor analysis. The contractor estimated that this fleet included 19,757 locomotives with more than 2500 hp. (Locomotives with 2500 hp or less were assumed to be used primarily in switching operations.) To be precise, this estimate was intended to reflect the locomotives that were subject to the Part 92 regulations and thus excluded Class II locomotives owned by small businesses. An additional 878 locomotives were added to account for the previously excluded Class II locomotives. Usage and scrappage patterns were developed to fit the fuel use and fleet composition data. The average in-use load factor was assumed to be the same as the load factor for a typical line-haul duty cycle test.

3.3.2.2 Large Switch

We generally used the same approach to calculate switch emissions as we used to calculate line-haul emissions, but we used different inputs. We also made one change to the analysis of future sales. We assumed that the majority of growth in switching activity will be achieved by using switch locomotives more rather than by adding new switch locomotives to the fleet. More specifically, we assumed that 1.2 percent of the annual 1.6 percent growth in activity will be achieved by using the existing switchers more, while only 0.4 percent of the growth will be achieved by increasing the number of switchers in the fleet.

As shown in Table 3-70, we believe that switch locomotives tend to last longer in the fleet and have a lower in-use load factor than line-haul locomotives. Thus the average age of switch locomotives is much older than for line-haul. We also estimate that switching operation will use approximately 7 percent of total large railroad fuel, and will grow at the same rate as line-haul operation. The switch fleet composition for all large railroads was estimated based on the same contractor analysis used for the line-haul fleet. The contractor estimated that this fleet included 5206 locomotives with 2500 hp or less. This included 1645 locomotives with 2250 to 2500 hp. While we recognize that some of these locomotives will be used in branch service[D], for this analysis they are assumed to be used primarily in switching operations. The FRM analysis includes an additional 66 switch locomotives owned by previously excluded Class II railroads.

3.3.2.3 Small Railroads

We used a simplified approach for small railroads (that is, railroads that are not required to retrofit their locomotive with new emission controls because they qualify as "small railroads" under the regulatory definition). We assume that these small railroads are unlike the larger railroads in the following ways:

- They do not purchase newly manufactured locomotives.
- They use their locomotives at a constant rate.
- They replace their existing locomotives at a constant rate of 3 percent per year.
- Brake-specific PM emissions are 0.03 g/bhp-hr higher for locomotives owned by small railroads (relative to Class I/II locomotives) because of their higher fuel consumption rates.

[D] Branch service includes short-haul operations that would be considered intermediate to intercity line-haul service and switch service.

For this analysis, we considered small railroad activity in the same two categories as the larger railroads: line-haul and switch. For small line-haul operations, we are projecting that railroads will scrap and replace their oldest locomotives with 25 year-old locomotives purchased from the larger railroads. Thus, the inventory analysis has these railroads obtaining Tier 1 locomotives starting in 2026, and Tier 2 locomotives in 2030. For small switch operations, the railroads are projected to replace their scrapped locomotives with only uncontrolled or Tier 0 locomotives purchased from the larger railroads. This analysis runs through 2040 and we consider it unlikely that any significant number of Tier 1 or later switch locomotives will be available for small railroads before 2040.

The analysis of small railroads is based on the survey information provided by the American Shortline Railroad Association for Class III railroads. These results had to be adjusted upward to correct for a response rate of approximately 85 percent. We also had to adjust these estimates because not all Class III railroads qualify as small railroads under the regulations. We estimate that one-third of these railroads are owned by Class I railroads or other large businesses. Finally, we estimated that Class III railroads use 50 percent of their fuel in switching service. We thus estimate that small Class III railroads used a total of 34 million gallons of diesel fuel in line-haul service in 2005, and 34 million gallons of diesel fuel in switching service, as shown in Table 3-64.

3.3.2.4 Passenger/Commuter

We used the same approach to calculate passenger and commuter emissions as we used to calculate large line-haul emissions, but we used different inputs. As shown in Table 3-1, we believe that passenger/commuter locomotives tend to have an average age that is slightly newer than for line-haul. We used estimates from AMTRAK and APTA for current fuel consumption rates, and project that these will grow at the same rate as line-haul operation.

3.3.2.5 Locomotive Baseline Inventory Summary

The baseline locomotive inventory is shown separately for PM_{10}, $PM_{2.5}$, NO_x, VOC, HC, CO, and SO_2 in Table 3-71 through Table 3-77.

The baseline air toxics inventories for locomotives were taken from the MSAT rule and are provided in Table 3-78. Inventories are provided for calendar years 1999, 2010, 2015, 2020, and 2030.

Table 3-71 Baseline (50-State) PM_{10} Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	28,477	2,304	492	1,023	32,296
2007	28,401	2,329	500	1,011	32,241
2008	23,293	2,071	442	822	26,629
2009	23,152	2,093	449	807	26,502
2010	22,989	2,115	456	793	26,353
2011	22,815	2,137	464	778	26,193
2012	22,635	2,159	471	762	26,028
2013	21,759	2,141	469	723	25,093
2014	21,582	2,163	477	708	24,930
2015	21,394	2,185	484	692	24,755
2016	21,193	2,208	491	676	24,567
2017	20,990	2,231	498	660	24,379
2018	20,792	2,254	505	644	24,195
2019	20,593	2,277	513	628	24,010
2020	20,388	2,301	520	612	23,821
2021	20,178	2,324	528	596	23,626
2022	19,964	2,348	535	581	23,428
2023	19,748	2,353	543	565	23,209
2024	19,542	2,350	551	549	22,992
2025	19,332	2,342	559	533	22,766
2026	19,151	2,329	567	520	22,567
2027	18,996	2,310	575	510	22,391
2028	18,868	2,286	584	501	22,239
2029	18,768	2,260	592	496	22,115
2030	18,692	2,227	597	492	22,007
2031	18,645	2,188	601	489	21,923
2032	18,625	2,143	606	489	21,863
2033	18,629	2,097	610	490	21,827
2034	18,662	2,046	615	493	21,816
2035	18,727	1,996	620	497	21,840
2036	18,827	1,945	624	501	21,898
2037	18,953	1,909	629	505	21,996
2038	19,105	1,879	633	509	22,127
2039	19,287	1,850	638	513	22,287
2040	19,497	1,819	642	517	22,476

Table 3-72 Baseline (50-State) $PM_{2.5}$ Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,622	2,235	478	992	31,327
2007	27,549	2,259	485	981	31,274
2008	22,595	2,009	429	797	25,830
2009	22,458	2,030	436	783	25,707
2010	22,300	2,051	443	769	25,562
2011	22,130	2,073	450	754	25,407
2012	21,956	2,094	457	740	25,247
2013	21,107	2,077	455	702	24,340
2014	20,935	2,098	462	686	24,182
2015	20,752	2,120	469	671	24,012
2016	20,557	2,142	476	656	23,830
2017	20,361	2,164	483	640	23,648
2018	20,168	2,186	490	625	23,469
2019	19,975	2,209	497	609	23,290
2020	19,776	2,232	504	594	23,106
2021	19,572	2,255	512	578	22,917
2022	19,365	2,278	519	563	22,725
2023	19,156	2,282	527	548	22,513
2024	18,955	2,280	534	533	22,302
2025	18,752	2,271	542	517	22,083
2026	18,576	2,259	550	505	21,890
2027	18,426	2,241	558	494	21,719
2028	18,302	2,218	566	486	21,572
2029	18,205	2,192	574	481	21,452
2030	18,131	2,160	579	477	21,347
2031	18,086	2,122	583	475	21,266
2032	18,066	2,079	588	474	21,207
2033	18,070	2,034	592	476	21,172
2034	18,102	1,985	597	478	21,162
2035	18,166	1,936	601	482	21,185
2036	18,262	1,887	605	486	21,241
2037	18,384	1,852	610	490	21,336
2038	18,532	1,823	614	494	21,463
2039	18,708	1,794	619	498	21,619
2040	18,913	1,765	623	502	21,802

Table 3-73 Baseline (50-State) NO_x Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	802,958	88,191	18,256	38,466	947,871
2007	791,683	89,152	18,548	36,409	935,793
2008	781,652	89,244	18,845	34,361	924,102
2009	775,692	90,220	19,146	32,338	917,397
2010	765,957	90,298	19,453	30,370	906,078
2011	756,495	91,286	19,764	28,459	896,004
2012	751,219	90,636	20,080	27,212	889,147
2013	747,643	91,627	20,402	26,017	885,689
2014	744,236	90,873	20,728	24,872	880,710
2015	740,810	91,866	20,960	24,382	878,018
2016	737,040	91,523	21,195	23,325	873,083
2017	733,648	92,522	21,431	22,922	870,523
2018	730,943	92,775	21,670	22,559	867,947
2019	729,027	93,779	21,851	22,197	866,854
2020	727,038	91,309	22,032	21,836	862,215
2021	725,264	92,294	22,214	21,477	861,249
2022	723,450	91,215	22,396	21,119	858,178
2023	721,953	91,400	22,578	20,797	856,728
2024	720,934	89,923	22,760	20,510	854,127
2025	720,243	87,571	22,942	20,256	851,012
2026	720,287	87,376	23,124	20,066	850,854
2027	720,940	87,055	23,254	19,935	851,184
2028	722,270	86,654	23,383	19,860	852,167
2029	724,347	86,197	23,509	19,836	853,890
2030	727,188	85,620	23,584	19,859	856,251
2031	730,771	84,916	23,656	19,926	859,269
2032	735,073	84,125	23,723	20,033	862,953
2033	740,040	83,298	23,787	20,160	867,284
2034	745,745	82,395	23,847	20,305	872,292
2035	752,326	81,507	23,902	20,468	878,203
2036	759,819	80,635	23,953	20,631	885,038
2037	768,001	80,347	24,000	20,797	893,145
2038	776,894	80,345	24,042	20,963	902,243
2039	786,558	80,358	24,079	21,131	912,125
2040	797,012	80,353	24,111	21,300	922,775

Table 3-74 Baseline (50-State) VOC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	44,756	5,585	928	1,609	52,878
2007	44,595	5,650	943	1,589	52,777
2008	44,431	5,730	958	1,568	52,685
2009	44,293	5,797	973	1,546	52,609
2010	44,122	5,865	989	1,523	52,498
2011	43,933	5,934	1,004	1,500	52,371
2012	43,739	6,004	1,020	1,476	52,239
2013	43,560	6,074	1,037	1,453	52,124
2014	43,392	6,146	1,053	1,429	52,020
2015	43,211	6,218	1,070	1,404	51,904
2016	43,010	6,292	1,087	1,380	51,769
2017	42,809	6,366	1,105	1,356	51,635
2018	42,616	6,441	1,122	1,332	51,511
2019	42,425	6,517	1,140	1,307	51,390
2020	42,227	6,595	1,159	1,283	51,263
2021	42,022	6,673	1,177	1,259	51,131
2022	41,813	6,752	1,196	1,235	50,996
2023	41,605	6,790	1,215	1,212	50,822
2024	41,416	6,814	1,235	1,188	50,653
2025	41,226	6,825	1,254	1,165	50,471
2026	41,085	6,829	1,274	1,146	50,335
2027	40,991	6,819	1,295	1,132	50,237
2028	40,942	6,801	1,316	1,121	50,180
2029	40,943	6,777	1,337	1,114	50,170
2030	41,000	6,740	1,358	1,110	50,208
2031	41,107	6,690	1,380	1,109	50,286
2032	41,261	6,630	1,402	1,111	50,405
2033	41,460	6,567	1,424	1,116	50,567
2034	41,708	6,494	1,447	1,123	50,772
2035	42,014	6,423	1,470	1,132	51,038
2036	42,379	6,352	1,494	1,141	51,366
2037	42,791	6,311	1,518	1,150	51,770
2038	43,249	6,285	1,542	1,159	52,236
2039	43,759	6,261	1,566	1,169	52,755
2040	44,321	6,234	1,592	1,178	53,325

Table 3-75 Baseline (50-State) HC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/Commuter	Total
2006	42,503	5,304	881	1,528	50,216
2007	42,350	5,366	895	1,509	50,121
2008	42,194	5,441	909	1,489	50,034
2009	42,064	5,505	924	1,468	49,961
2010	41,901	5,570	939	1,446	49,856
2011	41,722	5,635	954	1,424	49,735
2012	41,537	5,701	969	1,402	49,610
2013	41,368	5,769	985	1,379	49,500
2014	41,208	5,837	1,000	1,357	49,402
2015	41,036	5,905	1,016	1,334	49,292
2016	40,845	5,975	1,033	1,311	49,163
2017	40,654	6,046	1,049	1,288	49,036
2018	40,471	6,117	1,066	1,265	48,919
2019	40,290	6,189	1,083	1,242	48,804
2020	40,101	6,263	1,100	1,219	48,683
2021	39,907	6,337	1,118	1,196	48,557
2022	39,709	6,412	1,136	1,173	48,430
2023	39,511	6,448	1,154	1,151	48,264
2024	39,331	6,471	1,172	1,129	48,103
2025	39,151	6,482	1,191	1,107	47,931
2026	39,017	6,485	1,210	1,089	47,801
2027	38,928	6,476	1,230	1,075	47,709
2028	38,882	6,459	1,249	1,064	47,654
2029	38,882	6,436	1,269	1,058	47,645
2030	38,936	6,401	1,290	1,054	47,681
2031	39,038	6,353	1,310	1,053	47,755
2032	39,184	6,297	1,331	1,055	47,868
2033	39,373	6,236	1,352	1,060	48,022
2034	39,609	6,168	1,374	1,067	48,217
2035	39,899	6,099	1,396	1,075	48,469
2036	40,246	6,032	1,418	1,084	48,780
2037	40,637	5,994	1,441	1,092	49,164
2038	41,072	5,969	1,464	1,101	49,607
2039	41,557	5,946	1,488	1,110	50,100
2040	42,090	5,920	1,511	1,119	50,641

Table 3-76 Baseline (50-State) CO Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	118,701	9,788	1,863	4,201	134,553
2007	120,601	9,944	1,893	4,234	136,672
2008	122,530	10,103	1,923	4,268	138,825
2009	124,491	10,265	1,954	4,302	141,012
2010	126,483	10,429	1,985	4,337	143,234
2011	128,506	10,596	2,017	4,371	145,491
2012	130,562	10,766	2,049	4,406	147,784
2013	132,651	10,938	2,082	4,442	150,113
2014	134,774	11,113	2,116	4,477	152,480
2015	136,930	11,291	2,149	4,513	154,884
2016	139,121	11,472	2,184	4,549	157,326
2017	141,347	11,655	2,219	4,585	159,806
2018	143,609	11,842	2,254	4,622	162,327
2019	145,906	12,031	2,290	4,659	164,887
2020	148,241	12,224	2,327	4,696	167,488
2021	150,613	12,419	2,364	4,734	170,130
2022	153,023	12,618	2,402	4,772	172,814
2023	155,471	12,820	2,440	4,810	175,541
2024	157,958	13,025	2,480	4,849	178,311
2025	160,486	13,233	2,519	4,887	181,125
2026	163,054	13,445	2,559	4,926	183,984
2027	165,662	13,660	2,600	4,966	186,889
2028	168,313	13,879	2,642	5,006	189,839
2029	171,006	14,101	2,684	5,046	192,837
2030	173,742	14,326	2,727	5,086	195,882
2031	176,522	14,555	2,771	5,127	198,975
2032	179,346	14,788	2,815	5,168	202,118
2033	182,216	15,025	2,860	5,209	205,310
2034	185,131	15,265	2,906	5,251	208,553
2035	188,093	15,510	2,953	5,293	211,848
2036	191,103	15,758	3,000	5,335	215,196
2037	194,161	16,010	3,048	5,378	218,596
2038	197,267	16,266	3,097	5,421	222,050
2039	200,423	16,526	3,146	5,464	225,560
2040	203,630	16,791	3,196	5,508	229,125

Table 3-77 Baseline (50-State) SO_2 Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	84,429	6,685	1,429	2,988	95,531
2007	85,780	6,792	1,452	3,012	97,036
2008	10,168	805	172	354	11,499
2009	10,330	818	175	357	11,680
2010	10,496	831	178	360	11,864
2011	10,664	844	181	363	12,051
2012	10,834	858	183	366	12,241
2013	315	25	5	11	355
2014	320	25	5	11	361
2015	325	26	5	11	367
2016	330	26	6	11	372
2017	335	27	6	11	378
2018	340	27	6	11	384
2019	346	27	6	11	390
2020	351	28	6	11	396
2021	357	28	6	11	403
2022	363	29	6	11	409
2023	369	29	6	11	415
2024	375	30	6	11	422
2025	380	30	6	12	429
2026	387	31	7	12	435
2027	393	31	7	12	442
2028	399	32	7	12	449
2029	405	32	7	12	456
2030	412	33	7	12	464
2031	419	33	7	12	471
2032	425	34	7	12	478
2033	432	34	7	12	486
2034	439	35	7	12	494
2035	446	35	8	13	501
2036	453	36	8	13	509
2037	460	36	8	13	517
2038	468	37	8	13	526
2039	475	38	8	13	534
2040	483	38	8	13	542

Table 3-78 Baseline (50-State) Air Toxics Emissions for Locomotives (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	92	84	82	80	76
FORMALDEHYDE	1,467	1,339	1,318	1,280	1,214
ACETALDEHYDE	640	584	575	558	530
1,3-BUTADIENE	107	98	96	93	88
ACROLEIN	104	94	93	90	86
NAPHTHALENE	58	42	40	38	34
POM	35	25	24	23	20

3.3.3 Control Inventory Development

Control inventories were developed in the same manner as the baseline inventories. The only change was in the emission factors.

3.3.3.1 Control Scenario Modeled

The final regulations will apply in largely the same manner as the existing program. Thus, the control scenario can be defined simply by the final standards and the model years for which they become effective. Two new sets of emission standards are being finalized: line-haul locomotive standards and switch locomotive standards. The line-haul standards apply for freight and passenger line-haul locomotives, while the switch standards apply for freight and passenger switch locomotives. Note; we are not changing the emission standards for CO.

As in the baseline analysis, average in-use emission factors for the analysis of the final standards were generally assumed to be 10 percent below the applicable standards, to account for deterioration of emissions throughout the useful life, production variations, and the compliance margins that manufacturers incorporate into their designs. The exceptions to this general rule are the HC emissions for all locomotives and the NO_x emissions for Tier 4 locomotives. While we are changing the Tier 3 or earlier HC standards, we expect the emission controls for PM_{10} will generally achieve proportional reductions in HC. For Tier 4 NO_x standards, we expect that manufacturers will need to have lower zero-hour emission rates to account for potential deterioration and include larger compliance margins (expressed as a percentage of the standards).

The emission factors used to generate the control case inventories are given in Table 3-79 and Table 3-80.

Table 3-79 Projected Line-Haul Emission Factors with Final Standards

Tier	Initial Model Year	NO_x (g/bhp-hr)	PM_{10} (g/bhp-hr)	HC (g/bhp-hr)
TIER 0	2008/2010[A]	7.20	0.20	0.30
TIER 1	2008/2010[A]	6.70	0.20	0.29
TIER 2	2013	4.95	0.08	0.13
TIER 3	2012	4.95	0.08	0.13
TIER 4	2015	1.00	0.015	0.04

[A] The new Tier 0 standard would apply in 2008 where kits are available, and for all locomotives in 2010. This is modeled as apply the new Tier 0/1 standards to 660 locomotives in 2008 and 2009.

Table 3-80 Projected Switch Emission Factors with Final Standards

Tier	Initial Model Year	NO_x (g/bhp-hr)	PM_{10} (g/bhp-hr)	HC (g/bhp-hr)
TIER 0	2008	10.62	0.23	0.57
TIER 1	2008	9.90	0.23	0.57
TIER 2	2013	7.30	0.11	0.26
TIER 3	2012	5.40	0.08	0.26
TIER 4	2015	1.00	0.015	0.08

3.3.3.2 Locomotive Control Inventory Summary

The control locomotive inventory is shown separately for PM_{10}, $PM_{2.5}$, NO_x, VOC, and HC in Table 3-81 through Table 3-85. See section 3.3.2.5 for CO and SO_2 inventories which are not projected to change as a result of the final standards.

The control air toxic inventory for locomotives is provided in Table 3-86. The gas phase air toxics are assumed to be controlled proportionately to VOC, while POM is controlled proportionately to PM.

Table 3-81 Control Case PM_{10} Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	28,477	2,304	492	1,023	32,296
2007	28,401	2,329	500	1,011	32,241
2008	23,287	2,019	442	822	26,569
2009	22,804	2,039	449	807	26,100
2010	22,248	2,019	456	774	25,498
2011	21,234	2,037	464	741	24,476
2012	20,203	1,987	471	701	23,362
2013	18,945	1,972	469	647	22,034
2014	18,313	1,928	477	611	21,329
2015	17,451	1,942	481	574	20,448
2016	16,329	1,891	485	532	19,237
2017	15,214	1,904	490	490	18,097
2018	14,363	1,883	494	448	17,188
2019	13,540	1,895	498	407	16,341
2020	12,938	1,798	502	375	15,613
2021	12,324	1,809	507	350	14,990
2022	11,675	1,752	511	325	14,263
2023	11,016	1,732	515	300	13,563
2024	10,367	1,655	520	275	12,817
2025	9,712	1,543	524	250	12,029
2026	9,091	1,505	528	227	11,351
2027	8,492	1,460	533	207	10,692
2028	7,915	1,412	537	188	10,053
2029	7,363	1,361	542	172	9,438
2030	6,844	1,305	543	157	8,849
2031	6,349	1,244	544	144	8,281
2032	5,879	1,179	545	132	7,735
2033	5,431	1,111	546	121	7,209
2034	5,026	1,040	547	111	6,723
2035	4,653	969	547	101	6,270
2036	4,326	897	548	93	5,864
2037	4,033	840	548	86	5,508
2038	3,775	801	549	81	5,205
2039	3,556	761	549	76	4,941
2040	3,375	720	549	72	4,717

Table 3-82 Control Case $PM_{2.5}$ Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,622	2,235	478	992	31,327
2007	27,549	2,259	485	981	31,274
2008	22,588	1,958	429	797	25,772
2009	22,120	1,978	436	783	25,317
2010	21,580	1,959	443	751	24,733
2011	20,597	1,976	450	718	23,741
2012	19,597	1,928	457	680	22,661
2013	18,377	1,913	455	628	21,373
2014	17,764	1,870	462	593	20,689
2015	16,928	1,883	467	557	19,835
2016	15,839	1,835	471	516	18,660
2017	14,757	1,847	475	475	17,554
2018	13,933	1,826	479	435	16,673
2019	13,134	1,838	483	395	15,850
2020	12,550	1,744	487	364	15,145
2021	11,954	1,755	492	340	14,540
2022	11,325	1,700	496	315	13,835
2023	10,685	1,680	500	291	13,156
2024	10,056	1,606	504	266	12,433
2025	9,421	1,497	508	242	11,668
2026	8,818	1,459	513	220	11,010
2027	8,237	1,416	517	200	10,371
2028	7,678	1,370	521	183	9,751
2029	7,143	1,320	525	167	9,155
2030	6,638	1,266	526	153	8,584
2031	6,159	1,207	528	140	8,033
2032	5,703	1,143	529	128	7,503
2033	5,268	1,078	529	117	6,993
2034	4,875	1,009	530	107	6,521
2035	4,513	940	531	98	6,082
2036	4,196	871	532	91	5,689
2037	3,912	815	532	84	5,342
2038	3,662	777	532	78	5,049
2039	3,449	738	533	74	4,793
2040	3,274	698	533	70	4,575

Table 3-83 Control Case NO_x Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	802,958	88,191	18,256	38,466	947,871
2007	791,683	89,152	18,548	36,409	935,793
2008	777,326	88,424	18,845	34,361	918,955
2009	769,265	89,386	19,146	32,338	910,135
2010	748,176	88,920	19,453	29,845	886,393
2011	719,947	89,750	19,764	27,408	856,869
2012	706,002	88,058	20,080	25,933	840,074
2013	691,886	88,873	20,402	24,545	825,706
2014	685,692	87,106	20,728	23,239	816,764
2015	664,161	87,722	20,929	22,225	795,037
2016	634,126	86,130	21,131	20,406	761,792
2017	604,818	86,724	21,334	19,264	732,140
2018	584,819	86,169	21,538	18,185	710,710
2019	566,469	86,754	21,636	17,127	691,985
2020	548,958	82,365	21,732	16,351	669,405
2021	531,295	82,893	21,825	15,591	651,605
2022	512,821	80,480	21,915	14,833	630,049
2023	490,714	79,595	22,003	14,074	606,387
2024	468,890	76,258	22,089	13,316	580,553
2025	446,847	71,540	22,171	12,558	553,116
2026	425,402	69,917	22,250	11,833	529,401
2027	404,319	68,040	22,313	11,182	505,853
2028	383,636	65,996	22,372	10,555	482,558
2029	363,473	63,825	22,427	9,948	459,673
2030	344,049	61,413	22,428	9,355	437,245
2031	326,929	58,747	22,423	8,775	416,875
2032	310,357	55,897	22,413	8,204	396,872
2033	294,261	52,957	22,396	7,641	377,256
2034	279,046	49,854	22,374	7,082	358,355
2035	264,662	46,750	22,344	6,527	340,282
2036	251,877	43,649	22,308	6,048	323,882
2037	240,339	41,172	22,266	5,623	309,400
2038	230,075	39,498	22,216	5,270	297,059
2039	221,180	37,824	22,159	4,986	286,149
2040	213,678	36,091	22,094	4,765	276,629

Table 3-84 Control Case VOC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	44,756	5,585	928	1,609	52,878
2007	44,595	5,650	943	1,589	52,777
2008	43,784	5,574	958	1,568	51,884
2009	42,751	5,639	973	1,546	50,909
2010	41,527	5,572	989	1,470	49,558
2011	39,032	5,624	1,004	1,395	47,055
2012	36,485	5,455	1,020	1,299	44,259
2013	34,151	5,505	1,037	1,205	41,898
2014	32,533	5,347	1,053	1,114	40,048
2015	30,731	5,386	1,070	1,032	38,218
2016	28,146	5,207	1,087	933	35,374
2017	25,595	5,244	1,105	837	32,781
2018	23,874	5,164	1,122	742	30,902
2019	22,241	5,200	1,140	648	29,229
2020	21,372	4,861	1,159	582	27,974
2021	20,495	4,892	1,177	542	27,107
2022	19,568	4,691	1,196	503	25,958
2023	18,629	4,637	1,215	463	24,944
2024	17,708	4,387	1,235	423	23,752
2025	16,780	3,999	1,254	384	22,416
2026	15,904	3,889	1,274	348	21,416
2027	15,061	3,767	1,295	317	20,440
2028	14,252	3,636	1,316	288	19,492
2029	13,481	3,499	1,337	263	18,580
2030	12,758	3,366	1,358	240	17,722
2031	12,074	3,220	1,380	219	16,892
2032	11,427	3,065	1,402	200	16,093
2033	10,812	2,905	1,424	184	15,325
2034	10,264	2,738	1,447	168	14,617
2035	9,764	2,570	1,470	154	13,959
2036	9,332	2,404	1,494	142	13,371
2037	8,952	2,274	1,518	131	12,875
2038	8,624	2,193	1,542	123	12,481
2039	8,353	2,112	1,566	115	12,147
2040	8,141	2,029	1,592	110	11,871

Table 3-85 Control Case HC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	42,503	5,304	881	1,528	50,216
2007	42,350	5,366	895	1,509	50,121
2008	41,581	5,293	909	1,489	49,272
2009	40,600	5,355	924	1,468	48,347
2010	39,437	5,291	939	1,396	47,064
2011	37,067	5,341	954	1,325	44,687
2012	34,648	5,180	969	1,233	42,031
2013	32,432	5,228	985	1,144	39,789
2014	30,896	5,077	1,000	1,058	38,032
2015	29,184	5,114	1,016	980	36,295
2016	26,729	4,945	1,033	886	33,593
2017	24,307	4,980	1,049	795	31,131
2018	22,672	4,904	1,066	704	29,346
2019	21,121	4,938	1,083	615	27,757
2020	20,297	4,616	1,100	553	26,566
2021	19,464	4,646	1,118	515	25,743
2022	18,583	4,455	1,136	477	24,652
2023	17,691	4,404	1,154	440	23,688
2024	16,817	4,166	1,172	402	22,557
2025	15,935	3,797	1,191	364	21,288
2026	15,104	3,694	1,210	330	20,338
2027	14,303	3,578	1,230	301	19,411
2028	13,535	3,453	1,249	274	18,511
2029	12,803	3,323	1,269	249	17,644
2030	12,116	3,196	1,290	228	16,830
2031	11,466	3,058	1,310	208	16,042
2032	10,851	2,910	1,331	190	15,283
2033	10,268	2,759	1,352	174	14,554
2034	9,747	2,600	1,374	160	13,881
2035	9,273	2,441	1,396	146	13,256
2036	8,862	2,283	1,418	135	12,698
2037	8,501	2,160	1,441	125	12,227
2038	8,190	2,083	1,464	116	11,853
2039	7,933	2,006	1,488	110	11,536
2040	7,731	1,926	1,511	104	11,273

Table 3-86 Control Case Air Toxic Emissions for Locomotives (short tons)

HAP	2010	2015	2020	2030
BENZENE	79	61	44	27
FORMALDEHYDE	1,264	971	698	429
ACETALDEHYDE	551	424	305	187
1,3-BUTADIENE	92	71	51	31
ACROLEIN	89	69	49	30
NAPHTHALENE	40	30	21	12
POM	25	20	15	8

3.3.4 Projected Locomotive Emission Reductions from the Final Rule

The projected emission reductions for $PM_{2.5}$, NO_x and VOC for each category of locomotives and calendar year are given in Table 3-87 through Table 3-89. Table 3-90 presents the air toxic emission reductions.

Table 3-87 Projected Locomotive $PM_{2.5}$ Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	6	51	0	0	58
2009	338	52	0	0	390
2010	719	93	0	18	830
2011	1,533	96	0	36	1,666
2012	2,360	167	0	60	2,586
2013	2,730	164	0	74	2,967
2014	3,171	228	0	93	3,492
2015	3,825	236	3	114	4,178
2016	4,718	307	5	140	5,170
2017	5,603	317	8	165	6,094
2018	6,235	360	11	190	6,796
2019	6,841	370	14	214	7,439
2020	7,226	488	17	230	7,961
2021	7,618	500	20	239	8,377
2022	8,040	578	23	248	8,890
2023	8,470	603	27	257	9,357
2024	8,899	674	30	266	9,869
2025	9,331	775	34	275	10,415
2026	9,758	800	37	285	10,880
2027	10,189	824	41	294	11,348
2028	10,624	848	45	304	11,821
2029	11,062	872	49	314	12,297
2030	11,493	894	52	324	12,764
2031	11,927	915	56	335	13,233
2032	12,363	936	59	347	13,705
2033	12,802	956	63	359	14,180
2034	13,227	976	66	371	14,640
2035	13,652	996	70	384	15,102
2036	14,067	1,016	74	395	15,552
2037	14,473	1,037	78	406	15,993
2038	14,870	1,046	82	416	16,414
2039	15,259	1,056	86	424	16,826
2040	15,638	1,066	90	432	17,227

Table 3-88 Projected Locomotive NO_x Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	4,327	820	0	0	5,147
2009	6,428	834	0	0	7,261
2010	17,781	1,378	0	526	19,684
2011	36,548	1,535	0	1,051	39,135
2012	45,217	2,578	0	1,278	49,073
2013	55,757	2,754	0	1,472	59,983
2014	58,545	3,767	0	1,634	63,946
2015	76,649	4,144	31	2,157	82,981
2016	102,915	5,393	64	2,919	111,291
2017	128,830	5,798	97	3,658	138,383
2018	146,125	6,605	132	4,374	157,237
2019	162,559	7,025	215	5,071	174,869
2020	178,080	8,944	301	5,486	192,811
2021	193,969	9,401	389	5,885	209,644
2022	210,629	10,734	480	6,286	228,129
2023	231,239	11,805	574	6,723	250,341
2024	252,043	13,665	671	7,195	273,574
2025	273,396	16,030	771	7,699	297,895
2026	294,886	17,460	873	8,233	321,452
2027	316,621	19,015	941	8,753	345,331
2028	338,635	20,659	1,011	9,305	369,609
2029	360,874	22,372	1,083	9,888	394,217
2030	383,139	24,207	1,157	10,504	419,006
2031	403,841	26,169	1,232	11,151	442,394
2032	424,715	28,228	1,310	11,828	466,082
2033	445,778	30,341	1,391	12,519	490,029
2034	466,699	32,542	1,473	13,223	513,937
2035	487,665	34,757	1,558	13,941	537,920
2036	507,942	36,986	1,645	14,584	561,156
2037	527,662	39,175	1,734	15,173	583,744
2038	546,818	40,847	1,826	15,693	605,184
2039	565,378	42,533	1,920	16,145	625,976
2040	583,334	44,261	2,017	16,534	646,146

Table 3-89 Projected Locomotive VOC Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	638	143	0	0	802
2009	1,477	144	0	0	1,700
2010	2,476	279	0	52	2,940
2011	4,727	296	0	105	5,316
2012	7,002	534	0	175	7,980
2013	9,102	554	0	242	10,226
2014	10,527	784	0	307	11,972
2015	12,054	817	0	359	13,686
2016	14,349	1,067	0	428	16,395
2017	16,617	1,104	0	495	18,855
2018	18,078	1,259	0	561	20,610
2019	19,468	1,299	0	625	22,162
2020	20,122	1,714	0	661	23,289
2021	20,778	1,760	0	674	24,024
2022	21,480	2,040	0	687	25,038
2023	22,194	2,126	0	699	25,878
2024	22,908	2,395	0	713	26,900
2025	23,629	2,780	0	726	28,055
2026	24,346	2,887	0	740	28,919
2027	25,077	2,993	0	754	29,797
2028	25,819	3,100	0	770	30,688
2029	26,570	3,207	0	786	31,590
2030	27,329	3,297	0	803	32,486
2031	28,099	3,387	0	822	33,393
2032	28,878	3,477	0	841	34,312
2033	29,667	3,566	0	861	35,242
2034	30,439	3,656	0	882	36,156
2035	31,220	3,745	0	904	37,080
2036	31,992	3,835	0	924	37,994
2037	32,759	3,926	0	943	38,895
2038	33,521	4,016	0	960	39,755
2039	34,276	4,107	0	976	40,608
2040	35,026	4,198	0	990	41,454

Table 3-90 Projected Locomotive Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	5	22	36	49
FORMALDEHYDE	75	348	581	786
ACETALDEHYDE	33	152	254	343
1,3-BUTADIENE	5	25	42	57
ACROLEIN	5	25	41	55
NAPHTHALENE	2	11	17	22
POM	1	4	8	12

3.4 Projected Total Emission Reductions from the Final Rule

The total base and control inventories, as well as emission reductions by calendar year, for $PM_{2.5}$, NO_x, and VOC are given in Table 3-91. The totals include emissions from the three major categories affected by this final rule: commercial marine diesel engines, recreational marine diesel engines, and locomotives. The results for $PM_{2.5}$ and NO_x are also illustrated in Figure 1 and Figure 2. Reductions by pollutant and category are also provided in Table 3-92 through Table 3-94.

The total air toxics reductions are provided in Table 3-95.

Calendar year 2040 was chosen as the end date for the analysis; however, additional reductions are expected to occur beyond this date.

Figure 1 Estimated PM2.5 Reductions from Locomotive and Marine Diesel Engine Standards (short tons)

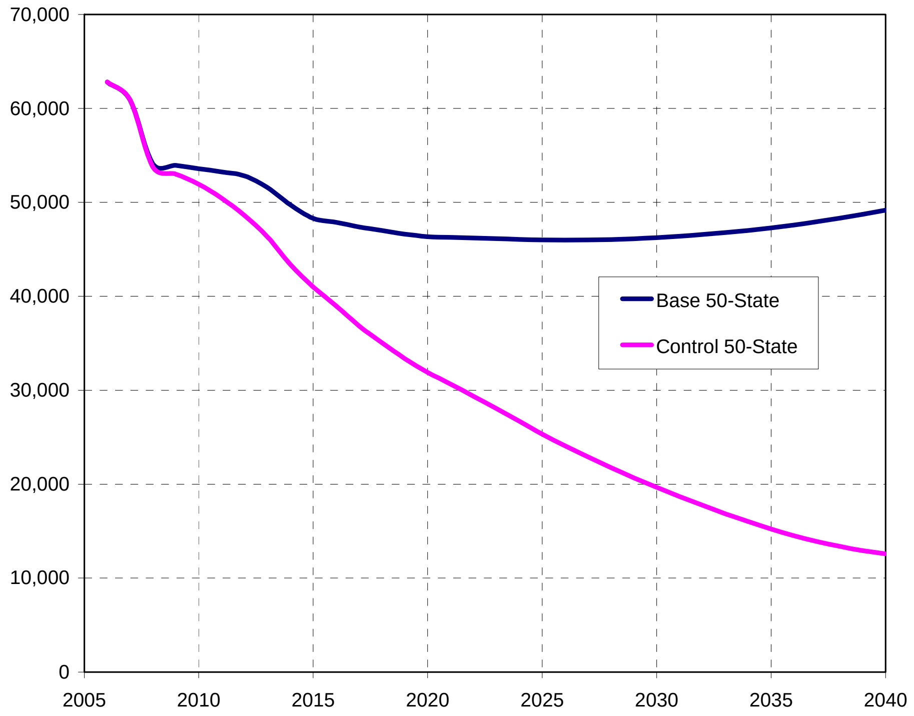

Figure 2 Estimated NOx Reductions from Locomotive and Marine Diesel Engine Standards (short tons)

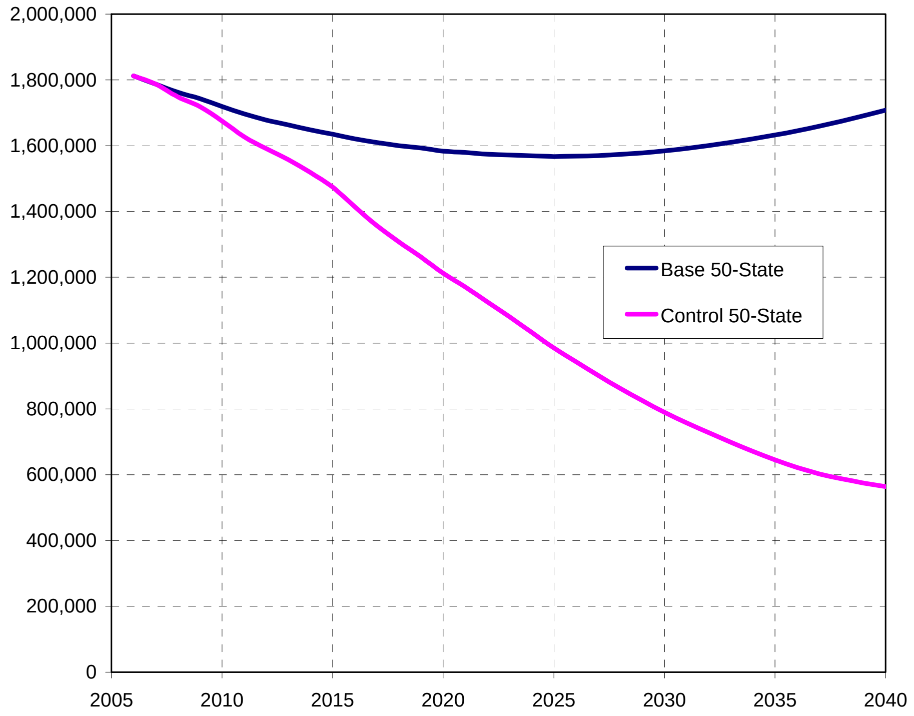

Table 3-91 Total Emissions and Projected Reductions (short tons)

Year	$PM_{2.5}$			NO_X			VOC		
	Base	Control	Reduction	Base	Control	Reduction	Base	Control	Reduction
2006	62,797	62,797	0	1,812,229	1,812,229	0	71,875	71,875	0
2007	60,893	60,893	0	1,787,163	1,787,163	0	71,699	71,699	0
2008	54,082	53,760	322	1,762,615	1,748,592	14,023	71,535	70,733	802
2009	53,942	53,011	931	1,743,151	1,718,947	24,204	71,391	69,684	1,708
2010	53,579	51,921	1,658	1,719,287	1,675,398	43,889	71,218	68,262	2,956
2011	53,233	50,443	2,790	1,696,911	1,627,108	69,803	71,032	65,692	5,340
2012	52,810	48,598	4,212	1,678,040	1,591,136	86,904	70,846	62,707	8,139
2013	51,572	46,338	5,234	1,663,297	1,557,820	105,476	70,683	60,078	10,605
2014	49,750	43,400	6,350	1,647,759	1,518,782	128,976	70,539	57,677	12,862
2015	48,296	40,993	7,303	1,634,987	1,474,272	160,715	70,392	55,306	15,086
2016	47,879	38,986	8,893	1,620,503	1,414,569	205,934	70,243	51,869	18,374
2017	47,381	36,867	10,514	1,609,712	1,357,341	252,371	70,131	48,628	21,504
2018	47,002	35,052	11,951	1,600,291	1,307,606	292,686	70,061	46,095	23,966
2019	46,620	33,376	13,245	1,593,148	1,261,385	331,763	70,011	43,788	26,223
2020	46,348	31,905	14,443	1,583,847	1,212,782	371,065	69,988	41,938	28,049
2021	46,266	30,666	15,600	1,579,669	1,170,501	409,167	69,991	40,513	29,478
2022	46,213	29,347	16,866	1,574,245	1,125,428	448,817	70,007	38,828	31,179
2023	46,141	28,049	18,092	1,571,689	1,079,540	492,149	69,994	37,297	32,697
2024	46,070	26,700	19,370	1,569,185	1,032,778	536,407	69,996	35,612	34,384
2025	46,006	25,330	20,676	1,566,788	985,485	581,303	69,994	33,823	36,171
2026	45,981	24,092	21,889	1,567,997	943,123	624,875	70,041	32,417	37,624
2027	45,993	22,905	23,087	1,570,259	902,211	668,048	70,128	31,086	39,042
2028	46,042	21,768	24,274	1,573,643	862,660	710,983	70,262	29,827	40,435
2029	46,130	20,681	25,449	1,578,219	824,927	753,292	70,447	28,638	41,809
2030	46,247	19,654	26,593	1,584,378	789,523	794,855	70,685	27,546	43,140
2031	46,395	18,679	27,716	1,592,027	757,840	834,186	70,966	26,520	44,447
2032	46,572	17,749	28,823	1,600,710	727,630	873,080	71,293	25,553	45,739
2033	46,781	16,858	29,923	1,610,338	698,634	911,704	71,666	24,640	47,025
2034	47,016	16,017	30,999	1,620,871	671,073	949,798	72,084	23,806	48,278
2035	47,285	15,224	32,061	1,632,511	645,094	987,417	72,564	23,039	49,525
2036	47,591	14,512	33,079	1,645,247	621,689	1,023,558	73,107	22,363	50,744
2037	47,937	13,896	34,040	1,659,436	602,427	1,057,009	73,728	21,814	51,914
2038	48,318	13,371	34,947	1,674,792	587,424	1,087,368	74,413	21,402	53,011
2039	48,729	12,927	35,802	1,691,093	574,726	1,116,367	75,152	21,066	54,087
2040	49,168	12,586	36,582	1,708,303	564,133	1,144,170	75,943	20,806	55,137

Table 3-92 Projected Total $PM_{2.5}$ Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	264	0	58	322
2009	541	0	390	931
2010	828	0	830	1,658
2011	1,124	1	1,666	2,790
2012	1,623	3	2,586	4,212
2013	2,262	5	2,967	5,234
2014	2,848	9	3,492	6,350
2015	3,112	13	4,178	7,303
2016	3,706	17	5,170	8,893
2017	4,400	21	6,094	10,514
2018	5,130	25	6,796	11,951
2019	5,776	29	7,439	13,245
2020	6,448	34	7,961	14,443
2021	7,185	38	8,377	15,600
2022	7,933	43	8,890	16,866
2023	8,687	48	9,357	18,092
2024	9,447	53	9,869	19,370
2025	10,203	59	10,415	20,676
2026	10,945	64	10,880	21,889
2027	11,670	70	11,348	23,087
2028	12,378	75	11,821	24,274
2029	13,072	81	12,297	25,449
2030	13,743	86	12,764	26,593
2031	14,391	92	13,233	27,716
2032	15,022	97	13,705	28,823
2033	15,642	101	14,180	29,923
2034	16,253	105	14,640	30,999
2035	16,851	108	15,102	32,061
2036	17,416	111	15,552	33,079
2037	17,933	114	15,993	34,040
2038	18,416	116	16,414	34,947
2039	18,857	119	16,826	35,802
2040	19,233	122	17,227	36,582

Table 3-93 Projected Total NO_x Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	8,876	0	5,147	14,023
2009	16,942	0	7,261	24,204
2010	24,204	0	19,684	43,889
2011	30,668	0	39,135	69,803
2012	37,792	39	49,073	86,904
2013	45,319	174	59,983	105,476
2014	64,616	415	63,946	128,976
2015	77,077	657	82,981	160,715
2016	93,741	902	111,291	205,934
2017	112,839	1,148	138,383	252,371
2018	134,052	1,397	157,237	292,686
2019	155,247	1,647	174,869	331,763
2020	176,357	1,898	192,811	371,065
2021	197,373	2,151	209,644	409,167
2022	218,283	2,405	228,129	448,817
2023	239,149	2,659	250,341	492,149
2024	259,918	2,915	273,574	536,407
2025	280,237	3,171	297,895	581,303
2026	299,996	3,426	321,452	624,875
2027	319,036	3,681	345,331	668,048
2028	337,439	3,935	369,609	710,983
2029	354,888	4,187	394,217	753,292
2030	371,411	4,437	419,006	794,855
2031	387,110	4,682	442,394	834,186
2032	402,084	4,915	466,082	873,080
2033	416,556	5,120	490,029	911,704
2034	430,573	5,288	513,937	949,798
2035	444,063	5,434	537,920	987,417
2036	456,832	5,570	561,156	1,023,558
2037	467,563	5,702	583,744	1,057,009
2038	476,356	5,828	605,184	1,087,368
2039	484,440	5,951	625,976	1,116,367
2040	491,954	6,070	646,146	1,144,170

Table 3-94 Projected Total VOC Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	8,876	0	5,147	14,023
2009	16,942	0	7,261	24,204
2010	24,204	0	19,684	43,889
2011	30,668	0	39,135	69,803
2012	37,792	39	49,073	86,904
2013	45,319	174	59,983	105,476
2014	64,616	415	63,946	128,976
2015	77,077	657	82,981	160,715
2016	93,741	902	111,291	205,934
2017	112,839	1,148	138,383	252,371
2018	134,052	1,397	157,237	292,686
2019	155,247	1,647	174,869	331,763
2020	176,357	1,898	192,811	371,065
2021	197,373	2,151	209,644	409,167
2022	218,283	2,405	228,129	448,817
2023	239,149	2,659	250,341	492,149
2024	259,918	2,915	273,574	536,407
2025	280,237	3,171	297,895	581,303
2026	299,996	3,426	321,452	624,875
2027	319,036	3,681	345,331	668,048
2028	337,439	3,935	369,609	710,983
2029	354,888	4,187	394,217	753,292
2030	371,411	4,437	419,006	794,855
2031	387,110	4,682	442,394	834,186
2032	402,084	4,915	466,082	873,080
2033	416,556	5,120	490,029	911,704
2034	430,573	5,288	513,937	949,798
2035	444,063	5,434	537,920	987,417
2036	456,832	5,570	561,156	1,023,558
2037	467,563	5,702	583,744	1,057,009
2038	476,356	5,828	605,184	1,087,368
2039	484,440	5,951	625,976	1,116,367
2040	491,954	6,070	646,146	1,144,170

Table 3-95 Projected Total Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	5	69	202	426
FORMALDEHYDE	79	693	1,796	3,551
ACETALDEHYDE	35	323	857	1,716
1,3-BUTADIENE	5	26	44	62
ACROLEIN	5	31	65	109
NAPHTHALENE	2	14	28	45
POM	1	5	11	18

3.5 Contribution of Marine Diesel Engines and Locomotives to Baseline National Emission Inventories

This section provides the contribution of marine diesel engines and locomotives to baseline nationwide emission inventories in 2001, 2020, and 2030. The baseline represents current and future emissions with the existing standards. The calendar years correspond to those chosen for the air quality modeling.

The pollutants included in this section are directly emitted $PM_{2.5}$, NO_x, VOC, CO, and SO_2. While we do not provide estimates for other pollutants here, it should be noted that the affected engines also contribute to national ammonia (NH_3) and air toxics inventories.

3.5.1 Categories and Sources of Data

As described more fully earlier in this chapter, our current inventories for marine diesel engines and locomotives were developed using multiple methodologies, but they all are based on combining engine populations, hours of use, average engine loads, and in-use emissions factors. Locomotive emissions were calculated based on estimated current and projected fuel consumption rates. Emissions were calculated separately for the following locomotive categories: Large Railroad Line-Haul Locomotives, Large Railroad Switching (including Class III Switch railroads owned by Class I railroads), Other Line-Haul Locomotives (i.e., local railroads), Other Switcher/Terminal Locomotives and Passenger Locomotives. The inventories for marine diesel engines were created separately for Category 1 and 2 propulsion and auxiliary engines, including those less than or equal to 37 kW, and diesel fueled recreational marine propulsion engines.

The locomotive, commercial marine (C1 & C2), and diesel recreational marine values given for 2001 are actually 2002 estimates, since that is the base year that was used for air quality modeling. The stationary, aircraft, onroad diesel, and C3 commercial marine values are from the PM NAAQS 2001 air quality modeling platform, which is more recent than, but essentially the same as CAIR (2001 platform) for these sources. The 2030 stationary source values are set equal to 2020, since no specific estimates for 2030 stationary source emissions are available. All the stationary source values exclude "non-manmade" sources, such as fires and fugitive dust. Onroad gasoline vehicle values are from the National Mobile Inventory

Model (NMIM) outputs for the final Mobile Source Air Toxics rulemaking, which includes the assumed implementation of Renewable Fuels Standards (RFS) and corrections for cold-start HC effects. Nonroad land-based diesel values are from the latest publicly released version of EPA's nonroad model (NONROAD2005a). Nonroad spark-ignition (SI) values in these tables (small SI, SI recreational marine, large SI, and SI recreational vehicles) are also from NONROAD2005a. The NONROAD2005 model runs were all done at the nationwide/annual level using single default nationwide temperature & RVP and the full 50-state equipment population including all California equipment.

3.5.2 $PM_{2.5}$ Contributions to Baseline

Table 3-96 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source diesel and to total man-made $PM_{2.5}$ emissions. $PM_{2.5}$ emissions from these sources are 18 percent of the mobile source diesel $PM_{2.5}$ emissions in 2001, and this percentage increases to about 65 percent by 2030. $PM_{2.5}$ emissions from the affected sources decreases from almost 60,000 tons in 2002 to 46,000 tons in 2020 due to the existing emission standards. From 2020 to 2025 emissions remain relatively constant as growth offsets the effect of continued turnover of older engines to engines meeting the existing emission standards. These emissions begin to increase again around 2025 and exceed 2015 levels by 2035.

3.5.3 NO_x Contributions to Baseline

Table 3-97 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source NO_x and to total man-made NO_x emissions. NO_x emissions from these sources are 16 percent of the mobile source NO_x emissions in 2001, and this percentage increases to 35 percent by 2030. NO_x emissions from affected sources decrease from about 2 million tons in 2002 to almost 1.6 million tons in 2020 due to the existing emission standards. From 2020 to 2025 emissions remain relatively constant as growth offsets the effect of continued turnover of older engines to engines meeting the existing emission standards. These emissions begin to increase again in 2025 and by 2035 exceed 2015 emission levels.

3.5.4 VOC Contributions to Baseline

Table 3-98 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source VOC and to total man-made VOC emissions. Due to the efficient combustion in diesel engines, mobile source VOC emissions are dominated by spark-ignition engines, and the VOC emissions from the affected sources are only 0.8 percent of the mobile source VOC in 2001, increasing to 1.3 percent by 2030. VOC emissions from affected sources increase from 69,000 tons in 2002 to 70,000 tons in 2020 and 71,000 tons in 2030, since the existing emission standards are not aimed at controlling VOC.

3.5.5 CO Contributions to Baseline

Table 3-99 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source carbon monoxide (CO) and to total man-made

CO emissions. As with VOC, mobile source CO emissions are dominated by spark-ignition engines, so the CO emissions from the affected sources are only 0.3 percent of the mobile source CO in 2001, increasing to 0.5 percent by 2030. CO emissions from affected sources increase from 281,000 tons in 2002 to 317,000 tons in 2020 and 350,000 tons in 2030, since the existing emission standards are not aimed at controlling CO.

3.5.6 SO_2 Contributions to Baseline

Table 3-100 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source SO_2 and to total man-made SO_2 emissions. SO_2 emissions from these sources are 21 percent of the mobile source SO_2 emissions in 2001, and this percentage decreases significantly to about one percent in 2020 and 2030 due to existing diesel fuel sulfur standards. SO_2 emissions from affected sources decrease from 162,000 tons in 2002 to 3,700 tons in 2020. From 2020 to 2030 emissions increase to 4,200 tons due to continued projected growth in these sectors.

Table 3-96 50-State Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

Category	**2001**[a]			**2020**			**2030**		
	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total
Locomotive	29,660	8.9%	1.2%	23,106	21.4%	1.1%	21,347	28.7%	1.0%
Recreational Marine Diesel	1,096	0.3%	0.0%	1,006	0.9%	0.0%	1,140	1.5%	0.1%
Commercial Marine (C1 & C2)	28,730	8.6%	1.2%	22,236	20.5%	1.1%	23,760	32.0%	1.2%
Land-Based Nonroad Diesel	164,180	49.2%	6.8%	46,075	42.6%	2.2%	17,934	24.2%	0.9%
Commercial Marine (C3)[b]	20,023	-	0.8%	36,141	-	1.7%	52,682	-	2.6%
Small Nonroad SI	25,575		1.1%	31,083		1.5%	35,761		1.7%
Recreational Marine SI	17,101		0.7%	6,595		0.3%	6,378		0.3%
SI Recreational Vehicles	12,301		0.5%	11,773		0.6%	9,953		0.5%
Large Nonroad SI (>25hp)	1,610		0.1%	2,421		0.1%	2,844		0.1%
Aircraft	5,664		0.2%	7,044		0.3%	8,569		0.4%
Total Off Highway	305,941		12.6%	187,480		9.1%	180,368		8.7%
Highway Diesel	109,952	33.0%	4.5%	15,800	14.6%	0.8%	10,072	13.6%	0.5%
Highway non-diesel	50,277		2.1%	47,354		2.3%	56,734		2.7%
Total Highway	160,229		6.6%	63,154		3.1%	66,806		3.2%
Total Diesel (distillate) Mobile	333,619	100%	13.7%	108,223	100%	5.2%	74,253	100%	3.6%
Total Mobile Sources	466,170		19.2%	250,634		12.1%	247,174		12.0%
Stationary Point and Area Sources	1,963,264		80.8%	1,817,722		87.9%	1,817,722		88.0%
Total Man-Made Sources	2,429,434		100%	2,068,356		100%	2,064,896		100%

Notes:

[a] The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

[b] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 3-97 50-State Annual NO$_x$ Baseline Emission Levels for Mobile and Other Source Categories

Category	2001[a]			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	1,118,786	9.0%	5.1%	862,215	17.3%	7.8%	856,251	19.1%	8.1%
Recreational Marine Diesel	40,437	0.3%	0.2%	45,477	0.9%	0.4%	48,102	1.1%	0.5%
Commercial Marine (C1 & C2)	834,025	6.7%	3.8%	676,154	13.5%	6.1%	680,025	15.1%	6.4%
Land-Based Nonroad Diesel	1,548,236	12.5%	7.1%	678,377	13.6%	6.1%	434,466	9.7%	4.1%
Commercial Marine (C3)[b]	224,100	1.8%	1.0%	369,160	7.4%	3.3%	531,641	11.8%	5.0%
Small Nonroad SI	100,319	0.8%	0.5%	98,620	2.0%	0.9%	114,287	2.5%	1.1%
Recreational Marine SI	42,252	0.3%	0.2%	83,312	1.7%	0.8%	92,188	2.1%	0.9%
SI Recreational Vehicles	5,488	0.0%	0.0%	17,496	0.4%	0.2%	20,136	0.4%	0.2%
Large Nonroad SI (>25hp)	321,098	2.6%	1.5%	46,319	0.9%	0.4%	46,253	1.0%	0.4%
Aircraft	83,764	0.7%	0.4%	105,133	2.1%	0.9%	118,740	2.6%	1.1%
Total Off Highway	4,318,505	34.8%	19.8%	2,982,264	59.8%	26.9%	2,942,089	65.5%	27.7%
Highway Diesel	3,750,886	30.2%	17.2%	646,961	13.0%	5.8%	260,915	5.8%	2.5%
Highway non-diesel	4,354,430	35.0%	20.0%	1,361,276	27.3%	12.3%	1,289,780	28.7%	12.2%
Total Highway	8,105,316	65.2%	37.2%	2,008,237	40.2%	18.1%	1,550,695	34.5%	14.6%
Total Diesel (distillate) Mobile	7,292,308	58.7%	33.5%	2,907,578	58.3%	26.2%	2,277,735	50.7%	21.5%
Total Mobile Sources	12,423,821	100%	57.0%	4,990,501	100%	44.9%	4,492,784	100%	42.4%
Stationary Point and Area Sources	9,355,659	-	43.0%	6,111,866	-	55.1%	6,111,866	-	57.6%
Total Man-Made Sources	21,779,480	-	100%	11,102,367	-	100%	10,604,650	-	100%

Notes:

[a] The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

[b] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 3-98 50-State Annual VOC Baseline Emission Levels for Mobile and Other Source Categories

Category	**2001**[a]			**2020**			**2030**		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	50,665	0.6%	0.3%	51,263	1.0%	0.4%	50,208	0.9%	0.4%
Recreational Marine Diesel	1,540	0.0%	0.0%	2,653	0.0%	0.0%	3,299	0.1%	0.0%
Commercial Marine (C1 & C2)	17,229	0.2%	0.1%	16,071	0.3%	0.1%	17,178	0.3%	0.1%
Land-Based Nonroad Diesel	188,884	2.3%	1.1%	76,047	1.4%	0.5%	63,144	1.1%	0.4%
Commercial Marine (C3)[b]	9,572	0.1%	0.1%	18,458	0.3%	0.1%	27,582	0.5%	0.2%
Small Nonroad SI	1,314,015	15.9%	7.3%	999,810	18.6%	7.2%	1,156,408	19.7%	8.1%
Recreational Marine SI	1,212,446	14.7%	6.8%	688,774	12.8%	5.0%	697,712	11.9%	4.9%
SI Recreational Vehicles	512,059	6.2%	2.9%	454,979	8.5%	3.3%	391,541	6.7%	2.7%
Large Nonroad SI (>25hp)	132,888	1.6%	0.7%	12,429	0.2%	0.1%	10,276	0.2%	0.1%
Portable Fuel Containers	244,545	3.0%	1.4%	254,479	4.7%	1.8%	288,630	4.9%	2.0%
Aircraft	22,084	0.3%	0.1%	27,644	0.5%	0.2%	30,331	0.5%	0.2%
Total Off Highway	3,705,926	44.9%	20.7%	2,602,608	48.4%	18.8%	2,736,309	46.7%	19.1%
Highway Diesel	223,519	2.7%	1.2%	123,449	2.3%	0.9%	138,758	2.4%	1.0%
Highway non-diesel	4,316,615	52.3%	24.1%	2,646,363	49.3%	19.1%	2,987,562	51.0%	20.8%
Total Highway	4,540,134	55.1%	25.3%	2,769,812	51.6%	20.0%	3,126,320	53.3%	21.8%
Total Diesel (distillate) Mobile	479,285	5.8%	2.7%	270,844	5.0%	2.0%	274,189	4.7%	1.9%
Total Mobile Sources	8,246,060	100%	46.0%	5,372,420	100%	38.8%	5,862,629	100%	40.9%
Stationary Point and Area Sources	9,692,344	-	54.0%	8,475,443	-	61.2%	8,475,443	-	59.1%
Total Man-Made Sources	17,938,404	-	100%	13,847,863	-	100%	14,338,072	-	100%

Notes:

[a] The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

[b] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 3-99 50-State Annual CO Baseline Emission Levels for Mobile and Other Source Categories

Category	**2001**[a]			**2020**			**2030**		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	123,210	0.1%	0.1%	167,488	0.3%	0.2%	195,882	0.3%	0.2%
Recreational Marine Diesel	6,467	0.0%	0.0%	9,374	0.0%	0.0%	10,930	0.0%	0.0%
Commercial Marine (C1 & C2)	151,331	0.2%	0.2%	139,712	0.2%	0.2%	143,791	0.2%	0.2%
Land-Based Nonroad Diesel	893,320	1.0%	0.9%	310,258	0.5%	0.4%	155,625	0.2%	0.2%
Commercial Marine (C3)[b]	19,391	0.0%	0.0%	37,459	0.1%	0.1%	56,713	0.1%	0.1%
Small Nonroad SI	18,843,914	21.4%	19.4%	27,269,797	41.7%	36.8%	31,623,016	42.5%	38.1%
Recreational Marine SI	2,816,005	3.2%	2.9%	2,136,234	3.3%	2.9%	2,178,413	2.9%	2.6%
SI Recreational Vehicles	1,229,707	1.4%	1.3%	1,922,020	2.9%	2.6%	1,902,925	2.6%	2.3%
Large Nonroad SI (>25hp)	1,801,679	2.0%	1.9%	304,532	0.5%	0.4%	281,993	0.4%	0.3%
Aircraft	263,232	0.3%	0.3%	327,720	0.5%	0.4%	358,012	0.5%	0.4%
Total Off Highway	26,148,256	29.6%	26.9%	32,624,593	49.9%	44.1%	36,907,299	49.6%	44.4%
Highway Diesel	1,098,213	1.2%	1.1%	248,689	0.4%	0.3%	149,784	0.2%	0.2%
Highway non-diesel	60,985,008	69.1%	62.7%	32,503,404	49.7%	43.9%	37,399,211	50.2%	45.0%
Total Highway	62,083,221	70.4%	63.8%	32,752,093	50.1%	44.2%	37,548,995	50.4%	45.2%
Total Diesel (distillate) Mobile	2,272,530	2.6%	2.3%	877,583	1.3%	1.2%	658,428	0.9%	0.8%
Total Mobile Sources	88,231,477	100%	90.7%	65,376,686	100%	88.3%	74,456,294	100%	89.6%
Stationary Point and Area Sources	9,014,249	-	9.3%	8,641,678	-	11.7%	8,641,678	-	10.4%
Total Man-Made Sources	97,245,726	-	100%	74,018,364	-	100%	83,097,972	-	100%

Notes:

[a] The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

[b] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 3-100 50-State Annual SO_2 Baseline Emission Levels for Mobile and Other Source Categories

Category	2001[a]			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	76,727	9.7%	0.5%	396	0.1%	0.0%	464	0.1%	0.0%
Recreational Marine Diesel	5,145	0.7%	0.0%	162	0.0%	0.0%	192	0.0%	0.0%
Commercial Marine (C1 & C2)	80,353	10.2%	0.5%	3,104	0.9%	0.0%	3,586	0.7%	0.0%
Land-Based Nonroad Diesel	167,615	21.2%	1.1%	999	0.3%	0.0%	1,078	0.2%	0.0%
Commercial Marine (C3)[b]	166,739	21.1%	1.1%	272,535	79.9%	3.2%	400,329	83.2%	4.6%
Small Nonroad SI	6,723	0.9%	0.0%	8,620	2.5%	0.1%	9,990	2.1%	0.1%
Recreational Marine SI	2,755	0.3%	0.0%	2,980	0.9%	0.0%	3,160	0.7%	0.0%
SI Recreational Vehicles	1,241	0.2%	0.0%	2,643	0.8%	0.0%	2,784	0.6%	0.0%
Large Nonroad SI (>25hp)	925	0.1%	0.0%	905	0.3%	0.0%	1,020	0.2%	0.0%
Aircraft	7,890	1.0%	0.0%	9,907	2.9%	0.1%	11,137	2.3%	0.1%
Total Off Highway	516,113	65.4%	3.3%	302,251	88.7%	3.5%	433,741	90.2%	5.0%
Highway Diesel	103,632	13.1%	0.7%	3,443	1.0%	0.0%	4,453	0.9%	0.1%
Highway non-diesel	169,125	21.4%	1.1%	35,195	10.3%	0.4%	42,709	8.9%	0.5%
Total Highway	272,757	34.6%	1.7%	38,638	11.3%	0.5%	47,162	9.8%	0.5%
Total Diesel (distillate) Mobile	433,465	54.9%	2.7%	8,108	2.4%	0.1%	9,777	2.0%	0.1%
Total Mobile Sources	788,870	100%	5.0%	340,889	100%	4.0%	480,903	100%	5.5%
Stationary Point and Area Sources	15,057,420	-	95.0%	8,215,016	-	96.0%	8,215,016	-	94.5%
Total Man-Made Sources	15,846,290	-	100%	8,555,905	-	100%	8,695,919	-	100%

Notes:

[a] The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

[b] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

3.6 Contribution of Marine Diesel Engines and Locomotives to Non-Attainment Area Emission Inventories

Table 3-101 and Table 3-102 show the percent contribution to mobile source diesel $PM_{2.5}$ and total mobile source NO_x for certain non-attainment areas where there are large rail yards and/or commercial marine ports. The county-level inventories were estimated by allocating the nationwide baseline inventories to the counties using the same county:national ratios as used in the 2002 National Emissions Inventory (NEI).[43] It can be seen that locomotives and diesel marine vessels make up a substantial portion of the $PM_{2.5}$ and NO_x mobile source inventories in these areas. For instance, the combination of rail and commercial marine activity in the Huntington-Ashland WV-KY-OH area yields a contribution over 50% of mobile source diesel PM2.5 in 2002, increasing to 90% in 2030.

Additional details, including the annual tons of $PM_{2.5}$ and NOx from locomotives, diesel marine engines, and all mobile sources within each of the counties of these metropolitan areas are provided in Appendix 3A of this chapter.

Table 3-101 Locomotive and Diesel Marine Engine Contributions to Non-Attainment Area Mobile Source Diesel $PM_{2.5}$ Emissions

$PM_{2.5}$ Metropolitan Area	**2002**	**2020**	**2030**
	LM %	**LM %**	**LM %**
Huntington-Ashland WV-KY-OH	52.9%	82.1%	90.4%
Houston, TX	41.9%	72.9%	84.6%
Los Angeles, CA	31.3%	49.3%	72.1%
Cleveland-Akron-Lorain, OH	25.1%	56.0%	72.0%
Chicago, IL	24.6%	54.9%	70.0%
Cincinnati, OH	23.2%	53.6%	69.5%
Chattanooga, TN	21.1%	56.3%	69.5%
Kansas City, MO	20.6%	51.3%	68.0%
Baltimore, MD	22.5%	52.6%	67.8%
St. Louis, MO	21.4%	51.3%	67.5%
Philadelphia, PA	19.6%	47.0%	63.9%
Seattle, WA	17.0%	43.3%	60.4%
Birmingham, AL	16.3%	46.6%	57.5%
Minneapolis-St. Paul, MN	10.7%	31.3%	47.8%
Boston, MA	7.8%	22.9%	40.5%
San Joaquin Valley, CA	8.8%	19.4%	38.2%
Atlanta, GA	5.2%	19.6%	29.9%
Indianapolis, IN	5.0%	17.5%	29.3%
Phoenix-Mesa, AZ	4.9%	17.3%	26.8%
Detroit, MI	4.1%	15.3%	26.0%
New York, NY	3.5%	11.1%	20.3%

Table 3-102 Locomotive and Diesel Marine Engine Contributions to Non-Attainment Area Total Mobile Source NO_x Emissions

NOx Metropolitan Area	2002	2020	2030
	LM %	LM %	LM %
Houston, TX	31.5%	46.3%	44.8%
Kansas City, MO	19.3%	39.3%	43.2%
Birmingham, AL	16.7%	38.3%	42.6%
Chicago, IL	19.9%	37.8%	41.1%
Cleveland-Akron-Lorain, OH	18.8%	37.2%	39.5%
Chattanooga, TN	15.6%	35.7%	39.1%
Cincinnati, OH	17.5%	35.7%	38.3%
Los Angeles, CA	18.1%	30.8%	37.2%
St. Louis, MO	15.7%	33.8%	36.9%
Huntington-Ashland WV-KY-OH	38.1%	41.9%	36.2%
Seattle, WA	13.2%	27.7%	30.3%
San Joaquin Valley, CA	8.4%	16.0%	25.7%
Minneapolis-St. Paul, MN	8.1%	17.5%	19.4%
Philadelphia, PA	13.4%	19.7%	18.8%
Phoenix-Mesa, AZ	5.1%	11.7%	14.6%
Atlanta, GA	4.2%	10.7%	12.8%
Indianapolis, IN	4.3%	10.7%	12.7%
Boston, MA	6.3%	10.6%	10.8%
Baltimore, MD	7.1%	10.4%	9.7%
Detroit, MI	2.8%	7.2%	8.2%
New York, NY	4.7%	7.4%	7.3%

3.7 Emission Inventories Used for Air Quality Modeling

3.7.1 Comparison of Air Quality and Final Rule Inventories

This section describes the differences in the inventories used for the final rule air quality analysis and the inventories used for the final rule. Chapter 2 of this document discusses the air quality analysis results and addresses the likely impact of these differences (if any) on the air quality outcomes from the final rule.

For the commercial marine vessel and diesel recreational marine categories affected by this rule, the baseline inventories for the air quality analysis are unchanged from those used for the final rule. For the diesel locomotive category, minor changes have been made to the baseline inventories. Minor changes to the control case have also been made for all three categories since the air quality analysis; these changes are described in this section.

In addition to the diesel locomotive, commercial marine vessel, and diesel recreational marine sources, the air quality inventories include emission contributions from all sources, including the following sources not directly affected by the final rule:

- Stationary and area sources
- Aircraft
- Oceangoing commercial marine vessels (Category 3)
- Onroad (highway) mobile sources
- Nonroad mobile sources other than diesel pleasure craft

The emission inventory estimates used in the air quality analysis for these sources are those included in the 2002-based CMAQ modeling platform. In comparison, the inventory estimates presented in section 3.5 were taken from the recent Clean Air Interstate Rule (CAIR)[44].

Table 3-103 through Table 3-105 summarize the differences between the air quality inventories and the final rule inventories for baseline VOC, NO_x, and $PM_{2.5}$. Similarly, Table 3-106 through Table 3-108 summarize the differences between the air quality inventories and the final rule inventories for control case VOC, NO_x, and $PM_{2.5}$. Lastly, Table 3-109 through Table 3-111 summarize the differences in ton reductions for these pollutants between the air quality inventories and the more updated final rule inventories. Only the years 2020 and 2030 are shown for the latter two sets of tables, since this rule has no benefits prior to 2008.

3.7.2 Locomotive Inventory Changes

Since the air quality analysis, changes were made to the baseline inputs, primarily to more accurately account for PM sulfate reductions from reduced future fuel sulfur levels. In addition, changes have been made in the control case to include all Class II railroads, exclude small businesses, and accelerate the Tier 4 NOx standard for the line-haul category. The net effect of these updates in 2030 is roughly a 4 percent increase in VOC and NO_x tons reduced and a 10 percent decrease in $PM_{2.5}$ tons reduced.

3.7.3 Marine Diesel Inventory Changes

Since the air quality analysis, changes have been made to expand the remanufacturing program requirements for Category 1 engines to include Tier 2 engines. Also, a 12 percent reduction in benefits for the remanufacturing program, affecting both Category 1 and Category 2 engines, was applied to account for the small business exclusion. For Category 2 engines, the Tier 3 and Tier 4 standards for the 2000-3700 kW category have been revised. These changes collectively affect NO_x, PM, and VOC emissions for the control case beginning in 2008.

Since the air quality analysis, the Tier 4 NOx and PM standards affecting 2000 hp and greater recreational marine engines have been eliminated. In addition, there have been minor changes to the Tier 3 NOx + HC and PM standards for engines greater than 1200 hp.

There was also an error applying the PM sulfur adjustment factor for recreational marine engines, which only affects the 2020 and 2030 baseline PM emissions used in the air quality analysis.

The net effect of these updates for marine diesel engines in 2030 is a 3 percent decrease in VOC tons reduced, a 2 percent increase in NO_x tons reduced, and a 9 percent increase in $PM_{2.5}$ tons reduced.

Table 3-103 50-State Annual VOC Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2002			2020			2030		
	AQ MODELING	FRM*	% DIFF	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	50,665	50,665	0.0%	52,634	51,263	-2.6%	51,813	50,208	-3.1%
MARINE DIESEL	18,839	18,768	-0.4%	18,927	18,724	-1.1%	20,780	20,477	-1.5%
ALL OTHER SOURCES (MOBILE & STATIONARY)	16,917,345	17,868,970	5.6%	12,415,007	13,777,876	11.0%	12,330,869	14,267,387	15.7%
TOTAL MAN-MADE SOURCES	16,986,849	17,938,403	5.6%	12,486,568	13,847,864	10.9%	12,403,462	14,338,072	15.6%
* THE FRM VALUE FOR ALL OTHER SOURCES IN THE "2002" COLUMN IS ACTUALLY A 2001 ESTIMATE.									

Table 3-104 50-State Annual NO_x Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2002			2020			2030		
	AQ MODELING	FRM*	% DIFF	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	1,118,788	1,118,786	0.0%	860,463	862,215	0.2%	854,238	856,251	0.2%
MARINE DIESEL	868,315	874,462	0.7%	717,259	721,632	0.6%	724,061	728,127	0.6%
ALL OTHER SOURCES (MOBILE & STATIONARY)	18,820,689	19,786,232	5.1%	9,198,907	9,518,521	3.5%	8,722,491	9,020,273	3.4%
TOTAL MAN-MADE SOURCES	20,807,792	21,779,480	4.7%	10,776,629	11,102,368	3.0%	10,300,790	10,604,651	2.9%
* THE FRM VALUE FOR ALL OTHER SOURCES IN THE "2002" COLUMN IS ACTUALLY A 2001 ESTIMATE.									

Table 3-105 50-State Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2002			2020			2030		
	AQ MODELING	FRM*	% DIFF	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	29,214	29,660	1.5%	25,901	23,106	-10.8%	24,726	21,347	-13.7%
MARINE DIESEL	29,184	29,827	2.2%	22,300	23,242	4.2%	23,674	24,900	5.2%
ALL OTHER SOURCES (MOBILE & STATIONARY)	2,228,545	2,369,947	6.3%	2,066,257	2,022,009	-2.1%	2,062,331	2,018,649	-2.1%
TOTAL MAN-MADE SOURCES	2,286,943	2,429,434	6.2%	2,114,458	2,068,357	-2.2%	2,110,731	2,064,896	-2.2%
* THE FRM VALUE FOR ALL OTHER SOURCES IN THE "2002" COLUMN IS ACTUALLY A 2001 ESTIMATE.									

Table 3-106 50-State Annual VOC Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	30,135	27,974	-7.2%	20,383	17,722	-13.1%
MARINE DIESEL	13,991	13,964	-0.2%	9,800	9,824	0.2%
ALL OTHER SOURCES (MOBILE & STATIONARY)	12,415,007	13,777,876	11.0%	12,330,869	14,267,387	15.7%
TOTAL MAN-MADE SOURCES	12,459,133	13,819,814	10.9%	12,361,052	14,294,933	15.6%

Table 3-107 50-State Annual NO_x Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	712,492	669,405	-6.0%	453,651	437,245	-3.6%
MARINE DIESEL	543,668	543,377	-0.1%	354,310	352,279	-0.6%
ALL OTHER SOURCES (MOBILE & STATIONARY)	9,198,907	9,518,521	3.5%	8,722,491	9,020,273	3.4%
TOTAL MAN-MADE SOURCES	10,455,067	10,731,303	2.6%	9,530,452	9,809,796	2.9%

Table 3-108 50-State Annual $PM_{2.5}$ Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	16,368	15,145	-7.5%	10,512	8,584	-18.3%
MARINE DIESEL	16,767	16,760	0.0%	10,997	11,071	0.7%
ALL OTHER SOURCES (MOBILE & STATIONARY)	2,066,257	2,022,009	-2.1%	2,062,331	2,018,649	-2.1%
TOTAL MAN-MADE SOURCES	2,099,392	2,053,914	-2.2%	2,083,840	2,038,303	-2.2%

Table 3-109 50-State Annual VOC Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	22,499	23,289	3.5%	31,430	32,486	3.4%
MARINE DIESEL	4,936	4,760	-3.6%	10,980	10,653	-3.0%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	27,435	28,049	2.2%	42,410	43,140	1.7%

Table 3-110 50-State Annual NO_x Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	147,971	192,811	30.3%	400,587	419,006	4.6%
MARINE DIESEL	173,591	178,255	2.7%	369,751	375,848	1.6%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	321,562	371,065	15.4%	770,338	794,855	3.2%

Table 3-111 50-State Annual $PM_{2.5}$ Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	FRM	% DIFF	AQ MODELING	FRM	% DIFF
LOCOMOTIVE	9,533	7,961	-16.5%	14,214	12,764	-10.2%
MARINE DIESEL	5,533	6,482	17.2%	12,677	13,829	9.1%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	15,066	14,443	-4.1%	26,891	26,593	-1.1%

APPENDIX 3A

Locomotive and Diesel Marine Contributions to County-Specific Mobile Source Emissions in Non-attainment Areas

Table 3-112 2002 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2002 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.77	0.01	41	14.3%
13015	Atlanta	Bartow	GA	20.64	0.20	109	19.1%
13045	Atlanta	Carroll	GA	5.65	0.08	92	6.2%
13057	Atlanta	Cherokee	GA	0.00	0.19	118	0.2%
13063	Atlanta	Clayton	GA	10.87	0.03	164	6.7%
13067	Atlanta	Cobb	GA	28.66	0.08	504	5.7%
13077	Atlanta	Coweta	GA	14.35	0.06	123	11.8%
13089	Atlanta	DeKalb	GA	13.29	0.05	440	3.0%
13097	Atlanta	Douglas	GA	5.22	0.01	68	7.7%
13113	Atlanta	Fayette	GA	3.71	0.04	86	4.4%
13117	Atlanta	Forsyth	GA	0.00	0.39	114	0.3%
13121	Atlanta	Fulton	GA	39.07	0.11	857	4.6%
13135	Atlanta	Gwinnett	GA	9.95	0.07	476	2.1%
13139	Atlanta	Hall	GA	6.62	0.65	146	5.0%
13149	Atlanta	Heard	GA	0.00	0.09	11	0.8%
13151	Atlanta	Henry	GA	14.63	0.04	154	9.5%
13217	Atlanta	Newton	GA	1.65	0.05	80	2.1%
13223	Atlanta	Paulding	GA	12.13	0.03	86	14.2%
13237	Atlanta	Putnam	GA	0.35	0.30	15	4.3%
13247	Atlanta	Rockdale	GA	2.35	0.03	71	3.4%
13255	Atlanta	Spalding	GA	0.62	0.03	53	1.2%
13297	Atlanta	Walton	GA	1.99	0.01	47	4.2%
24003	Baltimore	Anne Arundel	MD	14.68	1.82	302	5.5%
24005	Baltimore	Baltimore	MD	39.65	1.22	576	7.1%
24013	Baltimore	Carroll	MD	6.14	0.04	158	3.9%
24025	Baltimore	Harford	MD	11.40	1.18	186	6.8%
24027	Baltimore	Howard	MD	17.07	0.41	203	8.6%
24510	Baltimore	Baltimore	MD	46.07	313.45	590	60.9%
1073	Birmingham	Jefferson	AL	80.24	1.08	631	12.9%
1117	Birmingham	Shelby	AL	41.96	0.29	157	26.9%
1127	Birmingham	Walker	AL	17.15	1.08	81	22.4%
9007	Boston	Middlesex	CT	0.00	1.70	114	1.5%
25001	Boston	Barnstable	MA	7.23	20.34	179	15.4%
25005	Boston	Bristol	MA	13.57	14.82	311	9.1%
25007	Boston	Dukes	MA	0.00	133.61	143	93.4%
25009	Boston	Essex	MA	17.74	4.90	424	5.3%
25019	Boston	Nantucket	MA	0.00	19.79	29	67.4%
25021	Boston	Norfolk	MA	21.42	6.80	460	6.1%
25023	Boston	Plymouth	MA	11.20	4.99	256	6.3%
25025	Boston	Suffolk	MA	11.57	57.64	2,518	2.7%
25027	Boston	Worcester	MA	43.94	1.04	556	8.1%
33011	Boston	Hillsborough	NH	1.33	0.42	266	0.7%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	1.00	36.02	263	14.1%
47065	Chattanooga	Hamilton	TN	40.53	29.56	283	24.7%
47115	Chattanooga	Marion	TN	5.67	5.70	63	18.1%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	7	0.0%
13047	Chattanooga	Catoosa	GA	12.28	0.01	52	23.6%
13083	Chattanooga	Dade	GA	11.66	0.00	46	25.3%
13295	Chattanooga	Walker	GA	0.00	0.01	48	0.0%
17031	Chicago	Cook	IL	708.71	209.67	3,661	25.1%
17043	Chicago	DuPage	IL	200.17	0.14	812	24.7%
17063	Chicago	Grundy	IL	13.55	6.45	114	17.6%
17089	Chicago	Kane	IL	70.19	0.10	371	19.0%
17093	Chicago	Kendall	IL	8.97	0.01	78	11.5%
17097	Chicago	Lake	IL	37.26	22.02	406	14.6%
17111	Chicago	McHenry	IL	20.29	0.16	189	10.8%
17197	Chicago	Will	IL	186.94	4.74	498	38.5%
18089	Chicago	Lake	IN	129.22	14.34	541	26.5%
18127	Chicago	Porter	IN	45.64	12.55	216	26.9%
18029	Cincinnati	Dearborn	IN	6.21	22.72	92	31.3%
21015	Cincinnati	Boone	KY	8.45	34.08	133	31.9%
21037	Cincinnati	Campbell	KY	16.05	23.57	95	41.5%
21117	Cincinnati	Kenton	KY	30.93	11.78	147	29.1%
39017	Cincinnati	Butler	OH	45.48	0.05	279	16.3%
39025	Cincinnati	Clermont	OH	1.96	44.98	181	25.9%
39061	Cincinnati	Hamilton	OH	44.25	133.23	737	24.1%
39165	Cincinnati	Warren	OH	6.75	0.09	192	3.6%
39007	Cleveland	Ashtabula	OH	30.49	178.56	310	67.4%
39035	Cleveland	Cuyahoga	OH	83.10	122.90	1,119	18.4%
39085	Cleveland	Lake	OH	21.22	26.15	190	25.0%
39093	Cleveland	Lorain	OH	50.28	113.72	414	39.6%
39103	Cleveland	Medina	OH	15.82	0.06	166	9.6%
39133	Cleveland	Portage	OH	31.34	0.24	198	15.9%
39153	Cleveland	Summit	OH	25.49	0.17	392	6.5%
26093	Detroit	Livingston	MI	2.47	0.07	174	1.5%
26099	Detroit	Macomb	MI	3.83	5.35	437	2.1%
26115	Detroit	Monroe	MI	18.09	8.90	198	13.6%
26125	Detroit	Oakland	MI	15.09	4.59	781	2.5%
26147	Detroit	St. Clair	MI	7.39	21.37	224	12.8%
26161	Detroit	Washtenaw	MI	4.04	0.05	269	1.5%
26163	Detroit	Wayne	MI	29.94	10.03	1,140	3.5%
48039	Houston	Brazoria	TX	18.79	247.18	463	57.4%
48071	Houston	Chambers	TX	1.07	7.41	57	14.8%
48157	Houston	Fort Bend	TX	26.30	0.09	270	9.8%
48167	Houston	Galveston	TX	13.07	566.43	751	77.1%
48201	Houston	Harris	TX	68.97	1,477.09	3,940	39.2%
48291	Houston	Liberty	TX	28.79	3.02	112	28.3%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	22.38	0.27	300	7.5%
48473	Houston	Waller	TX	6.50	0.04	45	14.5%
21019	Huntington	Boyd	KY	11.13	18.28	65	45.2%
21127	Huntington	Lawrence	KY	10.86	5.94	33	51.6%
39001	Huntington	Adams	OH	0.39	52.61	88	60.0%
39053	Huntington	Gallia	OH	3.44	23.13	62	42.8%
39087	Huntington	Lawrence	OH	12.48	34.34	86	54.5%
39145	Huntington	Scioto	OH	27.95	33.28	124	49.5%
54011	Huntington	Cabell	WV	24.48	25.26	112	44.5%
54053	Huntington	Mason	WV	6.12	39.72	92	50.0%
54099	Huntington	Wayne	WV	30.53	60.21	133	68.1%
18011	Indianapolis	Boone	IN	6.78	0.06	120	5.7%
18057	Indianapolis	Hamilton	IN	0.16	0.62	224	0.3%
18059	Indianapolis	Hancock	IN	5.17	0.03	107	4.9%
18063	Indianapolis	Hendricks	IN	18.14	0.03	188	9.7%
18081	Indianapolis	Johnson	IN	0.91	0.21	115	1.0%
18095	Indianapolis	Madison	IN	16.17	0.12	156	10.5%
18097	Indianapolis	Marion	IN	31.30	1.34	662	4.9%
18109	Indianapolis	Morgan	IN	0.41	0.22	93	0.7%
18145	Indianapolis	Shelby	IN	7.35	0.02	102	7.2%
20091	Kansas City	Johnson	KS	55.73	0.04	481	11.6%
20103	Kansas City	Leavenworth	KS	14.29	0.50	84	17.6%
20121	Kansas City	Miami	KS	81.56	0.15	139	58.6%
20209	Kansas City	Wyandotte	KS	30.24	4.47	148	23.5%
29037	Kansas City	Cass	MO	16.72	0.12	110	15.3%
29047	Kansas City	Clay	MO	28.19	4.43	188	17.3%
29049	Kansas City	Clinton	MO	0.00	0.16	49	0.3%
29095	Kansas City	Jackson	MO	90.00	33.46	646	19.1%
29107	Kansas City	Lafayette	MO	23.25	4.16	124	22.1%
29165	Kansas City	Platte	MO	22.68	0.84	151	15.6%
29177	Kansas City	Ray	MO	44.83	3.97	108	45.2%
6037	Los Angeles	Los Angeles	CA	241.14	1,666.68	5,016	38.0%
6059	Los Angeles	Orange	CA	63.57	176.82	1,696	14.2%
6065	Los Angeles	Riverside	CA	109.12	1.01	872	12.6%
6071	Los Angeles	San Bernardino	CA	359.75	0.47	1,040	34.6%
6111	Los Angeles	Ventura	CA	12.49	231.21	524	46.5%
27003	Minneapolis	Anoka	MN	21.27	12.73	232	14.7%
27019	Minneapolis	Carver	MN	0.05	0.79	82	1.0%
27037	Minneapolis	Dakota	MN	12.70	11.89	278	8.9%
27053	Minneapolis	Hennepin	MN	31.68	35.83	870	7.8%
27123	Minneapolis	Ramsey	MN	12.03	11.31	349	6.7%
27139	Minneapolis	Scott	MN	2.70	1.38	94	4.3%
27163	Minneapolis	Washington	MN	23.15	50.70	237	31.1%
9001	New York	Fairfield	CT	0.00	44.84	705	6.4%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
9005	New York	Litchfield	CT	0.00	0.89	109	0.8%
34003	New York	Bergen	NJ	26.97	3.48	512	6.0%
34013	New York	Essex	NJ	6.64	0.99	416	1.8%
34017	New York	Hudson	NJ	22.70	27.96	402	12.6%
34019	New York	Hunterdon	NJ	9.60	0.33	185	5.4%
34023	New York	Middlesex	NJ	12.54	4.94	421	4.1%
34025	New York	Monmouth	NJ	10.14	29.48	418	9.5%
34027	New York	Morris	NJ	6.96	0.53	300	2.5%
34029	New York	Ocean	NJ	0.52	13.26	256	5.4%
34031	New York	Passaic	NJ	6.11	0.51	233	2.8%
34035	New York	Somerset	NJ	13.21	0.02	195	6.8%
34037	New York	Sussex	NJ	0.99	0.63	113	1.4%
34039	New York	Union	NJ	11.04	17.95	355	8.2%
36005	New York	Bronx	NY	0.13	0.75	372	0.2%
36047	New York	Kings	NY	0.00	1.30	696	0.2%
36059	New York	Nassau	NY	0.00	11.73	518	2.3%
36061	New York	New York	NY	0.00	0.54	1,296	0.0%
36071	New York	Orange	NY	9.19	2.55	288	4.1%
36081	New York	Queens	NY	0.06	2.02	982	0.2%
36085	New York	Richmond	NY	0.00	2.29	166	1.4%
36087	New York	Rockland	NY	6.91	2.69	125	7.7%
36103	New York	Suffolk	NY	0.00	39.17	690	5.7%
36119	New York	Westchester	NY	0.00	3.76	479	0.8%
10003	Philadelphia	New Castle	DE	22.95	47.44	458	15.4%
24015	Philadelphia	Cecil	MD	9.27	1.70	125	8.7%
24029	Philadelphia	Kent	MD	0.07	1.41	42	3.6%
24031	Philadelphia	Montgomery	MD	28.82	0.53	485	6.0%
34005	Philadelphia	Burlington	NJ	0.00	54.50	328	16.6%
34007	Philadelphia	Camden	NJ	4.82	21.83	273	9.8%
34011	Philadelphia	Cumberland	NJ	0.57	55.22	155	36.0%
34015	Philadelphia	Gloucester	NJ	0.80	29.18	214	14.0%
34021	Philadelphia	Mercer	NJ	5.56	6.66	277	4.4%
34033	Philadelphia	Salem	NJ	0.27	16.91	86	19.9%
42017	Philadelphia	Bucks	PA	2.29	1.20	330	1.1%
42029	Philadelphia	Chester	PA	11.62	0.16	328	3.6%
42045	Philadelphia	Delaware	PA	4.55	193.17	409	48.4%
42101	Philadelphia	Philadelphia	PA	6.45	339.10	922	37.5%
4013	Phoenix	Maricopa	AZ	98.35	0.78	2,828	3.5%
4021	Phoenix	Pinal	AZ	52.54	0.17	256	20.6%
6019	San Joaquin	Fresno	CA	17.77	0.58	647	2.8%
6029	San Joaquin	Kern	CA	92.07	0.22	635	14.5%
6031	San Joaquin	Kings	CA	2.57	0.02	155	1.7%
6039	San Joaquin	Madera	CA	18.89	0.16	145	13.2%
6047	San Joaquin	Merced	CA	17.75	0.46	218	8.4%
6077	San Joaquin	San Joaquin	CA	29.94	30.32	437	13.8%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
6099	San Joaquin	Stanislaus	CA	12.07	0.24	267	4.6%
6107	San Joaquin	Tulare	CA	26.68	0.16	340	7.9%
53029	Seattle	Island	WA	0.00	19.63	69	28.5%
53033	Seattle	King	WA	28.95	191.88	1,568	14.1%
53035	Seattle	Kitsap	WA	0.00	1.27	134	0.9%
53045	Seattle	Mason	WA	0.00	0.58	37	1.6%
53053	Seattle	Pierce	WA	18.18	173.52	612	31.3%
53061	Seattle	Snohomish	WA	36.65	29.32	471	14.0%
53067	Seattle	Thurston	WA	10.80	12.02	179	12.7%
17027	St. Louis	Clinton	IL	23.14	0.08	99	23.5%
17083	St. Louis	Jersey	IL	1.86	19.07	65	32.1%
17119	St. Louis	Madison	IL	7.81	10.33	247	7.4%
17133	St. Louis	Monroe	IL	37.61	16.72	104	52.1%
17163	St. Louis	St. Clair	IL	8.93	19.78	229	12.5%
29055	St. Louis	Crawford	MO	5.23	0.04	45	11.6%
29071	St. Louis	Franklin	MO	31.20	2.36	153	21.9%
29099	St. Louis	Jefferson	MO	8.38	16.93	186	13.6%
29113	St. Louis	Lincoln	MO	13.80	6.69	87	23.4%
29183	St. Louis	St. Charles	MO	16.62	15.02	244	13.0%
29189	St. Louis	St. Louis	MO	26.77	19.32	831	5.5%
29219	St. Louis	Warren	MO	2.82	2.31	47	10.9%
29510	St. Louis	St. Louis	MO	23.28	261.28	456	62.4%

Table 3-113 2020 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.45	0.01	11	49.6%
13015	Atlanta	Bartow	GA	19.49	0.17	35	56.9%
13045	Atlanta	Carroll	GA	5.28	0.07	19	27.6%
13057	Atlanta	Cherokee	GA	0.00	0.17	23	0.7%
13063	Atlanta	Clayton	GA	10.27	0.02	41	25.2%
13067	Atlanta	Cobb	GA	26.96	0.07	137	19.8%
13077	Atlanta	Coweta	GA	13.55	0.05	33	41.2%
13089	Atlanta	DeKalb	GA	12.49	0.04	103	12.1%
13097	Atlanta	Douglas	GA	4.86	0.01	16	30.0%
13113	Atlanta	Fayette	GA	3.50	0.03	20	18.0%
13117	Atlanta	Forsyth	GA	0.00	0.35	24	1.5%
13121	Atlanta	Fulton	GA	36.74	0.09	224	16.4%
13135	Atlanta	Gwinnett	GA	9.33	0.06	118	8.0%
13139	Atlanta	Hall	GA	5.67	0.57	31	19.9%
13149	Atlanta	Heard	GA	0.00	0.08	2	4.4%
13151	Atlanta	Henry	GA	13.81	0.03	41	34.2%
13217	Atlanta	Newton	GA	1.56	0.04	15	10.4%
13223	Atlanta	Paulding	GA	11.45	0.02	24	47.5%
13237	Atlanta	Putnam	GA	0.31	0.26	3	17.2%
13247	Atlanta	Rockdale	GA	2.22	0.02	16	14.2%
13255	Atlanta	Spalding	GA	0.59	0.02	10	6.4%
13297	Atlanta	Walton	GA	1.88	0.01	10	18.8%
24003	Baltimore	Anne Arundel	MD	10.36	1.57	73	16.4%
24005	Baltimore	Baltimore	MD	34.68	1.03	154	23.1%
24013	Baltimore	Carroll	MD	5.34	0.03	37	14.6%
24025	Baltimore	Harford	MD	8.84	1.00	46	21.5%
24027	Baltimore	Howard	MD	12.62	0.32	56	22.9%
24510	Baltimore	Baltimore	MD	46.50	242.61	328	88.1%
1073	Birmingham	Jefferson	AL	75.36	0.86	188	40.6%
1117	Birmingham	Shelby	AL	39.49	0.26	65	61.4%
1127	Birmingham	Walker	AL	14.91	0.86	30	52.9%
9007	Boston	Middlesex	CT	0.00	1.50	22	6.7%
25001	Boston	Barnstable	MA	6.28	16.59	55	41.7%
25005	Boston	Bristol	MA	11.82	11.64	79	29.6%
25007	Boston	Dukes	MA	0.00	103.75	106	97.6%
25009	Boston	Essex	MA	15.42	4.13	101	19.4%
25019	Boston	Nantucket	MA	0.00	15.54	18	85.4%
25021	Boston	Norfolk	MA	18.39	5.32	114	20.9%
25023	Boston	Plymouth	MA	9.78	4.30	65	21.8%
25025	Boston	Suffolk	MA	9.83	44.70	688	7.9%
25027	Boston	Worcester	MA	37.77	0.92	142	27.3%
33011	Boston	Hillsborough	NH	1.15	0.37	56	2.7%

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	0.87	28.09	74	39.1%
47065	Chattanooga	Hamilton	TN	38.28	22.98	103	59.3%
47115	Chattanooga	Marion	TN	5.36	4.45	18	53.8%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	1	0.0%
13047	Chattanooga	Catoosa	GA	11.60	0.01	18	63.7%
13083	Chattanooga	Dade	GA	11.01	0.00	16	67.9%
13295	Chattanooga	Walker	GA	0.00	0.01	9	0.1%
17031	Chicago	Cook	IL	608.24	164.40	1,362	56.7%
17043	Chicago	DuPage	IL	162.78	0.12	317	51.4%
17063	Chicago	Grundy	IL	13.20	5.01	42	43.5%
17089	Chicago	Kane	IL	59.50	0.09	138	43.3%
17093	Chicago	Kendall	IL	8.18	0.01	27	30.5%
17097	Chicago	Lake	IL	30.80	19.13	138	36.2%
17111	Chicago	McHenry	IL	17.00	0.14	61	28.0%
17197	Chicago	Will	IL	163.07	3.70	242	68.9%
18089	Chicago	Lake	IN	132.19	12.15	232	62.3%
18127	Chicago	Porter	IN	40.84	10.56	85	60.4%
18029	Cincinnati	Dearborn	IN	5.59	17.59	35	65.7%
21015	Cincinnati	Boone	KY	7.99	26.40	54	63.8%
21037	Cincinnati	Campbell	KY	15.10	18.27	43	77.4%
21117	Cincinnati	Kenton	KY	29.20	9.12	59	65.4%
39017	Cincinnati	Butler	OH	40.67	0.04	92	44.2%
39025	Cincinnati	Clermont	OH	1.76	34.82	63	58.0%
39061	Cincinnati	Hamilton	OH	39.70	103.13	268	53.3%
39165	Cincinnati	Warren	OH	6.08	0.08	49	12.5%
39007	Cleveland	Ashtabula	OH	27.38	138.54	185	89.5%
39035	Cleveland	Cuyahoga	OH	76.82	96.57	379	45.7%
39085	Cleveland	Lake	OH	18.90	21.00	71	56.4%
39093	Cleveland	Lorain	OH	45.04	88.60	190	70.4%
39103	Cleveland	Medina	OH	14.17	0.05	45	31.8%
39133	Cleveland	Portage	OH	28.09	0.21	61	46.1%
39153	Cleveland	Summit	OH	22.96	0.15	101	22.8%
26093	Detroit	Livingston	MI	2.33	0.06	35	6.8%
26099	Detroit	Macomb	MI	3.62	4.26	96	8.2%
26115	Detroit	Monroe	MI	17.08	6.95	60	39.7%
26125	Detroit	Oakland	MI	14.21	3.58	188	9.5%
26147	Detroit	St. Clair	MI	6.90	16.67	64	37.1%
26161	Detroit	Washtenaw	MI	3.82	0.04	61	6.3%
26163	Detroit	Wayne	MI	28.47	7.97	253	14.4%
48039	Houston	Brazoria	TX	17.74	191.47	248	84.2%
48071	Houston	Chambers	TX	1.01	5.88	16	44.1%
48157	Houston	Fort Bend	TX	24.70	0.08	79	31.5%
48167	Houston	Galveston	TX	12.47	438.65	487	92.6%
48201	Houston	Harris	TX	65.54	1,143.23	1,727	70.0%
48291	Houston	Liberty	TX	27.14	2.35	45	65.6%

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	21.14	0.24	68	31.6%
48473	Houston	Waller	TX	6.14	0.04	15	42.5%
21019	Huntington	Boyd	KY	10.44	14.15	31	79.9%
21127	Huntington	Lawrence	KY	9.43	4.60	17	84.4%
39001	Huntington	Adams	OH	0.35	40.72	49	84.4%
39053	Huntington	Gallia	OH	3.09	17.90	28	73.8%
39087	Huntington	Lawrence	OH	11.20	26.58	44	85.6%
39145	Huntington	Scioto	OH	25.08	25.76	63	80.7%
54011	Huntington	Cabell	WV	22.84	19.57	54	78.0%
54053	Huntington	Mason	WV	5.31	30.79	47	76.4%
54099	Huntington	Wayne	WV	28.80	46.62	85	88.8%
18011	Indianapolis	Boone	IN	5.92	0.05	34	17.6%
18057	Indianapolis	Hamilton	IN	0.15	0.55	54	1.3%
18059	Indianapolis	Hancock	IN	4.58	0.03	28	16.2%
18063	Indianapolis	Hendricks	IN	16.27	0.03	55	29.9%
18081	Indianapolis	Johnson	IN	0.88	0.19	26	4.2%
18095	Indianapolis	Madison	IN	14.62	0.11	45	32.9%
18097	Indianapolis	Marion	IN	27.99	1.19	166	17.5%
18109	Indianapolis	Morgan	IN	0.40	0.20	19	3.1%
18145	Indianapolis	Shelby	IN	6.54	0.02	29	22.3%
20091	Kansas City	Johnson	KS	52.60	0.03	155	33.9%
20103	Kansas City	Leavenworth	KS	13.49	0.39	29	47.4%
20121	Kansas City	Miami	KS	77.03	0.14	92	83.9%
20209	Kansas City	Wyandotte	KS	28.47	3.46	56	57.5%
29037	Kansas City	Cass	MO	15.70	0.11	37	42.4%
29047	Kansas City	Clay	MO	26.78	3.48	64	47.6%
29049	Kansas City	Clinton	MO	0.00	0.14	12	1.2%
29095	Kansas City	Jackson	MO	85.15	25.94	223	49.8%
29107	Kansas City	Lafayette	MO	21.96	3.26	49	51.3%
29165	Kansas City	Platte	MO	21.42	0.67	51	42.9%
29177	Kansas City	Ray	MO	42.28	3.09	61	74.5%
6037	Los Angeles	Los Angeles	CA	217.08	1,290.10	2,697	55.9%
6059	Los Angeles	Orange	CA	56.50	136.94	729	26.6%
6065	Los Angeles	Riverside	CA	93.21	0.90	380	24.8%
6071	Los Angeles	San Bernardino	CA	321.96	0.42	574	56.2%
6111	Los Angeles	Ventura	CA	11.01	179.05	298	63.8%
27003	Minneapolis	Anoka	MN	19.93	10.06	72	41.9%
27019	Minneapolis	Carver	MN	0.05	0.67	20	3.6%
27037	Minneapolis	Dakota	MN	11.92	9.37	80	26.5%
27053	Minneapolis	Hennepin	MN	29.88	28.17	242	24.0%
27123	Minneapolis	Ramsey	MN	11.29	8.91	89	22.8%
27139	Minneapolis	Scott	MN	2.55	1.15	25	14.6%
27163	Minneapolis	Washington	MN	21.74	39.42	96	63.8%
9001	New York	Fairfield	CT	0.00	35.19	184	19.1%

FIPS	MSA	County	ST	2020 PM2.5 Diesel Locomotive	 Diesel Marine	 Total Diesel Mobile	 LM Percent
9005	New York	Litchfield	CT	0.00	0.79	23	3.4%
34003	New York	Bergen	NJ	22.36	2.76	146	17.2%
34013	New York	Essex	NJ	5.18	0.79	95	6.3%
34017	New York	Hudson	NJ	19.90	21.74	120	34.7%
34019	New York	Hunterdon	NJ	7.47	0.29	41	19.0%
34023	New York	Middlesex	NJ	11.14	3.88	106	14.1%
34025	New York	Monmouth	NJ	6.84	23.33	114	26.6%
34027	New York	Morris	NJ	5.01	0.47	73	7.6%
34029	New York	Ocean	NJ	0.41	11.45	58	20.3%
34031	New York	Passaic	NJ	4.28	0.45	54	8.7%
34035	New York	Somerset	NJ	11.03	0.01	51	21.8%
34037	New York	Sussex	NJ	0.96	0.55	23	6.6%
34039	New York	Union	NJ	8.53	13.90	97	23.1%
36005	New York	Bronx	NY	0.12	0.62	75	1.0%
36047	New York	Kings	NY	0.00	1.07	146	0.7%
36059	New York	Nassau	NY	0.00	9.33	139	6.7%
36061	New York	New York	NY	0.00	0.44	364	0.1%
36071	New York	Orange	NY	8.01	2.02	63	15.9%
36081	New York	Queens	NY	0.06	1.66	228	0.8%
36085	New York	Richmond	NY	0.00	1.84	39	4.8%
36087	New York	Rockland	NY	6.33	2.13	37	22.9%
36103	New York	Suffolk	NY	0.00	32.24	193	16.7%
36119	New York	Westchester	NY	0.00	3.02	123	2.5%
10003	Philadelphia	New Castle	DE	23.49	36.76	144	41.7%
24015	Philadelphia	Cecil	MD	7.73	1.40	30	30.2%
24029	Philadelphia	Kent	MD	0.06	1.21	12	10.5%
24031	Philadelphia	Montgomery	MD	21.88	0.43	127	17.6%
34005	Philadelphia	Burlington	NJ	0.00	42.25	100	42.2%
34007	Philadelphia	Camden	NJ	3.47	16.92	72	28.3%
34011	Philadelphia	Cumberland	NJ	0.55	43.19	65	67.8%
34015	Philadelphia	Gloucester	NJ	0.83	22.64	63	37.2%
34021	Philadelphia	Mercer	NJ	4.55	5.17	64	15.3%
34033	Philadelphia	Salem	NJ	0.25	13.18	28	47.6%
42017	Philadelphia	Bucks	PA	1.95	1.00	78	3.8%
42029	Philadelphia	Chester	PA	9.26	0.14	81	11.7%
42045	Philadelphia	Delaware	PA	3.76	149.53	199	77.0%
42101	Philadelphia	Philadelphia	PA	5.74	262.48	383	69.9%
4013	Phoenix	Maricopa	AZ	89.13	0.69	709	12.7%
4021	Phoenix	Pinal	AZ	48.94	0.15	92	53.5%
6019	San Joaquin	Fresno	CA	15.98	0.51	236	7.0%
6029	San Joaquin	Kern	CA	80.81	0.19	265	30.6%
6031	San Joaquin	Kings	CA	2.13	0.02	56	3.8%
6039	San Joaquin	Madera	CA	17.29	0.14	63	27.9%
6047	San Joaquin	Merced	CA	15.33	0.40	84	18.6%
6077	San Joaquin	San Joaquin	CA	26.62	23.51	184	27.3%

FIPS	MSA	County	ST	2020 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
6099	San Joaquin	Stanislaus	CA	10.69	0.21	101	10.8%
6107	San Joaquin	Tulare	CA	24.00	0.14	133	18.1%
53029	Seattle	Island	WA	0.00	15.26	25	60.2%
53033	Seattle	King	WA	27.06	149.20	484	36.4%
53035	Seattle	Kitsap	WA	0.00	1.13	27	4.2%
53045	Seattle	Mason	WA	0.00	0.50	7	7.1%
53053	Seattle	Pierce	WA	16.97	134.63	238	63.7%
53061	Seattle	Snohomish	WA	33.68	23.01	140	40.4%
53067	Seattle	Thurston	WA	9.33	9.42	48	39.1%
17027	St. Louis	Clinton	IL	21.27	0.07	41	51.8%
17083	St. Louis	Jersey	IL	1.73	14.76	28	57.9%
17119	St. Louis	Madison	IL	8.44	8.01	67	24.7%
17133	St. Louis	Monroe	IL	33.99	12.95	60	77.8%
17163	St. Louis	St. Clair	IL	9.49	15.31	69	36.2%
29055	St. Louis	Crawford	MO	4.54	0.04	12	38.8%
29071	St. Louis	Franklin	MO	29.11	1.86	54	57.6%
29099	St. Louis	Jefferson	MO	7.90	13.13	49	43.3%
29113	St. Louis	Lincoln	MO	13.04	5.22	34	53.8%
29183	St. Louis	St. Charles	MO	15.70	11.75	73	37.4%
29189	St. Louis	St. Louis	MO	25.09	15.01	214	18.8%
29219	St. Louis	Warren	MO	2.66	1.81	14	32.7%
29510	St. Louis	St. Louis	MO	22.18	202.23	256	87.7%

Table 3-114 2030 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.25	0.01	9	60.3%
13015	Atlanta	Bartow	GA	18.79	0.20	28	68.0%
13045	Atlanta	Carroll	GA	5.08	0.08	14	37.1%
13057	Atlanta	Cherokee	GA	0.00	0.19	14	1.3%
13063	Atlanta	Clayton	GA	9.90	0.03	27	36.7%
13067	Atlanta	Cobb	GA	25.96	0.08	85	30.8%
13077	Atlanta	Coweta	GA	13.06	0.06	25	53.1%
13089	Atlanta	DeKalb	GA	12.03	0.05	66	18.2%
13097	Atlanta	Douglas	GA	4.66	0.01	12	40.2%
13113	Atlanta	Fayette	GA	3.37	0.04	13	26.9%
13117	Atlanta	Forsyth	GA	0.00	0.40	14	2.9%
13121	Atlanta	Fulton	GA	35.38	0.11	130	27.4%
13135	Atlanta	Gwinnett	GA	8.98	0.07	69	13.2%
13139	Atlanta	Hall	GA	5.34	0.65	21	29.0%
13149	Atlanta	Heard	GA	0.00	0.09	1	8.2%
13151	Atlanta	Henry	GA	13.32	0.04	28	47.3%
13217	Atlanta	Newton	GA	1.50	0.05	9	16.7%
13223	Atlanta	Paulding	GA	11.04	0.03	19	58.6%
13237	Atlanta	Putnam	GA	0.29	0.30	2	26.8%
13247	Atlanta	Rockdale	GA	2.14	0.03	10	22.0%
13255	Atlanta	Spalding	GA	0.57	0.03	6	10.2%
13297	Atlanta	Walton	GA	1.81	0.01	6	28.3%
24003	Baltimore	Anne Arundel	MD	9.01	1.77	43	24.8%
24005	Baltimore	Baltimore	MD	32.54	1.15	94	36.0%
24013	Baltimore	Carroll	MD	5.05	0.04	22	23.1%
24025	Baltimore	Harford	MD	8.01	1.11	28	32.2%
24027	Baltimore	Howard	MD	11.21	0.35	35	33.5%
24510	Baltimore	Baltimore	MD	45.29	259.26	330	92.2%
1073	Birmingham	Jefferson	AL	72.52	0.94	143	51.5%
1117	Birmingham	Shelby	AL	38.03	0.29	52	73.3%
1127	Birmingham	Walker	AL	14.10	0.93	26	58.7%
9007	Boston	Middlesex	CT	0.00	1.70	14	12.3%
25001	Boston	Barnstable	MA	5.94	18.19	42	58.0%
25005	Boston	Bristol	MA	11.25	12.53	55	43.6%
25007	Boston	Dukes	MA	0.00	111.06	112	98.9%
25009	Boston	Essex	MA	14.59	4.59	63	30.3%
25019	Boston	Nantucket	MA	0.00	16.73	18	93.2%
25021	Boston	Norfolk	MA	17.74	5.72	72	32.7%
25023	Boston	Plymouth	MA	9.26	4.83	42	33.7%
25025	Boston	Suffolk	MA	9.40	47.81	295	19.4%
25027	Boston	Worcester	MA	35.83	1.04	91	40.4%
33011	Boston	Hillsborough	NH	1.09	0.42	31	4.9%

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	0.82	30.13	56	55.2%
47065	Chattanooga	Hamilton	TN	36.91	24.61	85	72.5%
47115	Chattanooga	Marion	TN	5.16	4.78	15	67.1%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	1	0.0%
13047	Chattanooga	Catoosa	GA	11.18	0.01	15	74.0%
13083	Chattanooga	Dade	GA	10.61	0.00	14	76.7%
13295	Chattanooga	Walker	GA	0.00	0.01	5	0.1%
17031	Chicago	Cook	IL	583.11	176.82	1,069	71.1%
17043	Chicago	DuPage	IL	150.13	0.14	227	66.1%
17063	Chicago	Grundy	IL	12.86	5.35	29	62.4%
17089	Chicago	Kane	IL	55.63	0.10	91	61.3%
17093	Chicago	Kendall	IL	7.87	0.01	16	48.2%
17097	Chicago	Lake	IL	28.70	21.57	96	52.5%
17111	Chicago	McHenry	IL	15.86	0.16	37	42.9%
17197	Chicago	Will	IL	154.37	3.97	195	81.2%
18089	Chicago	Lake	IN	129.63	13.55	186	77.1%
18127	Chicago	Porter	IN	39.03	11.74	68	75.0%
18029	Cincinnati	Dearborn	IN	5.39	18.81	30	79.5%
21015	Cincinnati	Boone	KY	7.70	28.23	46	78.5%
21037	Cincinnati	Campbell	KY	14.53	19.53	40	85.6%
21117	Cincinnati	Kenton	KY	28.15	9.75	49	78.1%
39017	Cincinnati	Butler	OH	38.73	0.05	64	60.4%
39025	Cincinnati	Clermont	OH	1.68	37.21	53	72.9%
39061	Cincinnati	Hamilton	OH	38.03	110.20	216	68.7%
39165	Cincinnati	Warren	OH	5.88	0.09	26	23.0%
39007	Cleveland	Ashtabula	OH	26.16	148.22	185	94.4%
39035	Cleveland	Cuyahoga	OH	73.82	103.97	280	63.4%
39085	Cleveland	Lake	OH	17.97	22.85	57	71.2%
39093	Cleveland	Lorain	OH	42.97	94.99	165	83.8%
39103	Cleveland	Medina	OH	13.67	0.06	30	45.8%
39133	Cleveland	Portage	OH	26.81	0.24	45	60.8%
39153	Cleveland	Summit	OH	21.98	0.17	63	35.3%
26093	Detroit	Livingston	MI	2.25	0.06	20	11.7%
26099	Detroit	Macomb	MI	3.49	4.61	56	14.6%
26115	Detroit	Monroe	MI	16.47	7.45	42	56.9%
26125	Detroit	Oakland	MI	13.69	3.84	108	16.2%
26147	Detroit	St. Clair	MI	6.63	17.88	44	55.4%
26161	Detroit	Washtenaw	MI	3.80	0.04	35	11.1%
26163	Detroit	Wayne	MI	29.36	8.63	151	25.1%
48039	Houston	Brazoria	TX	17.11	204.68	242	91.5%
48071	Houston	Chambers	TX	0.97	6.36	12	59.3%
48157	Houston	Fort Bend	TX	23.77	0.09	52	45.9%
48167	Houston	Galveston	TX	13.22	468.88	500	96.4%
48201	Houston	Harris	TX	67.89	1,221.64	1,557	82.8%
48291	Houston	Liberty	TX	26.15	2.52	37	77.9%

FIPS	MSA	County	ST	2030 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	20.38	0.27	49	42.2%
48473	Houston	Waller	TX	5.92	0.04	10	58.2%
21019	Huntington	Boyd	KY	10.05	15.13	29	87.4%
21127	Huntington	Lawrence	KY	8.93	4.91	15	90.7%
39001	Huntington	Adams	OH	0.34	43.51	48	92.1%
39053	Huntington	Gallia	OH	2.94	19.13	26	85.9%
39087	Huntington	Lawrence	OH	10.68	28.40	43	91.2%
39145	Huntington	Scioto	OH	23.91	27.52	58	89.0%
54011	Huntington	Cabell	WV	21.94	20.93	49	86.9%
54053	Huntington	Mason	WV	5.03	32.92	42	89.3%
54099	Huntington	Wayne	WV	27.75	49.83	82	95.0%
18011	Indianapolis	Boone	IN	5.59	0.06	19	30.0%
18057	Indianapolis	Hamilton	IN	0.18	0.63	26	3.1%
18059	Indianapolis	Hancock	IN	4.35	0.03	16	28.1%
18063	Indianapolis	Hendricks	IN	15.52	0.03	33	46.7%
18081	Indianapolis	Johnson	IN	1.02	0.21	14	8.9%
18095	Indianapolis	Madison	IN	13.96	0.12	29	47.9%
18097	Indianapolis	Marion	IN	26.79	1.35	98	28.7%
18109	Indianapolis	Morgan	IN	0.46	0.22	10	6.6%
18145	Indianapolis	Shelby	IN	6.23	0.02	17	36.6%
20091	Kansas City	Johnson	KS	50.70	0.04	101	50.4%
20103	Kansas City	Leavenworth	KS	13.00	0.42	21	63.9%
20121	Kansas City	Miami	KS	74.26	0.15	81	91.7%
20209	Kansas City	Wyandotte	KS	27.42	3.70	43	71.6%
29037	Kansas City	Cass	MO	15.11	0.12	26	59.1%
29047	Kansas City	Clay	MO	27.23	3.74	48	64.9%
29049	Kansas City	Clinton	MO	0.00	0.16	6	2.9%
29095	Kansas City	Jackson	MO	85.76	27.74	171	66.5%
29107	Kansas City	Lafayette	MO	21.17	3.50	36	68.5%
29165	Kansas City	Platte	MO	20.65	0.74	35	61.6%
29177	Kansas City	Ray	MO	42.32	3.31	53	86.7%
6037	Los Angeles	Los Angeles	CA	214.05	1,378.65	2,053	77.6%
6059	Los Angeles	Orange	CA	57.93	146.38	433	47.2%
6065	Los Angeles	Riverside	CA	87.56	1.02	189	46.8%
6071	Los Angeles	San Bernardino	CA	306.89	0.48	400	76.8%
6111	Los Angeles	Ventura	CA	10.79	191.39	247	81.7%
27003	Minneapolis	Anoka	MN	19.16	10.87	51	59.0%
27019	Minneapolis	Carver	MN	0.05	0.75	10	7.6%
27037	Minneapolis	Dakota	MN	11.47	10.11	51	42.4%
27053	Minneapolis	Hennepin	MN	28.80	30.34	153	38.7%
27123	Minneapolis	Ramsey	MN	10.87	9.61	56	36.4%
27139	Minneapolis	Scott	MN	2.46	1.27	14	26.4%
27163	Minneapolis	Washington	MN	20.93	42.22	81	78.3%
9001	New York	Fairfield	CT	0.00	37.87	112	33.7%

FIPS	MSA	County	ST	2030 PM2.5 Diesel Locomotive	 Diesel Marine	 Total Diesel Mobile	 LM Percent
9005	New York	Litchfield	CT	0.00	0.90	13	6.6%
34003	New York	Bergen	NJ	20.91	2.98	89	26.9%
34013	New York	Essex	NJ	4.68	0.85	50	11.0%
34017	New York	Hudson	NJ	18.73	23.28	79	53.1%
34019	New York	Hunterdon	NJ	6.78	0.33	25	28.1%
34023	New York	Middlesex	NJ	10.49	4.17	63	23.1%
34025	New York	Monmouth	NJ	5.78	25.21	75	41.6%
34027	New York	Morris	NJ	4.44	0.53	42	11.9%
34029	New York	Ocean	NJ	0.36	12.87	39	33.6%
34031	New York	Passaic	NJ	3.75	0.51	30	14.0%
34035	New York	Somerset	NJ	10.24	0.02	32	32.2%
34037	New York	Sussex	NJ	1.10	0.63	13	12.9%
34039	New York	Union	NJ	7.68	14.86	59	38.2%
36005	New York	Bronx	NY	0.12	0.69	38	2.1%
36047	New York	Kings	NY	0.00	1.18	77	1.5%
36059	New York	Nassau	NY	0.00	10.10	78	12.9%
36061	New York	New York	NY	0.00	0.48	168	0.3%
36071	New York	Orange	NY	7.53	2.18	39	25.2%
36081	New York	Queens	NY	0.05	1.83	103	1.8%
36085	New York	Richmond	NY	0.00	2.00	19	10.3%
36087	New York	Rockland	NY	6.09	2.31	23	36.8%
36103	New York	Suffolk	NY	0.00	35.49	118	30.1%
36119	New York	Westchester	NY	0.00	3.29	61	5.4%
10003	Philadelphia	New Castle	DE	23.04	39.30	105	59.6%
24015	Philadelphia	Cecil	MD	7.20	1.55	20	43.2%
24029	Philadelphia	Kent	MD	0.06	1.36	6	22.2%
24031	Philadelphia	Montgomery	MD	19.61	0.46	78	25.7%
34005	Philadelphia	Burlington	NJ	0.00	45.18	76	59.6%
34007	Philadelphia	Camden	NJ	3.05	18.09	49	43.0%
34011	Philadelphia	Cumberland	NJ	0.64	46.39	58	81.6%
34015	Philadelphia	Gloucester	NJ	0.83	24.22	45	55.3%
34021	Philadelphia	Mercer	NJ	4.21	5.53	38	25.5%
34033	Philadelphia	Salem	NJ	0.26	14.13	22	65.7%
42017	Philadelphia	Bucks	PA	1.82	1.10	44	6.7%
42029	Philadelphia	Chester	PA	8.44	0.16	46	18.8%
42045	Philadelphia	Delaware	PA	3.48	159.80	188	86.8%
42101	Philadelphia	Philadelphia	PA	5.93	280.49	347	82.6%
4013	Phoenix	Maricopa	AZ	85.15	0.79	425	20.2%
4021	Phoenix	Pinal	AZ	46.98	0.17	71	66.3%
6019	San Joaquin	Fresno	CA	15.23	0.58	101	15.7%
6029	San Joaquin	Kern	CA	76.62	0.22	145	52.9%
6031	San Joaquin	Kings	CA	1.98	0.02	21	9.3%
6039	San Joaquin	Madera	CA	16.55	0.16	32	52.1%
6047	San Joaquin	Merced	CA	14.48	0.46	41	36.8%
6077	San Joaquin	San Joaquin	CA	25.33	25.14	100	50.3%

FIPS	MSA	County	ST	2030 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
6099	San Joaquin	Stanislaus	CA	10.15	0.23	45	23.3%
6107	San Joaquin	Tulare	CA	22.89	0.16	65	35.4%
53029	Seattle	Island	WA	0.00	16.34	22	75.7%
53033	Seattle	King	WA	26.00	159.80	344	54.0%
53035	Seattle	Kitsap	WA	0.00	1.28	16	8.1%
53045	Seattle	Mason	WA	0.00	0.57	4	12.8%
53053	Seattle	Pierce	WA	16.30	144.03	206	77.8%
53061	Seattle	Snohomish	WA	32.24	24.77	102	56.0%
53067	Seattle	Thurston	WA	8.81	10.12	36	53.2%
17027	St. Louis	Clinton	IL	20.38	0.08	29	69.4%
17083	St. Louis	Jersey	IL	1.66	15.78	23	76.4%
17119	St. Louis	Madison	IL	8.64	8.56	43	40.3%
17133	St. Louis	Monroe	IL	32.45	13.84	52	88.4%
17163	St. Louis	St. Clair	IL	9.36	16.36	48	53.5%
29055	St. Louis	Crawford	MO	4.30	0.04	9	50.9%
29071	St. Louis	Franklin	MO	27.96	2.00	43	70.5%
29099	St. Louis	Jefferson	MO	7.62	14.04	38	57.1%
29113	St. Louis	Lincoln	MO	12.57	5.60	26	70.5%
29183	St. Louis	St. Charles	MO	15.14	12.62	51	54.2%
29189	St. Louis	St. Louis	MO	24.13	16.08	130	30.9%
29219	St. Louis	Warren	MO	2.56	1.95	9	49.3%
29510	St. Louis	St. Louis	MO	23.99	216.11	260	92.3%

Table 3-115 2002 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	224.1	0.5	2,039	11.0%
13015	Atlanta	Bartow	GA	799.6	7.0	5,172	15.6%
13045	Atlanta	Carroll	GA	219.5	3.0	4,762	4.7%
13057	Atlanta	Cherokee	GA	0.0	6.8	5,828	0.1%
13063	Atlanta	Clayton	GA	420.9	1.0	9,512	4.4%
13067	Atlanta	Cobb	GA	1,110.1	2.8	23,542	4.7%
13077	Atlanta	Coweta	GA	555.6	2.0	5,727	9.7%
13089	Atlanta	DeKalb	GA	515.4	1.8	26,283	2.0%
13097	Atlanta	Douglas	GA	202.2	0.5	3,952	5.1%
13113	Atlanta	Fayette	GA	143.8	1.3	3,977	3.6%
13117	Atlanta	Forsyth	GA	0.0	14.1	4,418	0.3%
13121	Atlanta	Fulton	GA	1,512.7	3.8	39,991	3.8%
13135	Atlanta	Gwinnett	GA	385.8	2.5	21,343	1.8%
13139	Atlanta	Hall	GA	258.8	23.1	6,452	4.4%
13149	Atlanta	Heard	GA	0.0	3.3	465	0.7%
13151	Atlanta	Henry	GA	567.2	1.3	6,479	8.8%
13217	Atlanta	Newton	GA	64.4	1.8	3,584	1.8%
13223	Atlanta	Paulding	GA	470.2	1.0	3,801	12.4%
13237	Atlanta	Putnam	GA	14.1	10.6	630	3.9%
13247	Atlanta	Rockdale	GA	91.1	1.0	3,158	2.9%
13255	Atlanta	Spalding	GA	24.5	1.0	2,584	1.0%
13297	Atlanta	Walton	GA	77.1	0.5	2,211	3.5%
24003	Baltimore	Anne Arundel	MD	520.4	63.4	15,497	3.8%
24005	Baltimore	Baltimore	MD	1,243.0	41.5	24,021	5.3%
24013	Baltimore	Carroll	MD	199.2	1.3	5,995	3.3%
24025	Baltimore	Harford	MD	389.4	40.2	7,894	5.4%
24027	Baltimore	Howard	MD	594.5	12.7	8,160	7.4%
24510	Baltimore	Baltimore	MD	1,282.5	1,670.4	23,591	12.5%
1073	Birmingham	Jefferson	AL	4,615.9	268.9	32,416	15.1%
1117	Birmingham	Shelby	AL	1,156.1	10.4	6,159	18.9%
1127	Birmingham	Walker	AL	889.2	116.8	3,687	27.3%
9007	Boston	Middlesex	CT	160.2	121.4	282	99.8%
25001	Boston	Barnstable	MA	318.1	474.3	8,446	9.4%
25005	Boston	Bristol	MA	588.4	238.7	15,719	5.3%
25007	Boston	Dukes	MA	0.0	1,589.6	2,042	77.9%
25009	Boston	Essex	MA	777.6	197.2	21,303	4.6%
25019	Boston	Nantucket	MA	0.0	282.5	596	47.4%
25021	Boston	Norfolk	MA	902.6	163.4	22,498	4.7%
25023	Boston	Plymouth	MA	493.8	169.6	12,655	5.2%
25025	Boston	Suffolk	MA	489.2	855.0	38,095	3.5%
25027	Boston	Worcester	MA	1,860.6	36.5	26,614	7.1%
33011	Boston	Hillsborough	NH	49.0	15.0	12,444	0.5%
33015	Boston	Rockingham	NH	37.0	1,112.9	11,846	9.7%
47065	Chattanooga	Hamilton	TN	1,569.2	909.5	14,329	17.3%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47115	Chattanooga	Marion	TN	220.0	176.6	2,998	13.2%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	270	0.0%
13047	Chattanooga	Catoosa	GA	475.9	0.3	2,527	18.8%
13083	Chattanooga	Dade	GA	452.1	0.0	2,263	20.0%
13295	Chattanooga	Walker	GA	0.0	0.3	1,996	0.0%
17031	Chicago	Cook	IL	24,769.1	6,520.5	178,269	17.6%
17043	Chicago	DuPage	IL	7,028.5	5.0	31,241	22.5%
17063	Chicago	Grundy	IL	479.6	198.0	3,244	20.9%
17089	Chicago	Kane	IL	2,446.9	3.5	8,879	27.6%
17093	Chicago	Kendall	IL	310.8	0.3	1,789	17.4%
17097	Chicago	Lake	IL	1,301.3	774.4	16,423	12.6%
17111	Chicago	McHenry	IL	700.7	5.8	5,103	13.8%
17197	Chicago	Will	IL	6,401.5	146.5	16,000	40.9%
18089	Chicago	Lake	IN	4,656.8	490.6	23,491	21.9%
18127	Chicago	Porter	IN	1,588.7	425.4	8,840	22.8%
18029	Cincinnati	Dearborn	IN	216.3	696.0	3,628	25.1%
21015	Cincinnati	Boone	KY	327.3	1,044.5	5,966	23.0%
21037	Cincinnati	Campbell	KY	621.1	722.6	4,914	27.3%
21117	Cincinnati	Kenton	KY	1,197.5	360.8	7,316	21.3%
39017	Cincinnati	Butler	OH	1,581.9	1.7	10,604	14.9%
39025	Cincinnati	Clermont	OH	68.2	1,377.2	7,579	19.1%
39061	Cincinnati	Hamilton	OH	1,540.5	4,078.9	34,403	16.3%
39165	Cincinnati	Warren	OH	235.3	3.2	5,948	4.0%
39007	Cleveland	Ashtabula	OH	1,062.3	5,482.2	12,796	51.1%
39035	Cleveland	Cuyahoga	OH	2,914.2	3,832.5	49,767	13.6%
39085	Cleveland	Lake	OH	738.0	837.5	8,866	17.8%
39093	Cleveland	Lorain	OH	1,749.1	3,509.5	15,702	33.5%
39103	Cleveland	Medina	OH	551.8	2.1	6,896	8.0%
39133	Cleveland	Portage	OH	1,090.9	8.6	8,119	13.5%
39153	Cleveland	Summit	OH	888.7	6.0	18,330	4.9%
26093	Detroit	Livingston	MI	95.5	1.9	7,393	1.3%
26099	Detroit	Macomb	MI	148.2	169.4	24,046	1.3%
26115	Detroit	Monroe	MI	700.2	276.4	7,675	12.7%
26125	Detroit	Oakland	MI	584.1	140.9	38,601	1.9%
26147	Detroit	St. Clair	MI	285.7	662.4	9,871	9.6%
26161	Detroit	Washtenaw	MI	154.9	1.3	12,742	1.2%
26163	Detroit	Wayne	MI	1,133.9	318.6	68,502	2.1%
48039	Houston	Brazoria	TX	728.4	7,573.7	18,133	45.8%
48071	Houston	Chambers	TX	41.6	234.3	2,586	10.7%
48157	Houston	Fort Bend	TX	1,019.2	3.3	11,057	9.2%
48167	Houston	Galveston	TX	491.0	17,352.7	30,023	59.4%
48201	Houston	Harris	TX	2,609.1	45,215.7	165,530	28.9%
48291	Houston	Liberty	TX	1,115.9	93.4	4,073	29.7%
48339	Houston	Montgomery	TX	867.4	9.7	13,754	6.4%
48473	Houston	Waller	TX	252.5	1.5	1,574	16.1%
21019	Huntington	Boyd	KY	430.5	559.8	3,171	31.2%

FIPS	MSA	County	ST	2002 NOx Diesel Locomotive	 Diesel Marine	 Total Mobile	 LM Percent
21127	Huntington	Lawrence	KY	425.1	181.8	1,317	46.1%
39001	Huntington	Adams	OH	13.7	1,610.6	3,248	50.0%
39053	Huntington	Gallia	OH	119.7	708.1	2,184	37.9%
39087	Huntington	Lawrence	OH	433.9	1,051.2	3,946	37.6%
39145	Huntington	Scioto	OH	972.1	1,018.7	4,780	41.7%
54011	Huntington	Cabell	WV	946.3	774.1	9,978	17.2%
54053	Huntington	Mason	WV	239.7	1,218.0	2,909	50.1%
54099	Huntington	Wayne	WV	1,182.1	1,844.2	4,489	67.4%
18011	Indianapolis	Boone	IN	235.9	2.1	3,600	6.6%
18057	Indianapolis	Hamilton	IN	5.7	22.6	7,413	0.4%
18059	Indianapolis	Hancock	IN	179.7	1.2	3,342	5.4%
18063	Indianapolis	Hendricks	IN	630.8	1.2	5,968	10.6%
18081	Indianapolis	Johnson	IN	33.0	7.6	4,964	0.8%
18095	Indianapolis	Madison	IN	563.4	4.3	6,314	9.0%
18097	Indianapolis	Marion	IN	1,089.8	48.3	33,822	3.4%
18109	Indianapolis	Morgan	IN	15.0	8.0	3,634	0.6%
18145	Indianapolis	Shelby	IN	255.6	0.9	3,130	8.2%
20091	Kansas City	Johnson	KS	2,157.3	1.4	18,312	11.8%
20103	Kansas City	Leavenworth	KS	553.1	15.5	2,984	19.1%
20121	Kansas City	Miami	KS	3,157.4	5.5	4,481	70.6%
20209	Kansas City	Wyandotte	KS	1,170.2	137.0	7,329	17.8%
29037	Kansas City	Cass	MO	646.8	4.4	3,752	17.4%
29047	Kansas City	Clay	MO	1,073.0	137.9	8,204	14.8%
29049	Kansas City	Clinton	MO	0.0	5.8	1,517	0.4%
29095	Kansas City	Jackson	MO	3,434.0	1,026.2	30,133	14.8%
29107	Kansas City	Lafayette	MO	899.9	129.2	3,796	27.1%
29165	Kansas City	Platte	MO	878.0	26.9	5,793	15.6%
29177	Kansas City	Ray	MO	1,713.2	122.5	3,190	57.5%
6037	Los Angeles	Los Angeles	CA	9,771.2	42,754.8	257,574	20.4%
6059	Los Angeles	Orange	CA	2,374.1	2,363.7	68,174	6.9%
6065	Los Angeles	Riverside	CA	4,414.1	56.3	45,019	9.9%
6071	Los Angeles	San Bernardino	CA	14,261.8	26.3	56,392	25.3%
6111	Los Angeles	Ventura	CA	479.2	4,087.6	18,815	24.3%
27003	Minneapolis	Anoka	MN	822.8	399.5	10,508	11.6%
27019	Minneapolis	Carver	MN	2.0	27.0	2,563	1.1%
27037	Minneapolis	Dakota	MN	491.2	371.9	11,559	7.5%
27053	Minneapolis	Hennepin	MN	1,226.2	1,117.3	42,042	5.6%
27123	Minneapolis	Ramsey	MN	465.4	353.7	18,199	4.5%
27139	Minneapolis	Scott	MN	104.5	46.1	2,947	5.1%
27163	Minneapolis	Washington	MN	895.5	1,560.4	9,536	25.8%
9001	New York	Fairfield	CT	589.7	257.5	28,368	3.0%
9005	New York	Litchfield	CT	100.0	31.6	4,615	2.9%
34003	New York	Bergen	NJ	1,055.1	193.9	23,136	5.4%
34013	New York	Essex	NJ	228.1	51.3	21,624	1.3%
34017	New York	Hudson	NJ	777.7	1,486.3	16,558	13.7%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34019	New York	Hunterdon	NJ	331.3	11.7	7,327	4.7%
34023	New York	Middlesex	NJ	481.9	282.2	19,497	3.9%
34025	New York	Monmouth	NJ	379.8	682.3	17,750	6.0%
34027	New York	Morris	NJ	234.4	18.7	13,461	1.9%
34029	New York	Ocean	NJ	19.6	435.6	12,234	3.7%
34031	New York	Passaic	NJ	229.2	18.1	11,334	2.2%
34035	New York	Somerset	NJ	509.9	0.6	8,259	6.2%
34037	New York	Sussex	NJ	36.0	22.2	4,546	1.3%
34039	New York	Union	NJ	420.7	1,084.1	14,897	10.1%
36005	New York	Bronx	NY	5.1	203.9	18,301	1.1%
36047	New York	Kings	NY	0.0	1,713.6	36,548	4.7%
36059	New York	Nassau	NY	0.0	586.4	22,268	2.6%
36061	New York	New York	NY	0.0	1,207.0	44,035	2.7%
36071	New York	Orange	NY	349.9	80.2	13,475	3.2%
36081	New York	Queens	NY	2.3	2,056.4	39,760	5.2%
36085	New York	Richmond	NY	0.0	2,386.5	8,667	27.5%
36087	New York	Rockland	NY	265.0	16.6	4,886	5.8%
36103	New York	Suffolk	NY	0.0	1,361.4	27,455	5.0%
36119	New York	Westchester	NY	0.0	127.5	16,193	0.8%
10003	Philadelphia	New Castle	DE	818.9	2,545.5	21,119	15.9%
24015	Philadelphia	Cecil	MD	306.8	56.0	5,150	7.0%
24029	Philadelphia	Kent	MD	2.4	48.8	984	5.2%
24031	Philadelphia	Montgomery	MD	987.2	16.9	23,771	4.2%
34005	Philadelphia	Burlington	NJ	0.0	1,178.2	13,449	8.8%
34007	Philadelphia	Camden	NJ	182.3	471.7	13,996	4.7%
34011	Philadelphia	Cumberland	NJ	20.8	1,242.9	5,472	23.1%
34015	Philadelphia	Gloucester	NJ	36.7	633.3	10,121	6.6%
34021	Philadelphia	Mercer	NJ	193.5	144.7	12,609	2.7%
34033	Philadelphia	Salem	NJ	10.3	374.9	3,009	12.8%
42017	Philadelphia	Bucks	PA	86.8	40.0	13,732	0.9%
42029	Philadelphia	Chester	PA	435.2	5.7	12,150	3.6%
42045	Philadelphia	Delaware	PA	171.7	5,914.4	18,361	33.1%
42101	Philadelphia	Philadelphia	PA	239.6	10,381.6	44,901	23.7%
4013	Phoenix	Maricopa	AZ	3,884.9	28.0	105,636	3.7%
4021	Phoenix	Pinal	AZ	2,030.8	6.2	10,844	18.8%
6019	San Joaquin	Fresno	CA	765.2	32.2	24,853	3.2%
6029	San Joaquin	Kern	CA	3,687.8	12.0	27,768	13.3%
6031	San Joaquin	Kings	CA	104.0	1.1	4,389	2.4%
6039	San Joaquin	Madera	CA	819.3	8.9	5,469	15.1%
6047	San Joaquin	Merced	CA	790.7	25.4	9,353	8.7%
6077	San Joaquin	San Joaquin	CA	1,287.6	603.0	18,977	10.0%
6099	San Joaquin	Stanislaus	CA	528.7	12.5	12,862	4.2%
6107	San Joaquin	Tulare	CA	1,172.3	8.9	13,310	8.9%
53029	Seattle	Island	WA	0.0	2,098.3	3,999	52.5%
53033	Seattle	King	WA	1,119.6	5,906.0	68,488	10.3%
53035	Seattle	Kitsap	WA	0.0	45.6	6,933	0.7%

FIPS	MSA	County	ST	2002 NOx Diesel Locomotive	2002 NOx Diesel Marine	2002 NOx Total Mobile	2002 NOx LM Percent
53045	Seattle	Mason	WA	0.1	26.7	1,679	1.6%
53053	Seattle	Pierce	WA	703.0	5,327.1	27,443	22.0%
53061	Seattle	Snohomish	WA	1,279.7	912.6	20,798	10.5%
53067	Seattle	Thurston	WA	369.2	373.3	8,518	8.7%
17027	St. Louis	Clinton	IL	801.1	2.8	2,597	31.0%
17083	St. Louis	Jersey	IL	64.8	583.9	1,759	36.9%
17119	St. Louis	Madison	IL	287.0	316.7	10,200	5.9%
17133	St. Louis	Monroe	IL	1,288.0	512.0	3,122	57.7%
17163	St. Louis	St. Clair	IL	325.2	605.6	10,049	9.3%
29055	St. Louis	Crawford	MO	204.7	1.5	2,080	9.9%
29071	St. Louis	Franklin	MO	1,206.1	73.8	6,434	19.9%
29099	St. Louis	Jefferson	MO	324.2	519.4	9,205	9.2%
29113	St. Louis	Lincoln	MO	534.3	206.8	2,771	26.7%
29183	St. Louis	St. Charles	MO	643.6	465.6	10,406	10.7%
29189	St. Louis	St. Louis	MO	1,035.3	594.2	41,254	4.0%
29219	St. Louis	Warren	MO	109.1	71.9	1,692	10.7%
29510	St. Louis	St. Louis	MO	866.5	7,998.7	23,595	37.6%

Table 3-116 2020 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2020 NOx Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	189.4	0.6	682	27.9%
13015	Atlanta	Bartow	GA	675.7	8.5	1,838	37.2%
13045	Atlanta	Carroll	GA	183.4	3.6	1,404	13.3%
13057	Atlanta	Cherokee	GA	0.0	8.1	1,834	0.4%
13063	Atlanta	Clayton	GA	355.6	1.2	3,382	10.6%
13067	Atlanta	Cobb	GA	933.8	3.3	7,245	12.9%
13077	Atlanta	Coweta	GA	469.5	2.4	1,995	23.7%
13089	Atlanta	DeKalb	GA	433.1	2.1	7,494	5.8%
13097	Atlanta	Douglas	GA	168.0	0.6	1,353	12.5%
13113	Atlanta	Fayette	GA	121.5	1.5	1,333	9.2%
13117	Atlanta	Forsyth	GA	0.0	16.9	1,392	1.2%
13121	Atlanta	Fulton	GA	1,272.1	4.5	15,332	8.3%
13135	Atlanta	Gwinnett	GA	323.3	3.0	6,226	5.2%
13139	Atlanta	Hall	GA	186.3	27.8	1,919	11.2%
13149	Atlanta	Heard	GA	0.0	3.9	128	3.1%
13151	Atlanta	Henry	GA	479.3	1.5	2,241	21.5%
13217	Atlanta	Newton	GA	54.4	2.1	996	5.7%
13223	Atlanta	Paulding	GA	397.3	1.2	1,372	29.0%
13237	Atlanta	Putnam	GA	10.3	12.7	202	11.4%
13247	Atlanta	Rockdale	GA	77.0	1.2	1,026	7.6%
13255	Atlanta	Spalding	GA	20.7	1.2	728	3.0%
13297	Atlanta	Walton	GA	65.1	0.6	664	9.9%
24003	Baltimore	Anne Arundel	MD	306.6	71.4	8,342	4.5%
24005	Baltimore	Baltimore	MD	936.5	45.1	11,487	8.5%
24013	Baltimore	Carroll	MD	145.4	1.5	2,579	5.7%
24025	Baltimore	Harford	MD	251.7	42.9	3,608	8.2%
24027	Baltimore	Howard	MD	366.4	10.6	3,859	9.8%
24510	Baltimore	Baltimore	MD	1,186.5	1,357.0	15,594	16.3%
1073	Birmingham	Jefferson	AL	4,173.3	221.1	12,112	36.3%
1117	Birmingham	Shelby	AL	1,026.2	12.5	2,492	41.7%
1127	Birmingham	Walker	AL	649.1	97.7	1,530	48.8%
9007	Boston	Middlesex	CT	110.6	121.2	233	99.6%
25001	Boston	Barnstable	MA	232.2	490.2	4,681	15.4%
25005	Boston	Bristol	MA	436.1	214.3	7,364	8.8%
25007	Boston	Dukes	MA	0.0	1,332.0	1,732	76.9%
25009	Boston	Essex	MA	567.6	201.2	9,768	7.9%
25019	Boston	Nantucket	MA	0.0	256.8	530	48.4%
25021	Boston	Norfolk	MA	682.9	140.1	10,197	8.1%
25023	Boston	Plymouth	MA	363.1	191.5	6,163	9.0%
25025	Boston	Suffolk	MA	362.6	703.7	17,700	6.0%
25027	Boston	Worcester	MA	1,382.7	43.9	12,067	11.8%
33011	Boston	Hillsborough	NH	35.8	18.0	6,327	0.8%
33015	Boston	Rockingham	NH	27.0	928.5	6,652	14.4%
47065	Chattanooga	Hamilton	TN	1,326.0	749.8	5,500	37.7%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47115	Chattanooga	Marion	TN	185.9	148.4	1,048	31.9%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	73	0.0%
13047	Chattanooga	Catoosa	GA	402.1	0.3	953	42.2%
13083	Chattanooga	Dade	GA	382.0	0.0	814	46.9%
13295	Chattanooga	Walker	GA	0.0	0.3	555	0.1%
17031	Chicago	Cook	IL	18,683.3	5,549.0	69,728	34.8%
17043	Chicago	DuPage	IL	4,853.4	5.9	11,856	41.0%
17063	Chicago	Grundy	IL	436.8	161.9	1,367	43.8%
17089	Chicago	Kane	IL	1,791.2	4.2	3,786	47.4%
17093	Chicago	Kendall	IL	253.3	0.3	774	32.7%
17097	Chicago	Lake	IL	930.4	886.7	6,916	26.3%
17111	Chicago	McHenry	IL	496.6	7.0	1,870	26.9%
17197	Chicago	Will	IL	4,767.5	122.8	7,685	63.6%
18089	Chicago	Lake	IN	4,582.7	527.6	12,632	40.5%
18127	Chicago	Porter	IN	1,239.8	449.0	4,478	37.7%
18029	Cincinnati	Dearborn	IN	172.0	565.9	1,708	43.2%
21015	Cincinnati	Boone	KY	276.6	850.5	3,457	32.6%
21037	Cincinnati	Campbell	KY	522.3	588.4	2,204	50.4%
21117	Cincinnati	Kenton	KY	1,011.3	293.3	2,771	47.1%
39017	Cincinnati	Butler	OH	1,225.0	2.0	3,504	35.0%
39025	Cincinnati	Clermont	OH	53.0	1,117.4	3,185	36.7%
39061	Cincinnati	Hamilton	OH	1,208.2	3,308.4	13,388	33.7%
39165	Cincinnati	Warren	OH	188.0	3.8	1,673	11.5%
39007	Cleveland	Ashtabula	OH	833.8	4,487.1	9,441	56.4%
39035	Cleveland	Cuyahoga	OH	2,405.6	3,286.2	18,923	30.1%
39085	Cleveland	Lake	OH	568.9	773.0	3,859	34.8%
39093	Cleveland	Lorain	OH	1,360.5	2,917.8	8,463	50.5%
39103	Cleveland	Medina	OH	438.3	2.5	1,945	22.7%
39133	Cleveland	Portage	OH	851.4	10.3	2,483	34.7%
39153	Cleveland	Summit	OH	702.5	7.2	4,985	14.2%
26093	Detroit	Livingston	MI	80.7	2.3	2,010	4.1%
26099	Detroit	Macomb	MI	125.2	151.8	7,234	3.8%
26115	Detroit	Monroe	MI	591.7	231.4	2,799	29.4%
26125	Detroit	Oakland	MI	492.0	117.6	12,011	5.1%
26147	Detroit	St. Clair	MI	238.4	552.6	4,414	17.9%
26161	Detroit	Washtenaw	MI	137.0	1.6	3,811	3.6%
26163	Detroit	Wayne	MI	1,064.0	284.1	23,915	5.6%
48039	Houston	Brazoria	TX	615.5	6,160.6	12,492	54.2%
48071	Houston	Chambers	TX	35.1	208.0	1,047	23.2%
48157	Houston	Fort Bend	TX	855.7	4.0	4,021	21.4%
48167	Houston	Galveston	TX	481.5	14,101.9	24,831	58.7%
48201	Houston	Harris	TX	2,463.1	36,663.4	88,044	44.4%
48291	Houston	Liberty	TX	940.8	77.6	1,866	54.6%
48339	Houston	Montgomery	TX	732.9	11.6	4,332	17.2%
48473	Houston	Waller	TX	213.4	1.8	593	36.3%
21019	Huntington	Boyd	KY	361.2	454.4	1,599	51.0%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
21127	Huntington	Lawrence	KY	310.3	147.8	706	64.9%
39001	Huntington	Adams	OH	10.6	1,305.9	2,379	55.3%
39053	Huntington	Gallia	OH	93.0	574.4	1,310	50.9%
39087	Huntington	Lawrence	OH	337.7	852.5	2,252	52.8%
39145	Huntington	Scioto	OH	755.3	826.2	2,737	57.8%
54011	Huntington	Cabell	WV	789.0	630.5	10,401	13.6%
54053	Huntington	Mason	WV	175.0	993.3	2,088	56.0%
54099	Huntington	Wayne	WV	997.3	1,498.1	3,047	81.9%
18011	Indianapolis	Boone	IN	178.0	2.5	1,171	15.4%
18057	Indianapolis	Hamilton	IN	6.4	27.1	2,259	1.5%
18059	Indianapolis	Hancock	IN	138.0	1.4	1,042	13.4%
18063	Indianapolis	Hendricks	IN	490.3	1.4	1,989	24.7%
18081	Indianapolis	Johnson	IN	37.1	9.1	1,445	3.2%
18095	Indianapolis	Madison	IN	444.2	5.2	2,073	21.7%
18097	Indianapolis	Marion	IN	851.8	58.0	11,238	8.1%
18109	Indianapolis	Morgan	IN	16.9	9.6	1,015	2.6%
18145	Indianapolis	Shelby	IN	197.5	1.0	1,011	19.6%
20091	Kansas City	Johnson	KS	1,821.4	1.7	6,851	26.6%
20103	Kansas City	Leavenworth	KS	467.1	13.3	1,177	40.8%
20121	Kansas City	Miami	KS	2,667.9	6.6	3,085	86.7%
20209	Kansas City	Wyandotte	KS	985.3	111.7	2,919	37.6%
29037	Kansas City	Cass	MO	543.2	5.2	1,476	37.1%
29047	Kansas City	Clay	MO	984.8	118.0	3,214	34.3%
29049	Kansas City	Clinton	MO	0.0	7.0	435	1.6%
29095	Kansas City	Jackson	MO	3,099.6	837.4	12,014	32.8%
29107	Kansas City	Lafayette	MO	760.4	109.5	1,724	50.5%
29165	Kansas City	Platte	MO	741.9	25.2	2,964	25.9%
29177	Kansas City	Ray	MO	1,528.5	101.4	2,106	77.4%
6037	Los Angeles	Los Angeles	CA	8,078.6	34,699.8	126,737	33.8%
6059	Los Angeles	Orange	CA	2,064.2	1,935.3	27,820	14.4%
6065	Los Angeles	Riverside	CA	3,206.9	67.6	18,781	17.4%
6071	Los Angeles	San Bernardino	CA	10,808.1	31.6	26,747	40.5%
6111	Los Angeles	Ventura	CA	380.6	3,334.9	9,593	38.7%
27003	Minneapolis	Anoka	MN	688.9	350.5	4,088	25.4%
27019	Minneapolis	Carver	MN	1.7	29.2	848	3.6%
27037	Minneapolis	Dakota	MN	412.2	322.9	4,372	16.8%
27053	Minneapolis	Hennepin	MN	1,034.8	960.2	16,513	12.1%
27123	Minneapolis	Ramsey	MN	390.6	306.8	6,337	11.0%
27139	Minneapolis	Scott	MN	88.3	47.8	1,053	12.9%
27163	Minneapolis	Washington	MN	752.2	1,287.7	4,813	42.4%
9001	New York	Fairfield	CT	497.8	269.3	13,775	5.6%
9005	New York	Litchfield	CT	112.5	37.9	2,050	7.3%
34003	New York	Bergen	NJ	778.5	164.7	11,244	8.4%
34013	New York	Essex	NJ	153.0	43.8	11,579	1.7%
34017	New York	Hudson	NJ	620.9	1,217.1	8,314	22.1%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34019	New York	Hunterdon	NJ	218.2	14.0	2,859	8.1%
34023	New York	Middlesex	NJ	393.0	235.8	9,099	6.9%
34025	New York	Monmouth	NJ	216.0	617.7	8,620	9.7%
34027	New York	Morris	NJ	149.1	22.5	6,081	2.8%
34029	New York	Ocean	NJ	13.6	500.0	6,071	8.5%
34031	New York	Passaic	NJ	139.0	21.8	5,226	3.1%
34035	New York	Somerset	NJ	368.6	0.7	3,670	10.1%
34037	New York	Sussex	NJ	40.5	26.7	1,901	3.5%
34039	New York	Union	NJ	278.8	880.2	7,151	16.2%
36005	New York	Bronx	NY	4.3	170.4	8,855	2.0%
36047	New York	Kings	NY	0.0	1,397.7	18,231	7.7%
36059	New York	Nassau	NY	0.0	506.2	11,407	4.4%
36061	New York	New York	NY	0.0	980.8	31,145	3.1%
36071	New York	Orange	NY	270.9	70.5	6,487	5.3%
36081	New York	Queens	NY	2.0	1,679.8	22,109	7.6%
36085	New York	Richmond	NY	0.0	1,942.3	4,992	38.9%
36087	New York	Rockland	NY	219.1	19.6	2,500	9.6%
36103	New York	Suffolk	NY	0.0	1,342.6	14,755	9.1%
36119	New York	Westchester	NY	0.0	117.2	7,870	1.5%
10003	Philadelphia	New Castle	DE	803.4	2,069.6	11,598	24.8%
24015	Philadelphia	Cecil	MD	213.9	56.2	2,142	12.6%
24029	Philadelphia	Kent	MD	1.8	53.8	541	10.3%
24031	Philadelphia	Montgomery	MD	627.6	15.6	12,024	5.3%
34005	Philadelphia	Burlington	NJ	0.0	963.9	6,299	15.3%
34007	Philadelphia	Camden	NJ	111.6	385.6	7,049	7.1%
34011	Philadelphia	Cumberland	NJ	23.4	1,063.5	3,128	34.8%
34015	Philadelphia	Gloucester	NJ	38.0	520.5	6,743	8.3%
34021	Philadelphia	Mercer	NJ	133.5	119.1	5,604	4.5%
34033	Philadelphia	Salem	NJ	9.3	315.8	1,442	22.5%
42017	Philadelphia	Bucks	PA	65.3	40.8	6,119	1.7%
42029	Philadelphia	Chester	PA	304.0	6.8	5,242	5.9%
42045	Philadelphia	Delaware	PA	125.2	4,798.6	12,519	39.3%
42101	Philadelphia	Philadelphia	PA	215.5	8,420.9	28,921	29.9%
4013	Phoenix	Maricopa	AZ	3,043.5	33.6	36,074	8.5%
4021	Phoenix	Pinal	AZ	1,689.8	7.5	4,626	36.7%
6019	San Joaquin	Fresno	CA	596.5	38.7	9,566	6.6%
6029	San Joaquin	Kern	CA	2,751.1	14.4	11,518	24.0%
6031	San Joaquin	Kings	CA	72.7	1.4	1,747	4.2%
6039	San Joaquin	Madera	CA	652.3	10.6	2,530	26.2%
6047	San Joaquin	Merced	CA	574.3	30.5	3,697	16.4%
6077	San Joaquin	San Joaquin	CA	980.7	496.4	7,856	18.8%
6099	San Joaquin	Stanislaus	CA	401.8	14.8	4,881	8.5%
6107	San Joaquin	Tulare	CA	905.5	10.6	5,493	16.7%
53029	Seattle	Island	WA	0.0	1,709.1	2,406	71.1%
53033	Seattle	King	WA	935.0	4,874.1	26,130	22.2%
53035	Seattle	Kitsap	WA	0.0	54.6	2,268	2.4%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
53045	Seattle	Mason	WA	0.1	28.7	541	5.3%
53053	Seattle	Pierce	WA	586.2	4,359.7	12,505	39.6%
53061	Seattle	Snohomish	WA	1,050.1	779.7	7,046	26.0%
53067	Seattle	Thurston	WA	267.7	317.1	3,088	18.9%
17027	St. Louis	Clinton	IL	653.3	3.4	1,223	53.7%
17083	St. Louis	Jersey	IL	54.0	473.6	1,104	47.8%
17119	St. Louis	Madison	IL	321.8	257.9	3,094	18.7%
17133	St. Louis	Monroe	IL	1,017.1	415.5	2,060	69.5%
17163	St. Louis	St. Clair	IL	339.2	491.8	3,360	24.7%
29055	St. Louis	Crawford	MO	149.4	1.7	640	23.6%
29071	St. Louis	Franklin	MO	1,005.6	63.6	2,226	48.0%
29099	St. Louis	Jefferson	MO	273.6	424.7	2,736	25.5%
29113	St. Louis	Lincoln	MO	451.5	172.5	1,301	48.0%
29183	St. Louis	St. Charles	MO	543.8	393.2	3,393	27.6%
29189	St. Louis	St. Louis	MO	867.4	489.5	12,921	10.5%
29219	St. Louis	Warren	MO	92.1	61.3	595	25.8%
29510	St. Louis	St. Louis	MO	874.5	6,486.7	13,766	53.5%

Table 3-117 2030 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	186.5	0.7	583	32.1%
13015	Atlanta	Bartow	GA	665.4	9.2	1,596	42.3%
13045	Atlanta	Carroll	GA	180.2	3.9	1,168	15.8%
13057	Atlanta	Cherokee	GA	0.0	8.8	1,502	0.6%
13063	Atlanta	Clayton	GA	350.2	1.3	2,912	12.1%
13067	Atlanta	Cobb	GA	918.9	3.6	5,714	16.1%
13077	Atlanta	Coweta	GA	462.3	2.6	1,676	27.7%
13089	Atlanta	DeKalb	GA	426.2	2.3	5,791	7.4%
13097	Atlanta	Douglas	GA	165.0	0.7	1,146	14.5%
13113	Atlanta	Fayette	GA	119.7	1.6	1,109	10.9%
13117	Atlanta	Forsyth	GA	0.0	18.3	1,115	1.6%
13121	Atlanta	Fulton	GA	1,251.8	4.9	13,644	9.2%
13135	Atlanta	Gwinnett	GA	318.0	3.3	4,804	6.7%
13139	Atlanta	Hall	GA	185.4	30.1	1,581	13.6%
13149	Atlanta	Heard	GA	0.0	4.3	100	4.3%
13151	Atlanta	Henry	GA	472.0	1.6	1,860	25.5%
13217	Atlanta	Newton	GA	53.5	2.3	800	7.0%
13223	Atlanta	Paulding	GA	391.3	1.3	1,152	34.1%
13237	Atlanta	Putnam	GA	10.3	13.8	169	14.2%
13247	Atlanta	Rockdale	GA	75.8	1.3	848	9.1%
13255	Atlanta	Spalding	GA	20.4	1.3	597	3.6%
13297	Atlanta	Walton	GA	64.1	0.7	550	11.8%
24003	Baltimore	Anne Arundel	MD	285.6	76.7	8,572	4.2%
24005	Baltimore	Baltimore	MD	896.2	48.2	11,329	8.3%
24013	Baltimore	Carroll	MD	145.3	1.7	2,442	6.0%
24025	Baltimore	Harford	MD	242.3	45.7	3,508	8.2%
24027	Baltimore	Howard	MD	347.0	10.7	3,770	9.5%
24510	Baltimore	Baltimore	MD	1,142.1	1,365.5	17,705	14.2%
1073	Birmingham	Jefferson	AL	4,081.7	223.2	10,639	40.5%
1117	Birmingham	Shelby	AL	1,005.0	13.6	2,211	46.1%
1127	Birmingham	Walker	AL	648.6	99.0	1,403	53.3%
9007	Boston	Middlesex	CT	105.1	127.5	234	99.4%
25001	Boston	Barnstable	MA	232.0	518.9	4,797	15.7%
25005	Boston	Bristol	MA	435.3	220.7	7,523	8.7%
25007	Boston	Dukes	MA	0.0	1,350.2	1,773	76.2%
25009	Boston	Essex	MA	567.2	212.4	9,820	7.9%
25019	Boston	Nantucket	MA	0.0	265.1	551	48.1%
25021	Boston	Norfolk	MA	679.2	142.8	10,138	8.1%
25023	Boston	Plymouth	MA	362.5	205.8	6,197	9.2%
25025	Boston	Suffolk	MA	360.0	710.3	16,310	6.6%
25027	Boston	Worcester	MA	1,368.9	47.6	11,980	11.8%
33011	Boston	Hillsborough	NH	35.8	19.5	6,461	0.9%
33015	Boston	Rockingham	NH	27.0	940.3	6,892	14.0%
47065	Chattanooga	Hamilton	TN	1,305.7	757.2	5,151	40.1%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47115	Chattanooga	Marion	TN	183.1	150.6	932	35.8%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	56	0.0%
13047	Chattanooga	Catoosa	GA	395.9	0.3	830	47.8%
13083	Chattanooga	Dade	GA	376.2	0.0	699	53.8%
13295	Chattanooga	Walker	GA	0.0	0.3	438	0.1%
17031	Chicago	Cook	IL	18,514.9	5,645.1	63,116	38.3%
17043	Chicago	DuPage	IL	4,720.6	6.5	10,269	46.0%
17063	Chicago	Grundy	IL	427.7	163.2	1,168	50.6%
17089	Chicago	Kane	IL	1,750.8	4.6	3,281	53.5%
17093	Chicago	Kendall	IL	250.2	0.4	641	39.1%
17097	Chicago	Lake	IL	906.2	955.2	6,310	29.5%
17111	Chicago	McHenry	IL	488.4	7.6	1,548	32.0%
17197	Chicago	Will	IL	4,733.7	124.5	7,002	69.4%
18089	Chicago	Lake	IN	4,451.2	562.4	12,715	39.4%
18127	Chicago	Porter	IN	1,230.3	477.1	4,520	37.8%
18029	Cincinnati	Dearborn	IN	171.1	569.5	1,694	43.7%
21015	Cincinnati	Boone	KY	272.4	856.3	3,615	31.2%
21037	Cincinnati	Campbell	KY	514.0	592.5	2,128	52.0%
21117	Cincinnati	Kenton	KY	995.8	295.2	2,456	52.6%
39017	Cincinnati	Butler	OH	1,215.2	2.2	2,901	42.0%
39025	Cincinnati	Clermont	OH	52.6	1,124.0	3,076	38.2%
39061	Cincinnati	Hamilton	OH	1,200.0	3,327.7	12,598	35.9%
39165	Cincinnati	Warren	OH	187.1	4.2	1,261	15.2%
39007	Cleveland	Ashtabula	OH	826.5	4,523.2	10,335	51.8%
39035	Cleveland	Cuyahoga	OH	2,374.0	3,348.9	17,334	33.0%
39085	Cleveland	Lake	OH	563.9	800.5	3,676	37.1%
39093	Cleveland	Lorain	OH	1,350.4	2,952.3	8,584	50.1%
39103	Cleveland	Medina	OH	435.4	2.7	1,508	29.1%
39133	Cleveland	Portage	OH	844.5	11.2	2,012	42.5%
39153	Cleveland	Summit	OH	696.4	7.8	3,944	17.9%
26093	Detroit	Livingston	MI	79.5	2.5	1,589	5.2%
26099	Detroit	Macomb	MI	123.3	156.2	6,116	4.6%
26115	Detroit	Monroe	MI	582.6	234.6	2,409	33.9%
26125	Detroit	Oakland	MI	484.2	119.1	10,112	6.0%
26147	Detroit	St. Clair	MI	234.3	559.6	4,539	17.5%
26161	Detroit	Washtenaw	MI	135.7	1.7	3,199	4.3%
26163	Detroit	Wayne	MI	1,061.8	292.0	21,886	6.2%
48039	Houston	Brazoria	TX	606.1	6,200.9	13,541	50.3%
48071	Houston	Chambers	TX	34.6	213.6	964	25.8%
48157	Houston	Fort Bend	TX	841.8	4.3	3,437	24.6%
48167	Houston	Galveston	TX	483.0	14,191.0	27,937	52.5%
48201	Houston	Harris	TX	2,459.9	36,874.9	91,005	43.2%
48291	Houston	Liberty	TX	926.1	78.5	1,679	59.8%
48339	Houston	Montgomery	TX	721.7	12.6	3,561	20.6%
48473	Houston	Waller	TX	210.1	1.9	497	42.7%
21019	Huntington	Boyd	KY	355.3	457.1	1,606	50.6%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
21127	Huntington	Lawrence	KY	310.0	148.8	704	65.2%
39001	Huntington	Adams	OH	10.5	1,313.4	2,628	50.4%
39053	Huntington	Gallia	OH	92.3	577.8	1,377	48.7%
39087	Huntington	Lawrence	OH	335.2	857.5	2,351	50.7%
39145	Huntington	Scioto	OH	749.9	831.1	2,788	56.7%
54011	Huntington	Cabell	WV	775.3	634.9	13,900	10.1%
54053	Huntington	Mason	WV	174.8	1,000.4	2,292	51.3%
54099	Huntington	Wayne	WV	981.9	1,507.4	3,047	81.7%
18011	Indianapolis	Boone	IN	175.6	2.7	922	19.3%
18057	Indianapolis	Hamilton	IN	6.6	29.4	1,804	2.0%
18059	Indianapolis	Hancock	IN	136.6	1.6	816	16.9%
18063	Indianapolis	Hendricks	IN	486.8	1.6	1,616	30.2%
18081	Indianapolis	Johnson	IN	37.8	9.9	1,158	4.1%
18095	Indianapolis	Madison	IN	440.3	5.6	1,721	25.9%
18097	Indianapolis	Marion	IN	845.5	62.9	9,848	9.2%
18109	Indianapolis	Morgan	IN	17.2	10.4	785	3.5%
18145	Indianapolis	Shelby	IN	195.8	1.1	797	24.7%
20091	Kansas City	Johnson	KS	1,793.4	1.8	5,960	30.1%
20103	Kansas City	Leavenworth	KS	460.0	13.6	1,012	46.8%
20121	Kansas City	Miami	KS	2,627.2	7.1	2,928	90.0%
20209	Kansas City	Wyandotte	KS	969.7	112.5	2,648	40.9%
29037	Kansas City	Cass	MO	534.4	5.7	1,248	43.3%
29047	Kansas City	Clay	MO	980.2	120.2	2,864	38.4%
29049	Kansas City	Clinton	MO	0.0	7.6	320	2.4%
29095	Kansas City	Jackson	MO	3,078.5	843.5	10,916	35.9%
29107	Kansas City	Lafayette	MO	748.8	111.3	1,515	56.8%
29165	Kansas City	Platte	MO	730.6	26.2	2,855	26.5%
29177	Kansas City	Ray	MO	1,515.9	102.4	1,995	81.1%
6037	Los Angeles	Los Angeles	CA	8,037.8	34,907.8	110,332	38.9%
6059	Los Angeles	Orange	CA	2,064.0	1,951.1	22,503	17.8%
6065	Los Angeles	Riverside	CA	3,176.5	73.4	12,138	26.8%
6071	Los Angeles	San Bernardino	CA	10,729.1	34.3	20,287	53.1%
6111	Los Angeles	Ventura	CA	379.6	3,359.2	8,627	43.3%
27003	Minneapolis	Anoka	MN	677.4	359.0	3,678	28.2%
27019	Minneapolis	Carver	MN	1.7	31.1	683	4.8%
27037	Minneapolis	Dakota	MN	405.5	330.0	3,860	19.1%
27053	Minneapolis	Hennepin	MN	1,018.8	979.0	15,108	13.2%
27123	Minneapolis	Ramsey	MN	384.3	313.5	5,585	12.5%
27139	Minneapolis	Scott	MN	86.9	50.7	871	15.8%
27163	Minneapolis	Washington	MN	740.1	1,300.7	4,730	43.1%
9001	New York	Fairfield	CT	484.0	285.7	13,975	5.5%
9005	New York	Litchfield	CT	114.5	41.2	2,010	7.7%
34003	New York	Bergen	NJ	756.3	167.5	11,281	8.2%
34013	New York	Essex	NJ	146.0	44.6	13,693	1.4%
34017	New York	Hudson	NJ	596.4	1,227.0	11,022	16.5%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34019	New York	Hunterdon	NJ	210.5	15.2	2,703	8.4%
34023	New York	Middlesex	NJ	377.1	238.9	10,943	5.6%
34025	New York	Monmouth	NJ	196.7	637.0	8,926	9.3%
34027	New York	Morris	NJ	138.6	24.4	5,958	2.7%
34029	New York	Ocean	NJ	12.6	539.0	6,186	8.9%
34031	New York	Passaic	NJ	129.1	23.6	5,198	2.9%
34035	New York	Somerset	NJ	358.4	0.8	3,620	9.9%
34037	New York	Sussex	NJ	41.2	29.0	1,794	3.9%
34039	New York	Union	NJ	265.7	885.6	8,205	14.0%
36005	New York	Bronx	NY	4.3	172.6	9,872	1.8%
36047	New York	Kings	NY	0.0	1,407.8	23,002	6.1%
36059	New York	Nassau	NY	0.0	516.6	11,386	4.5%
36061	New York	New York	NY	0.0	987.0	17,781	5.6%
36071	New York	Orange	NY	263.2	72.3	6,601	5.1%
36081	New York	Queens	NY	1.9	1,692.5	24,125	7.0%
36085	New York	Richmond	NY	0.0	1,955.3	6,930	28.2%
36087	New York	Rockland	NY	215.1	21.3	2,459	9.6%
36103	New York	Suffolk	NY	0.0	1,408.8	14,851	9.5%
36119	New York	Westchester	NY	0.0	121.2	8,399	1.4%
10003	Philadelphia	New Castle	DE	781.2	2,083.0	12,157	23.6%
24015	Philadelphia	Cecil	MD	210.9	59.2	2,059	13.1%
24029	Philadelphia	Kent	MD	1.8	57.6	506	11.7%
24031	Philadelphia	Montgomery	MD	593.4	16.1	12,274	5.0%
34005	Philadelphia	Burlington	NJ	0.0	971.5	6,198	15.7%
34007	Philadelphia	Camden	NJ	104.7	388.6	7,322	6.7%
34011	Philadelphia	Cumberland	NJ	23.8	1,083.2	3,125	35.4%
34015	Philadelphia	Gloucester	NJ	36.9	525.2	7,922	7.1%
34021	Philadelphia	Mercer	NJ	131.1	120.3	5,616	4.5%
34033	Philadelphia	Salem	NJ	9.4	320.5	1,393	23.7%
42017	Philadelphia	Bucks	PA	63.2	43.1	6,003	1.8%
42029	Philadelphia	Chester	PA	290.2	7.4	5,004	5.9%
42045	Philadelphia	Delaware	PA	120.5	4,827.0	13,735	36.0%
42101	Philadelphia	Philadelphia	PA	213.8	8,470.2	31,412	27.6%
4013	Phoenix	Maricopa	AZ	3,019.1	36.5	18,989	16.1%
4021	Phoenix	Pinal	AZ	1,660.1	8.1	4,001	41.7%
6019	San Joaquin	Fresno	CA	590.6	42.0	5,860	10.8%
6029	San Joaquin	Kern	CA	2,741.2	15.7	7,256	38.0%
6031	San Joaquin	Kings	CA	71.7	1.5	902	8.1%
6039	San Joaquin	Madera	CA	644.9	11.5	1,488	44.1%
6047	San Joaquin	Merced	CA	573.0	33.1	2,108	28.7%
6077	San Joaquin	San Joaquin	CA	974.8	501.1	5,322	27.7%
6099	San Joaquin	Stanislaus	CA	398.9	16.0	2,978	13.9%
6107	San Joaquin	Tulare	CA	898.7	11.5	3,414	26.7%
53029	Seattle	Island	WA	0.0	1,720.9	2,318	74.2%
53033	Seattle	King	WA	919.1	4,923.0	23,930	24.4%
53035	Seattle	Kitsap	WA	0.0	59.2	1,921	3.1%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
53045	Seattle	Mason	WA	0.1	30.6	449	6.8%
53053	Seattle	Pierce	WA	576.1	4,394.7	12,254	40.6%
53061	Seattle	Snohomish	WA	1,033.3	793.9	6,039	30.3%
53067	Seattle	Thurston	WA	266.9	322.4	2,775	21.2%
17027	St. Louis	Clinton	IL	645.5	3.7	1,056	61.4%
17083	St. Louis	Jersey	IL	53.2	476.4	1,134	46.7%
17119	St. Louis	Madison	IL	312.6	259.6	2,469	23.2%
17133	St. Louis	Monroe	IL	1,008.1	417.9	2,049	69.6%
17163	St. Louis	St. Clair	IL	328.1	494.8	2,832	29.1%
29055	St. Louis	Crawford	MO	149.3	1.9	526	28.7%
29071	St. Louis	Franklin	MO	988.2	64.9	1,850	56.9%
29099	St. Louis	Jefferson	MO	269.4	428.0	2,271	30.7%
29113	St. Louis	Lincoln	MO	444.6	174.7	1,179	52.5%
29183	St. Louis	St. Charles	MO	535.5	399.3	2,847	32.8%
29189	St. Louis	St. Louis	MO	853.1	494.2	11,003	12.2%
29219	St. Louis	Warren	MO	90.7	62.4	503	30.4%
29510	St. Louis	St. Louis	MO	880.1	6,524.3	14,654	50.5%

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[44] Clean Air Interstate Rule (CAIR). Docket EPA-HQ-OAR-2003-0053. Documentation is also available online at http://www.epa.gov/air/interstateairquality/index.html

CHAPTER 4: Locomotive and Marine Technological Feasibility

In this chapter we describe in detail the analysis of emission control technologies we used to develop the standards we are finalized in this rulemaking. Because of the range of engines and applications we cover in this proposal, the standards span a range of emissions levels. Correspondingly, we have identified a number of different emission control technologies we expect will be used to meet these standards. These technologies range from incremental improvements of existing engine components to highly advanced catalytic exhaust aftertreatment systems.

We first summarize our current locomotive and marine diesel engine standards and provide an overview of existing and future emission control technologies. We believe that further improvements in existing technologies will be used to meet the standards for existing engines that are remanufactured as new (i.e., Tier 0, 1, and 2 locomotives and marine engines greater than 600 kW manufactured from 1973 through 2011). We then describe how technologies similar to some of those already being implemented to meet our current and upcoming heavy-duty highway and nonroad diesel engine emissions standards can be applied to meet the standards for new engines (i.e., Tier 3). Throughout this chapter, we also address many of the comments submitted by stakeholders concerning the feasibility, applicability, performance, and durability of the emission control technologies we presented in the NPRM. We conclude this section with a discussion of catalytic exhaust aftertreatment technologies that we believe will be used to meet the Tier 4 standards.

All of our analyses in this chapter include how we expect these technologies to perform throughout their useful life as well as how we believe they will be implemented specifically into locomotive and marine applications. Note that much of this chapter's content is based upon the performance of currently available emission control technologies and results from testing that has already been completed. In most cases the already-published results show that currently available emission control technologies can be implemented without further improvements to meet the standards. In a few cases, we are projecting that further improvements to these technologies will be made between now and the Tier 4 standards implementation dates. These projected improvements will enable engine manufacturers to meet the standards finalized in this rulemaking.

4.1 Overview of Emissions Standards and Emission Control Technologies

Our current locomotive and marine diesel engine standards have already decreased NO_x emissions from unregulated levels. For example, since 1997, NO_x emissions standards for diesel locomotive engines have been reduced from an unregulated level of about 13.5 g/bhp-hr to the current Tier 2 level of 5.5 g/bhp-hr – a 60% reduction when evaluated over the locomotive line-haul duty cycle. Similar NO_x reductions have been realized for Category 1 & 2 (C1 & C2) commercial marine diesel engines. Our Tier 1 marine standards are equivalent to the International Maritime Organization's NO_x regulation known as MARPOL Annex VI. Beginning in 2004, these standards became mandatory for C1 & C2 Commercial vessels, and were voluntary in prior years. Beginning in 2007, EPA Tier 2 standards for C1 & C2 Commercial vessels superseded these MARPOL-equivalent standards. For a high-speed marine diesel engine, NO_x emissions have been reduced from a Tier 1 level of 9.8 g/kW-hr to 7.5 g/kW-hr - a 23% reduction. While these reductions in locomotive and marine NO_x emissions are significant, they do not keep pace with the 90% NO_x reduction (from 2.0 g/bhp-hr to 0.2 g/bhp-hr) set forth in the 2007 Heavy-Duty Highway Rule.[1] Neither do these reductions keep pace with the approximately 85% NO_x reductions set forth in the Nonroad Tier 4 Standards for 56 kW to 560 kW engines and for generator sets above 560 kW.[2,3] In a similar manner, locomotive and marine particulate matter (PM) emission reductions also lag behind the Heavy-Duty Highway and Nonroad Tier 4 Rules. For line-haul and switcher locomotives, a 67% reduction in PM already has been achieved in going from the Tier 0 to the Tier 2 standards. On the marine side, PM emissions for C1 & C2 Commercial have been reduced from essentially unregulated levels prior to May 2005, to a 0.2-0.4 g/kW-hr level for Tier 2.[A]

In contrast, the 2007 Heavy-Duty Highway Rule set forth PM reductions of 90% - from 0.1 g/bhp-hr to 0.01 g/bhp-hr. Similarly, post-2014 Nonroad Tier 4 PM emissions will be reduced 85 to 95% compared to Tier 3 Nonroad PM emissions for 56 kW to 560 kW engines and for generator sets above 560 kW.[2,3] In the timeframe of the Tier 3 and 4 Locomotive Standards that we are proposing, NO_x and PM emissions will continue to be a serious threat to public health, and, on a percentage basis, the locomotive and marine contributions to the nationwide inventory of these pollutants would continue to increase relative to today’s levels if current Tier 2 emission levels were maintained. Please refer to Chapter 3 of the Regulatory Impact Analysis for a more detailed discussion of the contribution of locomotive and marine emissions to the NO_x and PM inventory.

To date, the Tier 0 through Tier 2 locomotive and Tier 1 through Tier 2 marine emissions reductions have been achieved largely through engine calibration optimization and engine hardware design changes (e.g. improved fuel injectors, increased injection pressure, intake air after-cooling, combustion chamber design, injection timing, reduced oil consumption, etc.) To achieve the Tier 3 PM emission standards we are proposing, further reductions in lubricating oil consumption will be required. This will most likely be achieved via improvements to piston, piston ring, and cylinder liner design, as well as improvements to the crankcase ventilation system. To further reduce NO_x and PM emission beyond Tier 3 levels, an exhaust aftertreatment approach will be necessary.

Selective catalytic reduction (SCR) is a common catalytic exhaust emission control used for meeting more stringent NO_x emissions standards in worldwide diesel applications. Stationary, coal-fired power plants have used SCR for three decades as a means of controlling NO_x emissions, and currently, European heavy-duty truck manufacturers are using this technology to meet the Euro IV and Euro V limits. In the Category 2 and Category 3 marine sector, at least 100 vessels are equipped with SCR systems to control NOx emissions.[4] To a lesser extent, SCR has been introduced on diesels in the U.S. market, but the applications have been limited to marine ferryboat and stationary power generation demonstration projects in California and several northeast states. However, by 2010, when 100% of the heavy-duty

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[A] Marine Tier 2 PM emission standards are dependent on an engine's volumetric displacement-per-cylinder.

diesel trucks are required to meet the NO_x limits of the 2007 heavy-duty Highway Rule, several heavy-duty truck engine manufacturers have indicated that they will use SCR technology to meet these standards.[5,6] While other promising NO_x-reducing technologies such as lean NO_x catalysts, NO_x adsorbers, and advanced combustion control continue to be developed - and may be viable approaches to the standards we are proposing today - our analysis projects that SCR will be the technology chosen by the locomotive and marine diesel industries to meet the Tier 4 NO_x standards we are proposing. For a complete review of these other alternative NO_x emission control technologies, please refer to the Regulatory Impact Analysis from our Clean Air Nonroad diesel rule.[7]

The most effective exhaust aftertreatment used for diesel PM emission control is the diesel particulate filter (DPF). More than a million light diesel vehicles that are OEM-equipped with DPF systems have been sold in Europe, and over 200,000 DPF retrofits to diesel engines have been conducted worldwide.[8] Broad application of catalyzed diesel particulate filter (CDPF) systems with greater than 90% PM control is beginning with the introduction of 2007 model year heavy-duty diesel trucks in the United States. These systems use a combination of both passive and active soot regeneration. Our analysis projects that CDPF systems with a combination of passive and active backup regeneration will be the primary technology chosen by the locomotive and marine diesel industries to meet the Tier 4 PM standards.

4.2 Emission Control Technologies for Remanufactured Engine Standards and for Tier 3 New Engine Interim Standards

To meet the locomotive and marine remanufactured engine and Tier 3 standards, we believe engine manufacturers will utilize incremental improvements of existing engine components to reduce engine-out emissions. This will be accomplished primarily via application of technology originally developed to meet our current and upcoming standards for heavy-duty on-highway trucks and nonroad diesel equipment. This is especially true for many of the Category 1 and Category 2 marine engines, which are based on nonroad engine designs. This will allow introduction of technology originally developed to meet nonroad Tier 3 and Tier 4 standards to be used to meet the Tier 3 marine standards. Table 4-1, Table 4-2 and Table 4-3 provide summaries of the technologies that we believe will be used meet the remanufactured engine and Tier 3 new engine interim standards for switch locomotives, line-haul locomotives and marine engines, respectively. The technologies described in Tables 4-1 and 4-2 can also be applied to remanufactured marine engines >600 kW.

Table 4-1: Technologies for switch locomotive standards through Tier 3

Year	Standard	NO_x (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2010	T0-Remanufactured	11.8	0.26	New power assemblies to improve oil consumption, improved mechanical unit injectors
2010	T1-Remanufactured	11.0	0.26	New power assemblies to improve oil consumption, electronic unit injection, new unit injector cam profile
2013	T2-Remanufactured	8.1	0.13	For high-speed engines: Same as Tier 3 nonroad engines For medium-speed engines: Further improvements to power assembly and closed crankcase ventilation system to reduce oil consumption; new turbocharger (t/c), engine calibration, and unit injector cam profile
2011	T3	5.0	0.10	For high-speed engines: Same as Tier 3 nonroad engines For medium-speed engines: Further improvements to power assembly and CCV to reduce oil consumption, high pressure common rail injection with post-injection PM clean-up, injection timing retard, new t/c

Table 4-2: Technologies for Line Haul Locomotive Standards up to Tier 3

Year	Standard	NO_x (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2010 (2008 if available)	T0-Remanufactured	7.4	0.22	New power assemblies to improve oil consumption, improved mechanical unit injectors or switch to electronic unit injection, new t/c
2010 (2008 if available)	T1-Remanufactured	7.4	0.22	New power assemblies to improve oil consumption, electronic unit injection, new unit injector cam profile, new t/c
2013	T2-Remanufactured	5.5	0.10	Further improvements to power assembly and CCV to reduce oil consumption, electronic unit injection or high pressure common rail injection
2012	T3	5.5	0.10	Further improvements to power assembly to reduce oil consumption, electronic unit injection or high pressure common rail injection

Table 4-3: Technologies for Marine Category 1 and Category 2 to meet Tier 3 Standards

Year	Standard	$HC+NO_x$ (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2009-2014	Category 1 Tier 3 Marine (< 75 kW)	3.5 – 5.6	0.22 – 0.33	Same engine-out NO_x technologies as Tier 4 nonroad—with no Tier 4 PM aftertreatment technologies
2012-2018	Category 1 Tier 3 Marine (75-3700 kW)	4.0 – 4.3	0.07 – 0.11	Recalibration on nonroad Tier 4 engines without aftertreatment
2013	Category 2 Tier 3 Marine 7 – 15 liters/cyl.	5.5	0.10	Same engine-out NO_x technologies as pre-2014, non-generator-set, Tier 4 nonroad—with no Tier 4 PM aftertreatment technologies
2012	Category 2 Tier 3 Marine 15 – 30 liters/cyl.	6.5 – 8.2	0.20	Further improvements to power assembly to reduce oil consumption, electronic unit injection or high pressure common rail injection, new t/c

In section 4.2.1.1 we will describe some of the fundamentals of diesel combustion and pollutant formation. In section 4.2.2 we describe the manner in which engine-out emissions can be controlled in order to meet the locomotive and marine remanufactured engine standards and Tier 3 standards.

4.2.1 Diesel Combustion and Pollutant Formation

In this section we describe the mechanisms of pollutant formation. In order to lay the foundation for this discussion, we begin with a review of diesel combustion, especially as it is related to 2-stroke cycle and 4-stroke cycle diesel engine operation. We describe both of these types of diesel engine operation because both 2-stroke and 4-stroke engines are used in locomotive and marine applications. We then describe NO_x, PM, HC, and CO formation mechanisms.

4.2.1.1 Diesel Combustion

Category 1 marine diesel engines operate on a four-stroke cycle. The larger displacement Category 2 marine diesel engines and locomotive diesel engines operate on either a two-stroke cycle or a four-stroke cycle. The four-stroke cycle consists of an intake stroke, a compression stroke, an expansion (also called the power or combustion) stroke, and an exhaust stroke. The two-stroke cycle combines the intake and exhaust functions by using forced cylinder scavenging. Figure 1 provides an overview and brief comparison of the two-stroke and four-stroke cycles used by marine and locomotive diesel engines.

The diesel combustion event provides the energy for piston work. An example of the relationship between the different phases of diesel combustion and the net energy released from the fuel is shown in Figure 4.2. Combustion starts near the end of compression and continues through a portion of the expansion stroke. Near the end of the piston compression stroke, fuel is injected into the cylinder at high pressure and mixes with the contents of the cylinder (air + any residual combustion gases). This period of premixing is referred to as ignition delay. Ignition delay ends when the premixed cylinder contents self-ignite due to the high temperature and pressure produced by the compression stroke in a relatively short, homogenous, premixed combustion event. Immediately following premixed combustion, diesel combustion becomes primarily non-homogeneous and diffusion-controlled. The rate of combustion is limited by the rate of fuel and oxygen mixing. During this phase of combustion, fuel injection continues creating a region that consists of fuel only. The fuel diffuses out of this region and air is entrained into this region creating an area where the fuel to air ratio is balanced (i.e., near stoichiometric conditions) to support combustion. The fuel burns primarily in this region. One way to visualize this is to roughly divide the cylinder contents into fuel-rich and fuel-lean sides of the reaction-zone where combustion is taking place as shown in Figure 3. As discussed in the following subsections, the pollutant rate of formation in a diesel engine is largely defined by these combustion regions and how they evolve during the combustion process.[9]

Figure 1: A comparison of 2 complete revolutions of the four-stroke (top) and two-stroke diesel combustion cycles. Note that the two-stroke cycle relies on intake air-flow to scavenge the exhaust products from the cylinder. In the case of uniflow scavenged two-stroke diesel engines, cylinder scavenging is assisted by the use of a centrifugal or positive displacement blower to pressurize the intake ports located on the sides of the cylinder. Exhaust exits the cylinder through cam-actuated poppet valves in the cylinder head. Four-stroke diesel engines are the predominant type of Category 1 marine engine. Both four-stroke and uniflow-scavenged two-stroke diesel engines are used for Category 2 marine and locomotive applications.

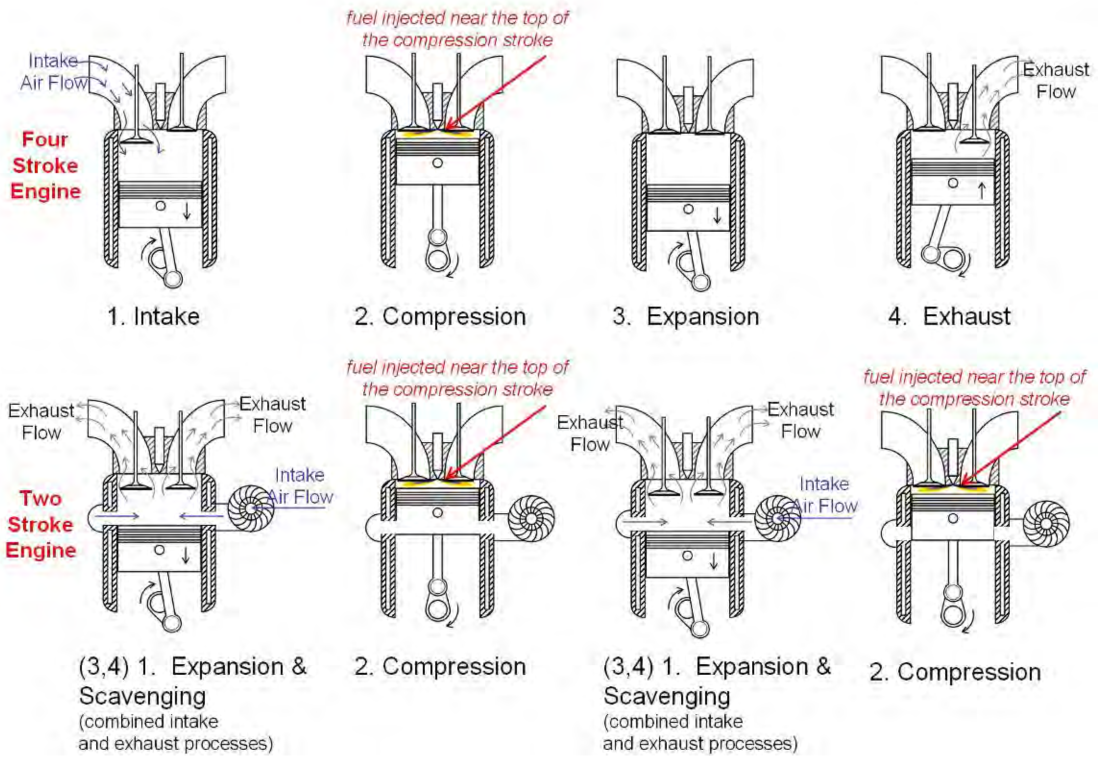


Figure 2: An idealized example of the net apparent rate of combustion heat release (derived from high-speed cylinder pressure measurements) for a direct injection diesel engine with indication of the major events and phases of combustion.

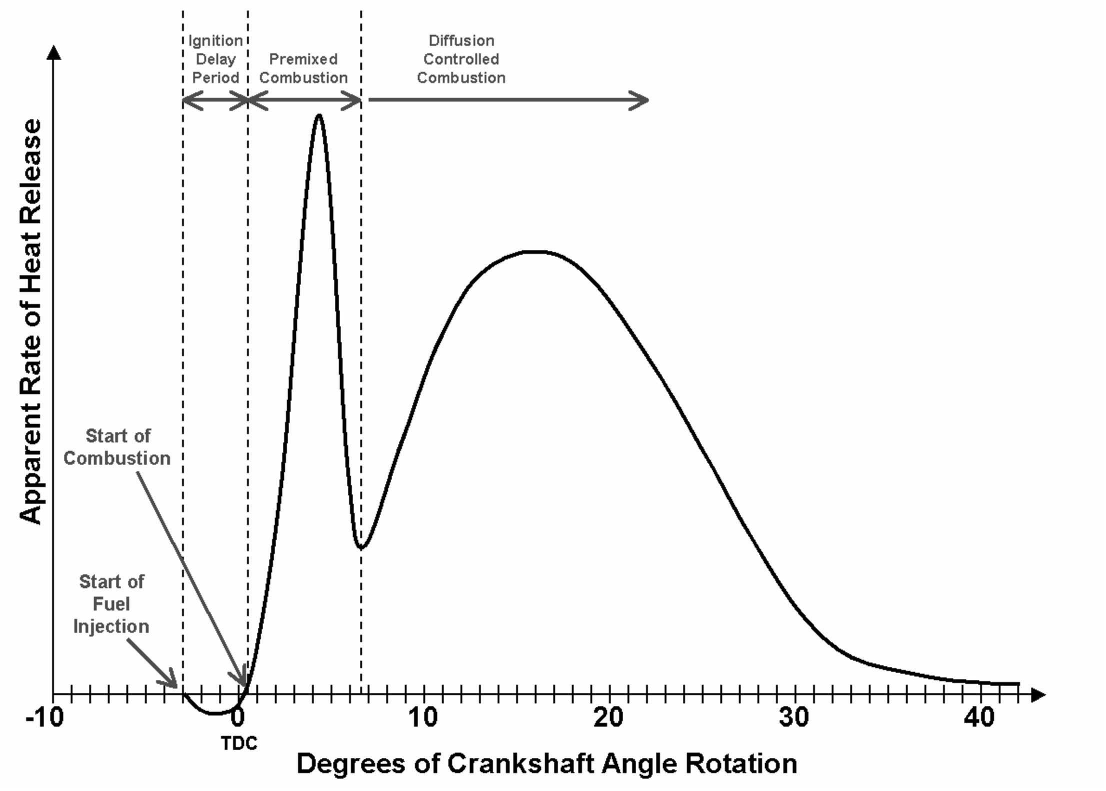
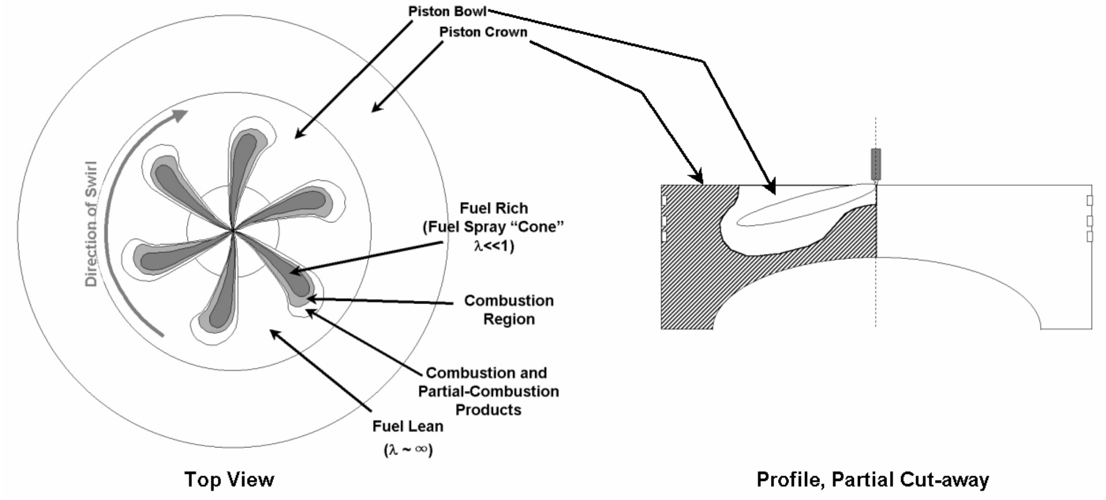


Figure 3: An idealized physical schematic of the diesel combustion process.



4.2.1.2 NO_x Emissions

Nitrogen oxides (NO_x) are formed in diesel engines by the oxidation of molecular nitrogen (N_2) in the stoichiometric combustion regions of the diffusion-controlled and premixed diesel combustion phases, described in the previous section. During the premixed phase of combustion, ignition and flame propagation occurs at high temperatures and at near stoichiometric mixtures of fuel and air. During diffusion-controlled combustion, the reaction zone is also near stoichiometric conditions. At the high temperatures present during premixed combustion or in the diffusion-controlled combustion reaction zone, a fraction of the nitrogen and oxygen can dissociate, forming radicals which then combine through a series of reactions to form nitric oxide (NO), the primary NO_x constituent. Nitrogen dioxide (NO_2), the other major NO_x constituent, is formed from oxidation of NO in the flame region. NO_2 formed during combustion rapidly decomposes to NO and molecular oxygen unless the reaction is quenched by mixing with cooler cylinder contents. Engine-out emissions of NO are typically 80% or more of total NO_x from direct injection diesel engines. The NO_x formation rate has a strong exponential relationship to temperature. Therefore, high temperatures result in high NO_x formation rates.[9,10] Any changes to engine design that can lower the peak temperature realized during combustion, the partial pressures of dissociated nitrogen and oxygen, or the duration of time at these peak temperatures can lower NO_x emissions. Most of the engine-out NO_x emission control technologies discussed in the following sections reduce NO_x emissions by reducing the peak combustion temperatures while balancing impacts on PM emissions, fuel consumption and torque output.

4.2.1.3 PM Emissions

Particulate matter (PM) emitted from diesel engines is a multi-component mixture composed chiefly of elemental carbon (or soot), semi-volatile organic carbon compounds, sulfate compounds (primarily sulfuric acid) with associated water, and trace quantities of metallic ash.

During diffusion-controlled combustion, fuel diffuses into a reaction zone and burns. Products of combustion and partial products of combustion diffuse away from the reaction zone where combustion occurs. At temperatures above 1300 K, fuel compounds on the fuel-rich side of the reaction zone can be pyrolized to form elemental carbon particles[11]. Most of the elemental carbon formed by fuel pyrolysis (80% to 98%) is oxidized during later stages of combustion.[12,13] The remaining elemental carbon agglomerates into complex chain-aggregate soot particles and leaves the engine as a component of PM emissions.

From this description, the formation of elemental carbon particles during combustion and emission as PM following the combustion event can be summarized as being dependent upon three primary factors:

1. Temperature
2. Residence time
3. Availability of oxidants

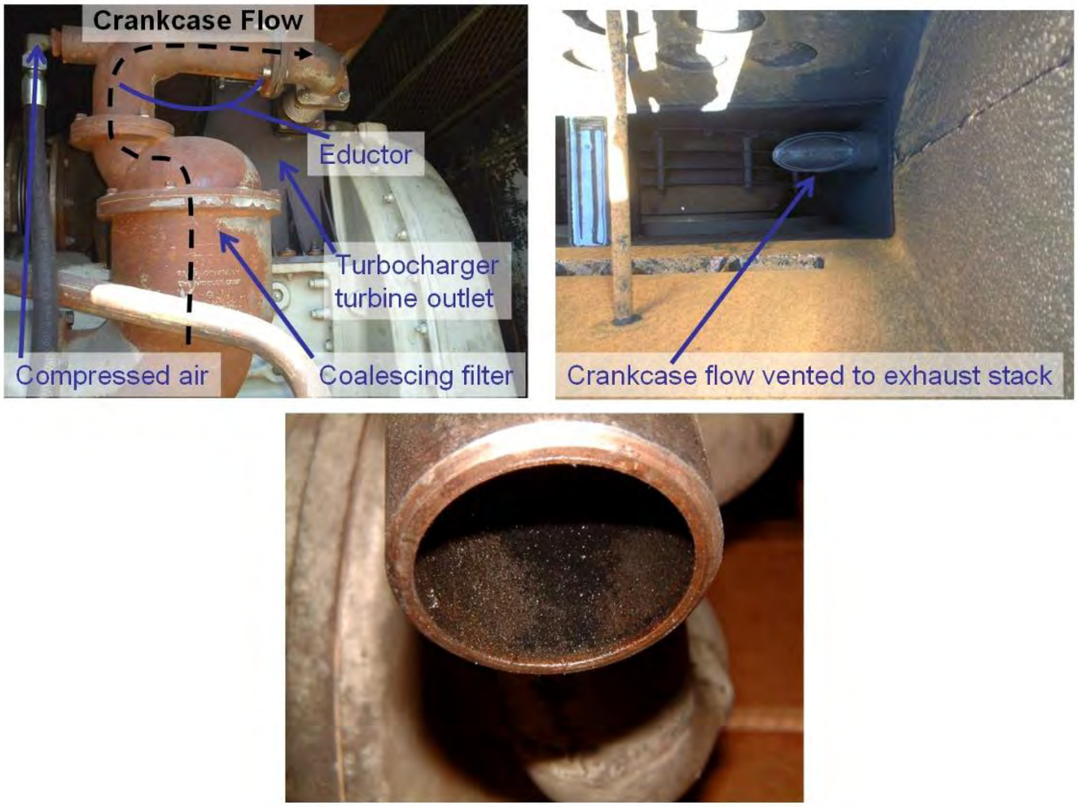
Thus, in-cylinder control of elemental carbon PM is accomplished by varying engine parameters that affect these variables while balancing the resultant effects on NO_x emissions and torque output.

The combinations of organic compounds (volatile and semi-volatile) that contribute to PM are referred to as the volatile organic fraction (VOF), the soluble organic fraction (SOF), or as organic carbon PM, depending upon the analytical procedure used to measure the compounds. Organic carbon PM primarily consists of lubricating oil and partial combustion products of lubricating oil. Some of the higher molecular weight fuel compounds from unburned or partially burned diesel fuel also contribute to organic carbon PM. Oil can be entrained into the cylinder contents from cylinder liner surfaces as they are uncovered by the piston and by leakage into the cylinder past the valve stems. Uniflow-scavenged two-stroke diesel engines typically have somewhat higher oil consumption and organic carbon PM emissions in part due to the lubricating oil entrained into the scavenging flow from around the intake ports in the cylinder wall. Compliance with the closed crankcase ventilation provisions in the Tier 0 and later locomotive and Tier 2 marine standards has typically been accomplished by using coarse filtration to separate a fraction of the oil aerosol from the crankcase flow and then entraining the crankcase flow directly into the exhaust downstream of the turbocharger exhaust turbine (Figure 4). Incomplete separation of the oil aerosol from the crankcase flow can increase the amount of lubricating oil directly entrained into the exhaust with subsequent formation of organic carbon PM.

Both organic carbon and sulfate PM are formed after cooling and air-dilution of the exhaust. Sulfur dioxide (SO_2) is formed via combustion of sulfur compounds from the fuel and lubricating oil burned during combustion. In the absence of post-combustion catalytic aftertreatment of the exhaust, approximately 1 to 3 % of fuel sulfur is oxidized to ionic sulfate (SO_3^-) and upon further cooling is present primarily as a hydrated sulfuric acid aerosol. For example, sulfate PM currently accounts for approximately 0.06 to 0.08 g/bhp-hr over the line-haul cycle for locomotive engines using 3000 ppm sulfur nonroad diesel fuel.

Diesel oxidation catalysts (DOC) and catalyzed diesel particulate filters (CDPF) using platinum catalysts can oxidize the organic compounds thereby lowering PM emissions but they can also oxidize 50% or more of the SO_2 emissions to sulfate PM, depending on the exhaust temperature and the platinum content of the catalyst formulation that is used.

Figure 4: Crankcase ventilation system for a medium speed locomotive diesel engine. An eductor uses compressed air to draw crankcase gases through a coarse coalescing filter (top left photo). The outlet of the crankcase ventilation system can be clearly seen from the outlet of the locomotive's exhaust stack (top right photo). The bottom photo shows tubing from a crankcase ventilation system removed from downstream of a similar coarse coalescing filter. There was considerable wetting of the inner wall of the tubing with lubricating oil.



4.2.1.4 HC Emissions

Hydrocarbon (HC) emissions from diesel engines are generally much lower compared to other mobile sources due to engine operation that, on a bulk-cylinder-content basis, is significantly fuel-lean of the stoichiometric air-to-fuel ratio. HC emissions primarily occur due to fuel and lubricant trapped in crevices (e.g., at the top ring land and the injector sac) which prevents sufficient mixing with air for complete combustion. Fuel related HC can also be emitted due to "over mixing" during ignition delay, a condition where fuel in the induced swirl flow has mixed beyond the lean flammability limit. Higher molecular weight HC compounds adsorb to soot particles or nucleate and thus contribute to the organic carbon PM. Lower molecular weight HC compounds are primarily emitted in the gas phase. During engine start-up under cold ambient conditions or following prolonged engine idling, fuel-related HC can be emitted as a concentrated, condensed aerosol ("white smoke").

4.2.1.5 CO Emissions

Carbon monoxide emissions (CO) from diesel engines are generally low compared to other mobile sources due to engine operation that, on a bulk-cylinder-content basis, is significantly fuel-lean of the stoichiometric air-to-fuel ratio. Catalytic emission controls that effectively oxidize PM constituents and HC emissions are also effective for oxidation of CO, reducing CO emissions to even lower levels.

4.2.2 Engine-out Emission Control

Control of diesel emissions via modification of combustion processes is often characterized by trade-offs in NO_x emission control vs. other parameters such as PM emissions, fuel consumption, and lubricating oil soot loading. For example, lower oxygen content (lowering the air-to-fuel ratio) lowers NO_x formation but increases PM formation. Advanced (earlier) injection timing reduces PM emissions but increases NO_x formation. Retarded (later) injection timing reduces NO_x formation but increases PM formation, increases fuel consumption, and at high torque output levels can increase soot accumulation within the lubricating oil. During engine development, these trade-offs are balanced against each other in order to obtain effective NO_x and PM control while maintaining acceptable power output, fuel efficiency and engine durability. The introduction of more-advanced fuel injection systems and improved turbocharging can improve these tradeoffs, allowing for reduced emisssions of both NO_x and PM.

4.2.2.1 Ultra Low Sulfur Diesel Fuel

We estimate that the use of ultra low sulfur diesel (ULSD) fuel (<15 ppm S) will reduce sulfate PM emissions from locomotive and marine engines by approximately 0.06 to 0.08 g/bhp-hr, as compared to PM emissions when ~3000 ppm S fuel is used. The use of ULSD fuel also reduces depletion of TBN in the oil and substantially reduces condensation of acidic aerosols within cooled exhaust gas recirculation systems (see section 4.2.2.5). In addition to the direct sulfate PM emissions reductions realized through the use of ULSD, this fuel is also necessary to enable the use of advanced catalytic exhaust aftertreatment technologies, as discussed later in this chapter. While we describe the emission reductions due to the use of lower sulfur diesel fuel here, we should be clear that these reductions are part of our baseline emissions inventory because ULSD is already in place and this rule does not change the fuel sulfur standard.

4.2.2.2 Turbocharger Improvements

The majority of Category 1 and 2 marine diesel engines and Tier 0 and later locomotive diesel engines are equipped with turbocharging and aftercooling. Tier 0 and later two-stroke locomotive engines (and some Tier 1 and later marine engines) are equipped with a hybrid mechanical centrifugal supercharger/exhaust turbocharger system. This system is gear driven up to approximately the notch 6 operating mode and is exhaust driven at higher operating modes or higher numbered notches (e.g., notches 7 and 8). This arrangement helps to provide sufficient scavenging boost at lower notch settings where there is insufficient exhaust energy for the exhaust turbine to drive the compressor. Significant improvements have been made in recent years in matching turbocharger turbine and compressor performance to the highway, nonroad, marine, and locomotive diesel engines. Improvements to turbochargers and the match of the turbocharger's design to the engine reduce the incidence of insufficient oxygen during transients and help maintain sufficient air flow to the engine during high load operation. The corresponding improvements in oxygen availability throughout the operational range of the engine reduce the formation of elemental carbon PM. We expect that new Tier 0 and Tier 1 (remanufactured) locomotive engines will include improvements to turbocharger design that are similar to those of current Tier 2 locomotive designs. We also expect that engine manufacturers will continue with incremental improvements in turbochargers and the match of the turbocharger's design to Tier 3 locomotive and marine engines.

4.2.2.3 Charge Air Cooling

Improvements in engine-out NO_x emissions to meet the locomotive and marine remanufactured engine and Tier 3 standards will be accomplished in part via lowering charge air cooling temperature. This was one of the primary methods used by locomotive engine manufacturers to reduce NO_x emissions to meet the Tier 1 and Tier 2 locomotive standards and the Tier 3 nonroad diesel standards. Lowering the intake manifold temperature lowers the peak temperature of combustion and thus NO_x emissions. The NO_x reduction realized from lowering the intake manifold temperature can vary depending upon the engine design but one estimate suggests NO_x emissions can be reduced by five to seven percent with every 10 °C decrease in intake manifold temperature.[14] Typically the intake manifold temperature is lowered by cooling the intake gases through a heat exchanger, also known as a charge air cooler or aftercooler, located between the turbocharger compressor outlet and the intake manifold. Locomotive applications typically use air-to-air aftercoolers. Locomotive aftercoolers use electrically powered auxiliary fans since oftentimes conditions at high torque output require significant intake air heat rejection, especially at speeds too low for effective passive air-flow. Operation of the locomotive in multi-engine train configurations or "consists" can also impede air-flow to heat exchangers. Increased cooling capacity in locomotive applications can be accomplished via increased air-flow through the air-to-air after cooler, often through use of either variable speed or multiple-staged electric fans. Marine applications with access to sea-water heat-exchanger coolant loops typically have excess heat rejection capacity with respect to charge air cooling. This cooling capacity can be limited within certain existing hull designs, but new hull designs can typically overcome these existing hull limitations.

4.2.2.4 Injection Timing

Electronic control of injection timing has been used by locomotive and marine engine manufacturers to balance NO_x emissions, PM emissions, fuel efficiency, engine performance and engine durability for engines certified to the Tier 2 locomotive and marine engine standards, Tier 3 nonroad standards, and the 1994 and later heavy-duty highway standards. We expect similar systems to be used to comply with the remanufactured engine standards and will continue to be used to comply with the Tier 3 locomotive and marine standards.

Delaying the start of fuel injection and thus the start of combustion can significantly reduce NO_x emissions from a diesel engine. The effect of injection timing on emissions and performance is well established.[15,16,17,18] Delaying the start of combustion by retarding injection timing aligns the heat release from the fuel combustion with the portion of the power (or combustion) stroke of the engine cycle after the piston has begun to move down. This means that the cylinder volume is increasing and that work (and therefore heat) is being extracted from the hot gases. The removal of this heat through expansion lowers the temperature in the combustion gases. NO_x is reduced because the premixed burning phase is shortened and because cylinder temperature and pressure are lowered. Timing retard typically increases HC, CO, PM, and fuel consumption because the end of injection comes later in the combustion stroke where the time for extracting energy from fuel combustion is shortened and the cylinder temperature and pressure are too low for more complete oxidation of PM. This can be offset by increasing injection pressure, allowing an earlier end of injection at the same torque output (i.e., shorter injection duration for the same quantity of fuel injected), and by using multiple injection events following the primary diffusion-combustion event to enhance soot oxidation (see 4.2.2.6 High Pressure Injection, Fuel injection Rate Shaping, Multiple Injections and Induced Charge Motion). We expect that these strategies will continue to be used to meet the locomotive and marine remanufactured engine and Tier 3 diesel engine standards.

4.2.2.5 Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) reintroduces or retains a fraction of the exhaust gases in the cylinder. Most highway diesel engine manufacturers used cooled external EGR to meet the 2004 and later Heavy-Duty Highway emission standards of 2.5 g/bhp-hr HC + NO_x and 0.10 g/bhp-hr PM. EGR has been a key technology used to reduce engine-out NO_x emissions to near 1.0 g/bhp-hr for CDPF-equipped 2007 heavy-duty truck and bus engines in the U.S. Although we do not expect that EGR will be needed to meet the Tier 3 locomotive and marine standards for remanufactured engines, we expect that some Category 1 marine diesel engines and high-speed locomotive switch engines that are based on Tier 3 and Tier 4 nonroad engine families that already use EGR, will also use EGR for their marine or switch locomotive applications of these engines to provide additional engine calibration flexibility.

The use of EGR decreases NO_x formation in three different ways:

1. EGR can thermally reduce peak combustion temperature. Increasing the mass of the cylinder contents by increasing carbon dioxide (CO_2) and water vapor concentrations reduces peak cylinder temperatures during combustion.[19]

2. A fraction of the air within the cylinder is replaced with inert exhaust, primarily CO_2 and water vapor. This reduces the amount of molecular oxygen available for dissociation into atomic oxygen, an important step in NO_x formation via the Zeldovich mechanism.[10]

3. The high temperature dissociation of CO_2 and water vapor is highly endothermic, and thus can reduce temperatures via absorption of thermal energy from the combustion process.[20]

EGR often is routed externally from the exhaust system to the induction system. The use of externally plumbed EGR can increase the intake manifold temperature substantially. This reduces intake charge density and lowers the fresh air/fuel ratio for a given level of turbocharger boost pressure. The result can be a large increase in PM emissions if the boost pressure cannot be increased to compensate for the lower intake charge density. For this reason, external EGR systems typically cool the exhaust gases using a heat exchanger in the exhaust recirculation loop. The introduction of ULSD fuel substantially reduces the risk of sulfuric acid condensation within an EGR cooler. EGR can also be accomplished entirely in-cylinder (internal EGR) through the use of camshaft phasing or other electronically controlled variable geometry valve-train systems, particularly when applied to varying two-stroke diesel engine exhaust scavenging, although it's use is limited by the inability to effectively cool the residual gases in-cylinder. For both internal and external EGR systems, the EGR rate is electronically controlled to prevent temporary, overly fuel-rich conditions that can lead to high PM emissions during transient engine operation.

Although we don't expect that EGR will be required to meet the remanufacturing standards or the Tier 3 locomotive and marine standards, we do believe that some engine manufacturers could select EGR as an effective NO_x emission control strategy. EGR can also provide increased flexibility in how engines are calibrated to meet emissions standards with the potential for improvement in part-load fuel consumption.

4.2.2.6 High Pressure Injection, Fuel injection Rate Shaping, Multiple Injections and Induced Charge Motion

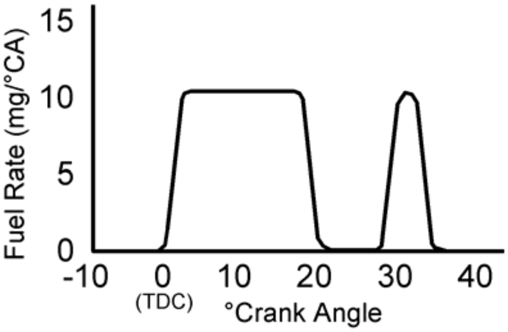
Inducing turbulent mixing is one means of increasing the likelihood of soot particles interacting with oxidants within the cylinder to decrease PM emissions. Turbulent mixing can be induced or increased by a number of means including:

- Changes to intake port/valve design and/or piston bowl design
- Increased (high) injection pressure
- Multiple/split injections using high pressure common rail injection or late post injection using electronic unit injection

As diesel fuel is injected into the cylinder during combustion, the high pressure fuel spray causes increased motion of the air and fuel within the cylinder. This increased motion leads to greater air and fuel interaction and reduced particulate matter emissions. Increasing fuel injection pressure increases the velocity of the fuel spray and therefore increases the mixing introduced by the fuel spray.

The most recent advances in fuel injection technology are high-pressure common rail injection systems with the ability to use rate shaping or multiple injections to vary the delivery of fuel over the course of a single combustion event. These systems are in widespread use in heavy-duty on-highway diesel engines, and they are used in many current nonroad diesel engines. These systems provide both NO_x and PM reductions. Igniting a small quantity of fuel early limits the rapid increase in pressure and temperature characteristic of premixed combustion and its associated NO_x formation. Injecting most of the fuel into an established flame then allows for a steady burn that limits NO_x emissions. Rate shaping can be done either mechanically or electronically, and has been shown to reduce NO_x emissions by up to 20 percent.[21] Multiple injection/split injection have also been shown to significantly reduce particulate emissions, most notably in cases that use retarded injection timing or a combination of injection timing retard and EGR to control NO_x.[22,23,24,25] The typical diffusion-burn combustion event is broken up into two events. A main injection is terminated, and then followed by a short dwell period with no injection, which is in turn followed by another short post-injection event, see Figure 4-5. The second pulse of injected fuel induces late-combustion turbulent mixing. The splitting of the injection event into two events aids in breaking up and entraining the “soot cloud” formed from the first injection event into the bulk cylinder contents.

Figure 5: An example of using multiple fuel injection events to induce late-combustion mixing and increase soot oxidation for PM control (Adapted form Pierpont, Montgomery and Reitz, 1995).

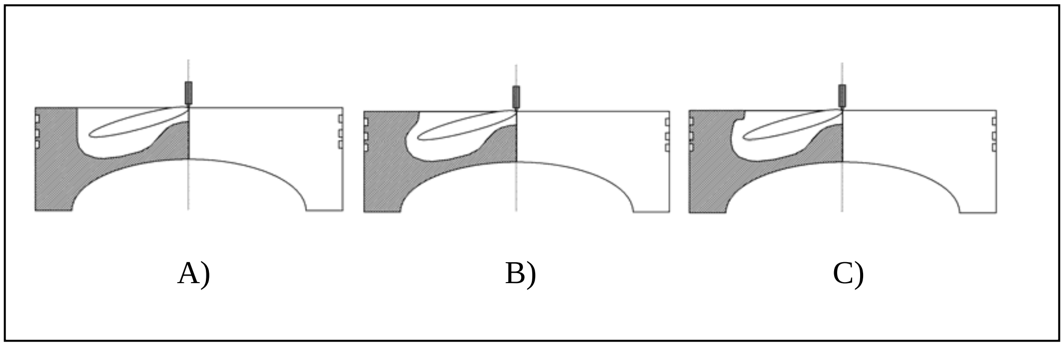


Increasing the turbulence of the intake air entering the combustion chamber (i.e., inducing swirl) can also reduce PM by improving the mixing of air and fuel in the combustion chamber. Historically, swirl was induced by routing the intake air to achieve a circular motion in the cylinder. Heavy-duty on-highway and nonroad engine manufacturers are increasingly using variations of "reentrant" piston designs in which the top surface of the piston is cut out to allow fuel injection and air motion in a smaller cavity in the piston to induce additional turbulence (Figure 4-6). Manufacturers have also changed to three or four valves per cylinder for on-highway and nonroad high-speed diesel engines, and to four valves per cylinder for medium-speed locomotive engines, which reduces pumping losses and can also allow for additional intake air charge motion generation. This valve arrangement also offers better positioning of the fuel injector by allowing it to be placed in-line with the centerline axis of the piston.

At low loads, increased swirl reduces HC, PM, and smoke emissions and lowers fuel consumption due to enhanced mixing of air and fuel. NO_x emissions might increase slightly at low loads as swirl increases. At high loads, swirl causes slight decreases in PM emissions and fuel consumption, but NO_x may increase because of the higher temperatures associated with enhanced mixing and reduced wall impingement.[26] A higher pressure fuel system can be used to offset some of the negative effects of swirl, such as increased NO_x, while enhancing positive effects like increased PM oxidation. Intake air turbulence such as “swirl” can be induced using shrouded intake valves or by use of a helical-shaped air intake port. Swirl is important in promoting turbulent mixing of fuel and soot with oxidants, but can also reduce volumetric efficiency.

Piston bowl design can be used to increase turbulent mixing. Reentrant bowl designs induce separation of the flow over the reentrant "ledge" of the piston and help to maintain swirl through the compression stroke and into the expansion stroke.[10]

Figure 6: Schematic examples of a straight-sided piston-bowl (A), a reentrant piston bowl (B), and a deep, square reentrant piston bowl (C) for high-speed diesel engines.



To meet our locomotive and marine remanufactured engine standards, we expect that manufacturers will use high pressure electronically controlled unit injection and improvements to piston bowl design. To meet the Tier 3 locomotive and marine standards, we expect that manufacturers of high-speed Category 1 and 2 marine diesel engines, high-speed switch locomotive engines and some Category 2 marine and locomotive medium speed engines will use advanced electronic fuel systems, including in many cases high-pressure common rail fuel injection systems.

4.2.2.7 Reduced Oil Consumption

Reducing oil consumption not only decreases maintenance costs, but also VOF and PM emissions. Reducing oil consumption has been one of the primary ways that heavy-duty truck diesel engines have complied with the 1994 U.S. PM standard. Reducing oil consumption also reduces poisoning of exhaust catalysts from exposure to zinc and phosphorous oil additives.

Redesign of the power assembly (pistons, piston rings and cylinder liner) played an important role in reducing organic carbon PM emissions from locomotive engines in order to meet the Tier 2 locomotive standards. Piston rings can be designed to improve the removal of oil from the cylinder liner surface and drainage back into the crankcase, reducing the amount of oil consumed. Valve stem seals can be used to reduce oil leakage from the lubricated regions of the engines valve train into the intake and exhaust ports of the engine. Improvements to the closed-crankcase ventilation systems that incorporate drain-back to the crankcase of oil separated from the crankcase flow and the use of high-efficiency filtration, either with replaceable high-efficiency coalescing filters or multiple-disc inertial separation, will reduce oil consumption and can remove oil-aerosol from the crankcase flow sufficiently to allow introduction of the crankcase gases into the turbocharger compressor inlet with little or no fouling of the turbocharger compressor, aftercooler or the remainder of the induction system. Euro IV and U.S. 2004 and 2007 heavy-duty truck engine designs that incorporate these technologies have significantly reduced engine-out organic carbon PM emissions.

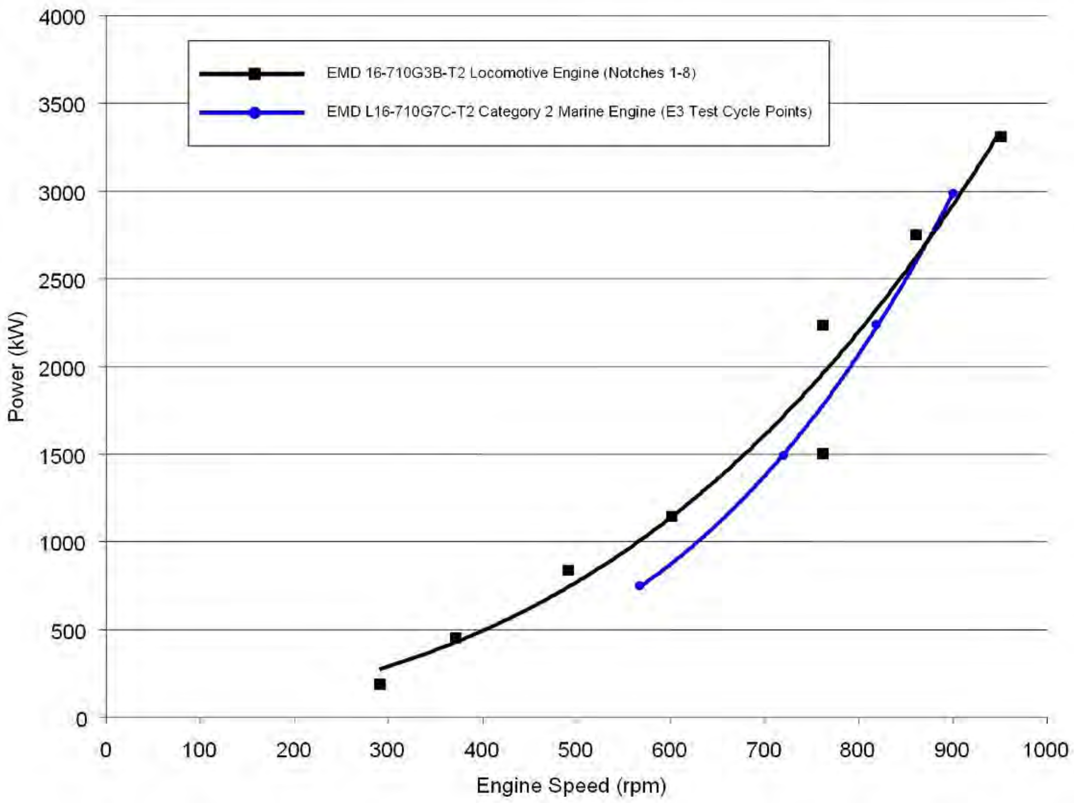
Particularly in the case of medium-speed engines, which have a relatively high fraction of PM emissions due to organic carbon PM, reduced oil consumption will be an effective means of meeting the locomotive and marine remanufactured engine and Tier 3 PM standards. We expect Tier 0 and Tier 1 remanufactured locomotive engines to receive power assembly designs similar to those of current Tier 2 locomotives. We expect that remanufactured Tier 2 locomotive engines and new Tier 3 locomotive and marine engines will receive incremental improvements in the design of the power assembly, valve stem seals and improved crankcase ventilation systems—especially if the crankcase ventilation system routes the crankcase vent to the turbocharger inlet and incorporates high-efficiency oil separation from the crankcase flow. When applying catalytic exhaust controls to meet the Tier 4 standards, reduced oil consumption will improve the durability of catalyst systems by reducing their exposure to zinc- and phosphorous-containing oil additives.

4.2.2.8 Application Specific Differences in Emissions and Emission Control

In much of the preceding discussion we have relied on previous experience primarily from high-speed (approximately >1600 rpm rated speed) on-highway and nonroad engines to provide specific examples of emissions formation and engine-out emission control. There are, however, some important operational and design differences between these engines and locomotive and marine diesel engines, particularly the medium speed locomotive and marine engines.

High-speed diesel engines used in on-highway and nonroad applications (with the exception of generator applications) undergo significant transient operation that can create temporary conditions of insufficient availability of oxidants due to the inability of the air-supply from the turbocharger to follow engine transients. For these applications, the majority of elemental carbon PM is emitted during these transients of insufficient oxygen availability. Such transients are greatly reduced in locomotive and marine applications. Marine propulsion engines operate primarily along a propeller curve that effectively forms a narrower outer boundary within which engine operation occurs. Marine generators and locomotive engines operate within even narrower bounds. Generators generally operate at close to a fixed engine speed with varying load. Locomotives operate at 8 distinct speed-load operational notches with gradual transitions between each notch. Figure 7 illustrates the speed and power ranges over which typical locomotives and marine engines operate.

Figure 7: A comparison engine power output versus engine speed for a locomotive engine operated over notches one through eight and for a Category 2 marine engine operated over the E3 marine cycle, which approximates a propeller curve with a cubic relationship between speed and load. A cubic fit through the locomotive notch points is remarkably similar to the E3 prop-curve. The specific example shown is for two similar versions of the EMD two-stroke medium-speed diesel engine.



In addition to operational differences, medium-speed diesel engines (750 to 1200 rpm rated speed) are the predominant type used in Category 2 marine and line-haul locomotive applications. Medium-speed diesel engines are also predominant in older switch locomotives, although the majority of locomotive switch families certified to the Tier 2 locomotive standards now use high-speed diesel engines. Medium speed diesel engines typically have even lower elemental carbon PM emissions due to increased residence time available at high load conditions for late-cycle burn-up of elemental carbon PM as compared to high-speed diesel applications such as heavy-duty on-highway engines. The increased duration of combustion also increases NO_x formation for medium-speed diesel engines.

Large-bore locomotive and Category 2 medium speed diesel engines also have significantly higher lubricating oil consumption than many high-speed diesel engines. Lubricating oil consumption for current 2007 on-highway diesel truck engines is approximately 0.09 to 0.13% of fuel consumed versus approximately 0.30 to 0.35% for 2-stroke medium-speed diesel locomotive and marine engines and approximately 0.25% for 4-stroke medium-speed locomotive engines. To some degree, this higher consumption of lubricating oil is by design. Higher lubricating oil consumption allows for a reduced frequency of complete oil changes, while at the same time the resulting frequent topping off of oil replenishes lubricant additives that maintain the lubricating oil's total base number (TBN) to prevent acidic corrosion. Frequent topping off also maintains the oil's oxidation stability to maintain oil viscosity. Because improvements in high-pressure fuel injection systems and electronic engine management were used to reduce carbon PM emissions to meet Tier 2 locomotive and marine engine PM standards, only moderate improvements in lubricating oil consumption were necessary to meet the Tier 2 PM emission standards.

Reduced elemental carbon PM, coupled with still moderately high lubricating oil consumption, results in a PM composition of medium-speed diesel engines that different from that of on-highway diesel engines and many nonroad diesel engines. PM emissions from medium-speed diesel engines have a higher fraction of organic carbon PM emissions than what has been previously measured from on-highway and most non-road diesel engines. Figure 4-8 shows the relative contributions of elemental carbon, organic carbon, and sulfate PM emission from recent testing by AAR of Tier 0, Tier 1 and Tier 2 locomotives using solvent extraction with gravimetric analysis for determining soluble organic carbon PM and water extraction and ion chromatography for determining sulfate PM.[27] The AAR data shows soluble organic carbon PM dominating the PM composition. EPA recently conducted testing at Southwest Research Institute using a newly developed semi-continuous method for direct mass measurement of organic carbon and elemental carbon (OC-EC). The new OC-EC data shows somewhat different relative contributions of organic carbon and elemental carbon PM than the results determined via filter extraction but confirms that Tier 2 locomotives have a higher fraction of organic carbon PM emissions than other diesel engines, particularly at high-load conditions.[28]

Crankcase ventilation flow is considerably higher from very large displacement medium-speed diesel engine compared with smaller, high-speed engines. This has complicated the design of crankcase ventilation systems with effective oil-aerosol separation. Higher capacity, high efficiency inertial disc-type separators are now being introduced in medium-speed marine applications to reduce bilge water contamination and oil consumption. Inertial disc-type oil separators originally developed for Euro IV and 2007 U.S. Heavy-duty On-highway applications have provided sufficient oil separation to allow introduction of filtered crankcase gases into the turbocharger inlet without oil fouling of the turbocharger or aftercooler system. Similar systems are now optionally available on Wärtsilä medium-speed stationary generator and marine engines (Figure 9). We expect that similar systems will be used on Tier 3 and Tier 4 Category 2 marine engines and remanufactured Tier 2 and new Tier 3 and Tier 4 locomotive systems. Recent data shows the potential to reduce PM emissions from Tier 2 locomotives by 10 to 15% via improvements to the crankcase ventilation system.[28]

Improvements in oil formulation, including switching from Group 1 to Group 2 base oils with greatly improved oxidation stability also reduce the need for oil top-off to replenish lubricant additives. As Group 1 become unavailable in Europe, we expect increased use of Group 2 base oil formulations for use with EMD medium-speed engines in Europe. Future reductions in fuel sulfur for Tier 3 and Tier 4 locomotive and marine engines will also reduce the need for TBN control.

Figure 8: Emissions for 7 locomotives tested using 2800 ppm sulfur nonroad diesel fuel.

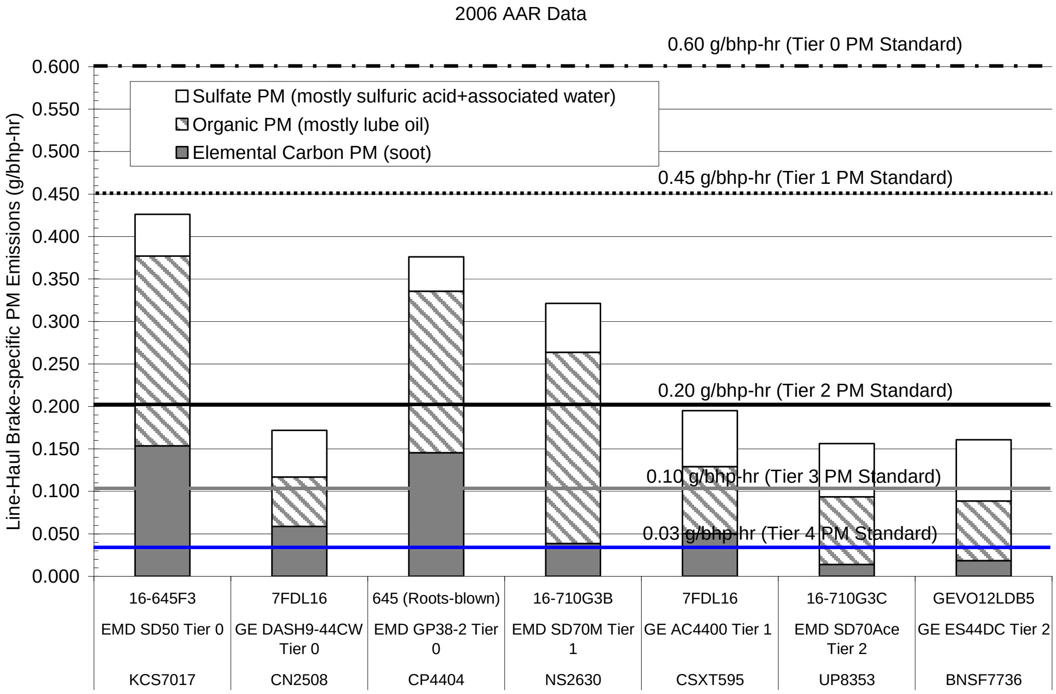
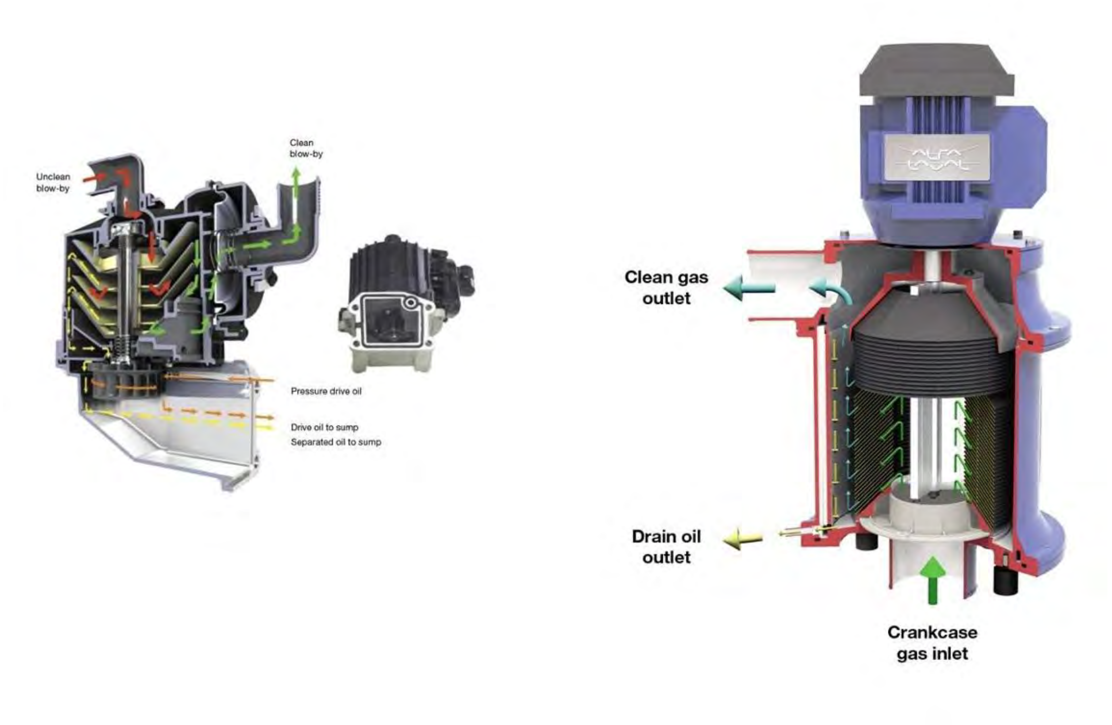


Figure 9: Alfa Laval disc-type inertial oil-aerosol separation systems for use with closed crankcase ventilation systems. The unit on the left is Alfdex system originally developed for Euro IV and U.S. 2007 heavy-duty on-highway applications. This system was designed as "fit for life", or essentially maintenance free for the useful life of the engine. A much higher volume system (right) was recently developed for Wärtsilä medium-speed engines.



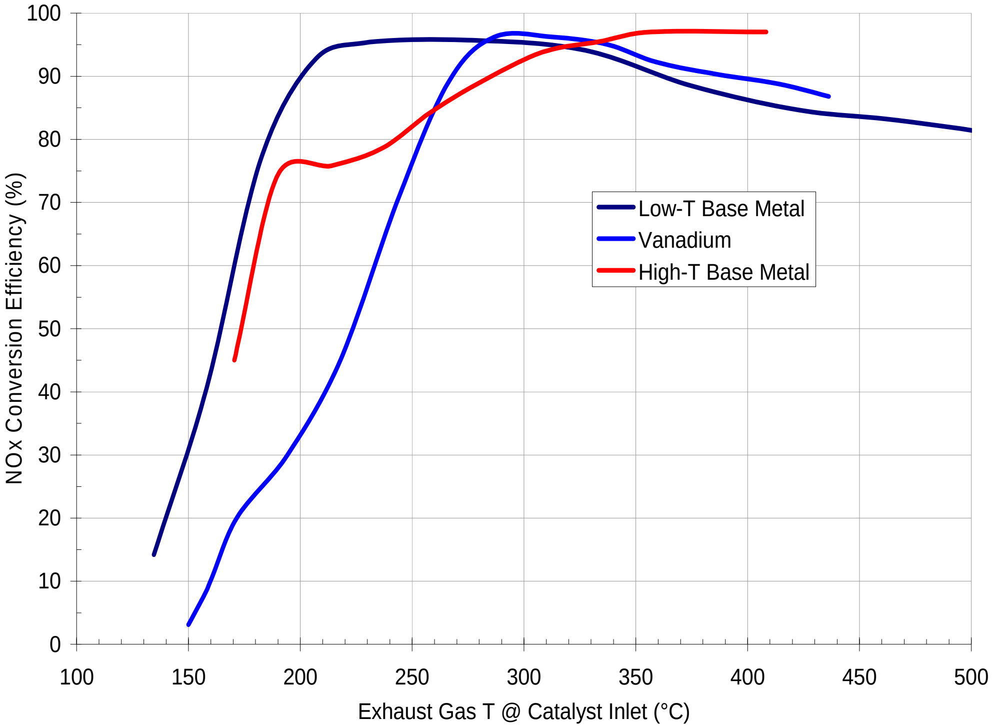
4.3 Feasibility of Tier 4 Locomotive and Marine Standards

In this section we describe the emission control technologies that we believe will be used to meet the Tier 4 locomotive and marine diesel engine standards. In general, these technologies involve the use of catalytic exhaust aftertreatment devices placed in an engine's exhaust system, downstream of an engine's exhaust manifold or turbocharger turbine outlet. The catalytic coatings of these aftertreatment devices are oftentimes sensitive to other constituents in diesel exhaust. For example, sulfur compounds within diesel fuel can decrease the effectiveness or useful life of a catalyst. For this reason, we will require the use of ULSD fuel in engines that will be designed to meet the Tier 4 emissions standards. We also expect that engine manufacturers will specify new lubricating oil formulations for these Tier 4 engines because of other trace compounds in some currently used lubricating oils,. These new oil formulations will help ensure that catalytic exhaust aftertreatment devices will operate properly throughout their useful life. Because we have already finalized and begun implementation of similar aftertreatment-forcing standards for both heavy-duty on-highway and nonroad diesel engines, we are confident that the application of similar, but appropriately designed, aftertreatment systems for locomotive and marine applications is technologically feasible, especially given the implementation timeframe of this rulemaking.

4.3.1 Selective Catalytic Reduction (SCR) NO_x Control Technology

Recent studies have shown that an SCR system is capable of providing well in excess of 80% NO_x reduction efficiency in high-power, heavy-duty diesel applications.[29, 30, 31] As shown in Figure 10, Vanadium and base-metal (Cu or Fe) SCR catalysts can achieve significant NO_x reduction throughout much of exhaust gas temperature operating range observed in heavy-duty diesel engines used in locomotive and marine applications. Collaborative research and development activities between diesel engine manufacturers, truck manufacturers, and SCR catalyst suppliers have also shown that SCR is a mature, cost-effective solution for NO_x reduction on heavy-duty diesel engines. While many of the published studies have focused on heavy-duty highway truck applications, similar trends, operational characteristics, and NO_x reduction efficiencies have been reported for heavy-duty marine and stationary electrical power generation applications as well.[32] An example of the performance capability of SCR in marine applications is the Staten Island Ferry *Alice Austen*. This demonstration project reports that 90-95% NO_x reduction is possible under steady-state conditions (where the exhaust gas temperature is above 270 °C.)[33] Given the preponderance of studies and data - and our analysis summarized here - we believe that this technology is appropriate for both locomotive and marine diesel applications.

Figure 10: SCR Catalyst NO_x Reduction versus Exhaust Gas Temperature Using an Ammonia-to-NO_x Ratio of 1:1[34,35,B]



An SCR catalyst reduces nitrogen oxides to N_2 and water by using ammonia (NH_3) as the reducing agent. The most-common method for supplying ammonia to the SCR catalyst is to inject an aqueous urea-water solution into the exhaust stream. In the presence of high-temperature exhaust gasses (>250 °C), the urea hydrolyzes to form NH_3 and CO_2 - the NH_3 is stored on the surface of the SCR catalyst where it is used to complete the NO_x-reduction reaction. In theory, it is possible to achieve 100% NO_x conversion if the NH_3-to-NO_x ratio (α) is 1:1 and the space velocity within the catalyst is not excessive (i.e. there is ample time for the reactions to occur). However, given the space limitations in packaging exhaust aftertreatment devices in mobile applications, an α of 0.85-1.0 is often used to balance the need for high NO_x conversion rates against the potential for NH_3 slip (where NH_3 passes through the catalyst unreacted).

Another approach to prevent NH_3 slip is to use an oxidation catalyst downstream of the SCR. This catalyst, also referred to as a slip catalyst, is able to oxidize the NH_3 which passes through (or is released from) the SCR. When this approach is used, it is possible to operate the SCR system at near-peak efficiency by optimizing the urea dosing rate to achieve the highest-possible level NO_x control (i.e. providing adequate NH_3 for optimum NO_x

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[B] The "High-T Base Metal" curve is based on a composite of low and high-space-velocity data provided by catalyst manufacturers. It is meant to represent high-hour performance of a system at a space velocity of 40,000 hr^{-1}.

reduction). A properly-designed slip catalyst, with good selectivity to nitrogen (N_2), can convert most of the excess NH_3 released from the SCR catalayst into N_2 and water. Recent studies have shown that an aged SCR system, equipped with a slip catalyst, can achieve tailpipe NH_3 levels of less of than 10 ppm when tested on the European Stationary Cycle (ESC) and European Transient Cycle (ETC).[36,37] In one study, the system was aged on a engine dynamometer test cycle which included 400 hours of high-temperature engine operation at 650 °C (to simulate active DPF regeneration events). Comments received from MECA stated that 90% NOx conversion can be maintained between 250 °C and 550 °C following 2000 hours of hydrothermal aging.[38] Our analysis of the locomotive engine operating conditions presumes a primarily "passive" DPF regeneration approach and maximum, post-turbine exhaust temperatures of 560 °C (during operation in non-ventilated tunnels).[39] Under these conditions, we expect slip catalysts to be durable and effective in reducing NH_3 slip.

The urea dosing strategy and the desired α are dependent on the conditions present in the exhaust gas; namely temperature and the quantity of NO_x present (which can be determined by engine mapping, temperature sensors, and NO_x sensors). Overall NO_x conversion efficiency, especially under low-temperature exhaust gas conditions, can be improved by controlling the ratio of two NO_x species within the exhaust gas; NO_2 and NO. This can be accomplished through use of an oxidation catalyst upstream of the SCR catalyst to promote the conversion of NO to NO_2. The physical size and catalyst formulation of the oxidation catalyst are the principal factors which control the NO_2:NO ratio, and by extension, improve the low-temperature performance of the SCR catalyst.

Published studies show that SCR systems will experience very little deterioration in NO_x conversion throughout the life-cycle of a diesel engine.[36,37,40] The principal mechanism of deterioration in an SCR catalyst is thermal sintering - the loss of catalyst surface area due to the melting and growth of active catalyst sites under high-temperature conditions (as the active sites melt and combine, the total number of active sites at which catalysis can occur is reduced). This effect can be minimized by design of the SCR catalyst washcoat and substrate for the exhaust gas temperature window in which it will operate. Another mechanism for catalyst deterioration is catalyst poisoning - the plugging and/or chemical de-activation of active catalytic sites. Phosphorus from the engine oil and sulfur from diesel fuel are the primary components in the exhaust stream which can de-activate a catalytic site. The risk of catalyst deterioration due to sulfur poisoning will be all but eliminated with the 2012 implementation of ULSD fuel (<15 ppm S) for locomotive/marine applications. Catalyst deterioration due to phosphorous poisoning can be reduced through the use of lubricating oil with low sulfated-ash, phosphorus, and sulfur content (commonly referred to as "low-SAPS" oil) and through reduced oil consumption (as discussed in 4.2.2.7). Previous oil formulations for heavy-duty, on-highway engines, such as API CI-4, did not specify a limit for sulfur content, and allowed higher levels of phosphorous (0.14% vs 0.12%) and ash (1.2~1.5% vs. 1.0%) content.[41] We expect the use of low-SAPS oil improve the performance of durability of catalyzed-DPF and SCR aftertreatment components in locomotive and marine applications. The high ash content in current locomotive and marine engine oils is related to the need for a high total base number (TBN) in the oil formulation. This high-TBN oil has been necessary because of the high sulfur levels typically present in diesel fuel - a high TBN is necessary to neutralize the acids created when fuel-borne sulfur migrates to the crankcase. With the use of

ULSD fuel, acid formation in the crankcase will not be a significant concern. This oil will be available for use in heavy-duty highway engines by October 2006 and is specified by the American Petroleum Institute as "CJ-4."[42] The durability of other exhaust aftertreatment devices, namely the DOC and DPF, will also benefit from the use of ULSD fuel and low-SAPS engine oil - less sulfur and phosphorous will improve DOC effectiveness and less ash will increase the DPF ash-cleaning intervals.

The migration of low-SAPS engine oil properties to future locomotive and marine oil formulations - while beneficial and directionally helpful in regards to the durability, performance, and maintenance of the exhaust aftertreatment components we reference – is not a required element of our feasibility analysis. European truck and marine applications have shown that SCR is a durable technology with low-SAPs oil. Several comments to our NPRM suggested that these newer, low-SAPS oil formulations, developed for use in on-highway and nonroad diesel engines, may not be appropriate for locomotive or marine applications. While we acknowledge that the exact oil formulation for locomotive and marine applications using ULSD fuel is not known today, we do believe that there is adequate time to develop an appropriate oil formulation. For example, in the State of California, all intra-state locomotives, marine vessels (in the SCAQMD), and nonroad engines have been operating with ULSD fuel since June, 2006 – so there should already be field data/experience available today to begin developing an oil formulation for ULSD in advance of the implementation date for aftertreatment-forcing standards. In addition, the nonroad sector will have transitioned to ULSD fuel nationwide by June, 2010, followed by the locomotive and marine sectors by June, 2012. The staggered introduction of ULSD fuel across these sectors (on-highway, nonroad, and finally, locomotive/marine), leaves ample time to develop oil formulations which do not contain any more sulphated-ash than necessary to neutralize crankcase acids. By adjusting amount of sulfated ash for each sector and the expected fuel sulfur level, it may be possible to reduce the ash quantity, resulting in extended ash cleaning intervals.

The onboard storage of the aqueous urea solution on locomotives and marine vessels can be accomplished through segmenting of the existing fuel tanks or fitment of a separate stainless steel or plastic urea tank. To assure consistent SCR operation between refueling stops, the volume of urea-water solution carried onboard will need to be at least 5% of the diesel fuel tank capacity. At the appropriate intervals, the crews will need to refill the urea tank. For the railroad and marine industries, the distribution and dispensing of urea is expected to benefit from any solutions put in place by the trucking industry and heavy-duty highway engine and vehicle manufacturers well in advance of the Tier 4 locomotive and marine regulations.

We project that locomotive and marine diesel engine manufacturers will benefit from any development taking place to implement DPF and SCR technologies in advance of the heavy-duty truck NO_x standards in Europe and the U.S. The Manufacturers of Emission Controls Association (MECA) supports the feasibility and timing of the Tier 4 locomotive and marine standards we are finalizing, and has stongly stated development work for SCR designs can begin today, with full implementation of this technology by 2015.[43] In addition, today's urea dosing systems for SCR - already in widespread use across many different diesel applications - are expected to become more-refined/robust/reliable in advance of the Tier 4 locomotive and marine standards. Given the steady-state operating characteristics of locomotive and marine engines, DPF regeneration strategies and urea dosing controls will certainly be capable of controlling PM and NO_x at the levels necessary to meet the standards finalized in this rulemaking.

4.3.1.1 Urea Infrastructure and Feasibility & Cost

The preferred concentration for the aqueous urea solution is 32.5% urea, which is the eutectic concentration (provides the lowest freezing point and the urea concentration does not change if the solution is partially frozen).[44] With a freezing temperature of -11 °C (12 °F), heaters and/or insulation may be necessary in Northern regions for urea storage/dispensing equipment and the urea dosing apparatus (tank, pump, and lines) on the on the engine. The centralized nature of locomotive and marine refueling from either large centralized fuel storage tanks or from tanker trucks with long-term purchase agreements provides a working example of how urea could also be distributed from storage tanks at centralized fueling facilities, tanker trucks and/or multi-compartment fuel-oil/urea tanker trucks at remote fueling sites. Given that only a small percentage of the locomotive and marine fleet will require urea prior to 2017, EPA believes that the infrastructure for supplying urea from centralized refueling points and tank trucks can be established to serve the rail and marine industries. Discussions concerning the urea infrastructure and specifications for an emissions-grade urea solution are beginning to take place amongst stakeholders in the light-duty and heavy-duty highway diesel industry. It is possible that these discussions will result in a fully-developed urea infrastructure for light-duty and heavy-duty diesel highway engine and vehicle applications by 2010. This will allow time to expand and develop this framework and support the needs of the railroad and marine industries. Even without these developments underway in the light-duty and heavy-duty highway industry, the centralized fueling nature of the locomotive and marine industries lends itself well to adaptation to support a supply of urea at their normal fueling locations.

In 2015, urea cost is expected to be ~$0.75/gallon for retail facilities dispensing 200,000 - 1,000,000 gallons/month, and ~$1.00/gallon for those dispensing 80,000 - 200,000 gallons/month.[45] The additional operating cost incurred by the rail industry will also be dependent on the volume of urea dispensed at each facility, with smaller refueling sites experiencing higher costs. It is estimated that 87% of the locomotive fleet is refueled at fixed facilities and 13% at direct truck-to-locomotive facilities.[46] The type of urea storage/dispensing equipment, and the ultimate cost-per-gallon, for railroad and marine industries will depend on the volume of fuel & urea dispensed at each site. High-volume fixed sites may choose to mix emissions-grade dry urea (or urea liquor) and de-mineralized water on-site, whereas others may choose bulk or container delivery of a pre-mixed 32.5% urea-water solution. Again, with the possible implementation of SCR for light-duty and heavy-duty highway applications in 2010, the economic factors for each urea supply option may be well-known prior to implementation of the 2017 standards. Even without these developments underway in the light-duty and heavy-duty highway industry, we believe that the urea supply options for the locomotive and marine industries will be numerous.

Urea production capacity in the U.S. is more than sufficient to meet the additional needs of the rail and marine industries. For example, in 2003, the total diesel fuel consumption for Class I railroads was approximately 3.8 billion gallons.[47] If 100% of the

Class I locomotive fleet were to be equipped with SCR catalysts, approximately 190 million gallons-per-year of 32.5% urea-water solution would be required.[45] It is estimated that 190 million gallons of urea solution requires 0.28 million tons of dry urea (1 ton dry urea is needed to produce 667 gallons of 32.5% urea-water solution).[45] Currently, the U.S. consumes 14.7 million tons of ammonia resources per year, and relies on imports for 41% of that total (of which, urea is the principal derivative). In 2005 domestic ammonia producers operated their plants at 66% of rated capacity, resulting in 4.5 million tons of reserve production capacity.[48] In the hypothetical situation above, where 100% of the locomotive fleet required urea, only 6.2% of the reserve domestic capacity would be needed to satisfy the additional demand. A similar analysis applied to the marine industry, with a yearly diesel fuel consumption of 2.2 billion gallons per year, would not significantly impact the urea demand-to-reserve capacity equation. Since the rate at which urea-SCR technology is introduced to the railroad and marine markets will be gradual, the reserve urea production will be adequate to meet the expected demand in the 2015 timeframe for implementation of the Tier 4 standards.

4.3.1.2 Establishing the Tier 4 NO_x Standard

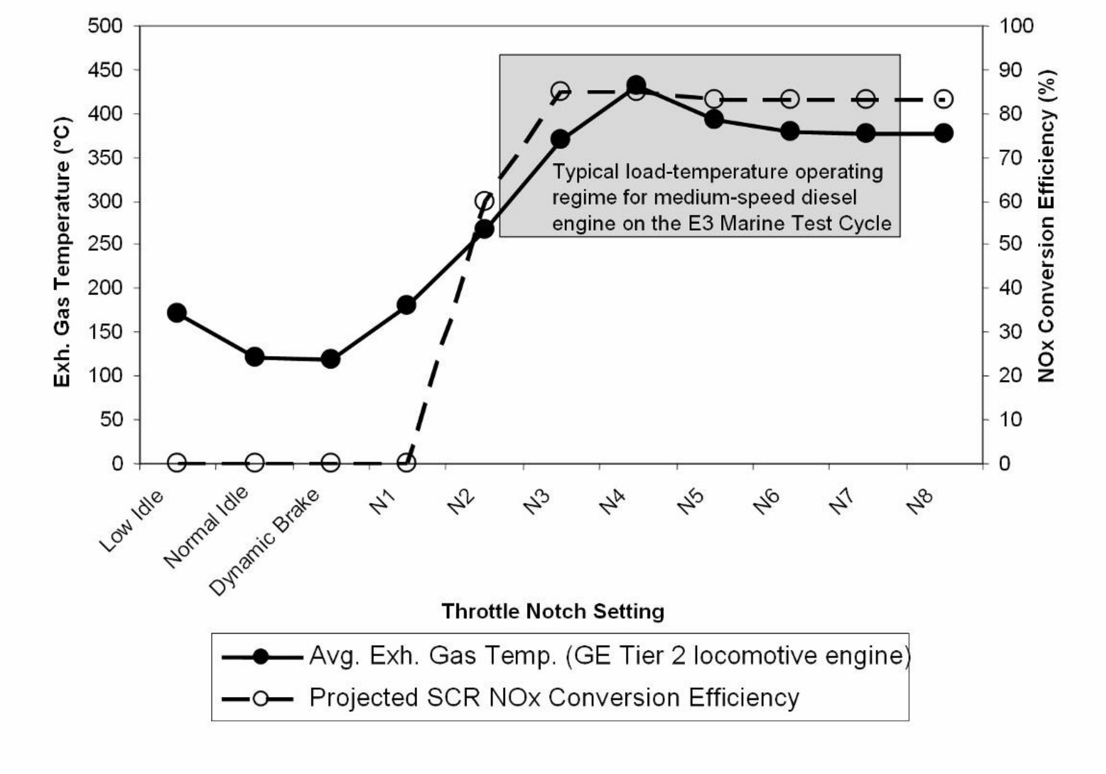
The basis for the locomotive Tier 4 Line-Haul NO_x standard is the Tier 3 NO_x emission standard (5.5 g/bhp-hr) reduced by the following SCR catalyst efficiency estimates at full useful life of the engine; 60% efficiency in operating mode notch 2 (where exhaust gas temperature is near the minimum-level for NO_x conversion), 85% conversion efficiency in operating modes notches 3 and 4 (where lower catalyst space velocities allow optimum reaction rates), and 83% conversion efficiency in the high-load operating modes, notches 5 through 8.[C] When these efficiencies are weighted according to the line-haul duty cycle emissions test, an overall NO_x reduction of 78% is obtained.

Figure 11 illustrates EPA's projection of an "aged" locomotive/marine SCR system at full useful life. When these levels of NO_x reduction are applied to engine out emissions from a typical Tier 2, 4-stroke-cycle locomotive diesel engine producing 5.5 g/bhp-hr of NO_x on the line-haul duty cycle, the worst-case, full useful life standard is established at 1.3 g/bhp-hr.[D] This standard includes a compliance margin and we expect that emissions of a new engine – and the emissions throughout much of the engine's life – will be closer to 0.8 g/bhp-hr. Because marine diesel engines will also operate under similar engine load/exhaust gas temperature conditions over their respective cycles, they also will be capable of similar NO_x reductions. As shown in the shaded area of Figure 4-11, the E3 Marine Test Cycle lies within the peak performance range of an SCR catalyst.

[C] For conditions present in Tier 0-2 locomotives, extended SCR operation (and hence, NO_x reduction) is not possible at the low power notches (NI, LI, DB, and N1) due to low exhaust gas temperatures.

[D] With an overall, duty-cycle-weighted, NO_x conversion efficiency of 78%, the remainder NO_x emissions will be 22% of the engine-out level (i.e. the Tier 2 Standard is 5.5 g/bhp-hr; 5.5 x 0.22 = 1.2 g/bhp-hr).

Figure 11: Typical 4-Stroke Diesel Locomotive Exhaust Gas Temperatures and Projected SCR Catalyst Efficiency at Full Useful Life.



For applications requiring improved SCR performance at lower exhaust gas temperatures, several options are available; throttling the engine airflow to increase exhaust gas temperature, using an SCR formulation designed for the low-temperature NO_x conversion, or a heated urea dosing system (or some combination of all three options). Throttling of the intake airflow on refuse trucks – which often operate under light-load conditions - has been shown to substantially increase exhaust gas temperatures.[49] Increasing the exhaust gas temperature at light load not only provides an opportunity for extended SCR operation, it is also improves performance of the DOC and DPF components. Low-temperature NO_x conversion can also be enhanced by use of a base-metal (Fe or Cu) zeolite SCR catalyst (see Figure 4-12). Systems for dosing urea at exhaust temperatures below 250 °C are being developed for heavy-duty, highway truck applications. One such system utilizes an electrically-heated bypass to hydrolyze the urea-water solution and produce NH3 when exhaust gas temperatures are as low as 160 °C – providing an additional 5-25% NO_x reduction relative to a system which stops urea dosing at 250 °C.[50] Use of a pre-turbocharger location for a DOC located upstream of the SCR system can also improve low temperature performance by driving NO to NO_2 conversion at lighter engine loads than would be possible with more remote mounting of the DOC. Use of air-gap or other types of insulated construction for exhaust system components can also improve thermal management and increase exhaust gas and catalyst temperatures. For further discussion of manifold-mounting of the DOC and exhaust system thermal management, see section 4.3.2 PM and HC Exhaust Aftertreatment Technology.

If no improvements were made to technologies which exist today, the 1.3 g/bhp-hr locomotive standard is technologically feasible. With projected improvements (that are currently more-difficult to quantify), we are confident in-use operation and end of useful life NO_x emission levels will be less than the 1.3 g/bhp-hr standard finalized in this rulemaking.

4.3.2 PM and HC Exhaust Aftertreatment Technology

The most effective exhaust aftertreatment used for diesel PM emission control is the diesel particulate filter (DPF). More than a million light diesel vehicles that are OEM-equipped with DPF systems have been sold in Europe, and over 200,000 DPF retrofits to diesel engines have been conducted worldwide.[8] Broad application of catalyzed diesel particulate filter (CDPF) systems with greater than 90% PM control is beginning with the introduction of 2007 model year heavy-duty diesel trucks in the United States. These systems use a combination of both passive and active soot regeneration. CDPF systems utilizing metal substrates are a further development that trades off a degree of elemental carbon soot control for reduced backpressure, greater design and packaging flexibility, improvements in the ability of the trap to clear oil ash, and better scaling to the large sizes needed for locomotive and marine applications. Metal-CDPFs were initially introduced as passive-regeneration retrofit technologies for diesel engines designed to achieve approximately 50 to 60% control of PM emissions.[51] Recent data has shown that metal-CDPF trapping efficiency for elemental carbon PM can exceed 70% for engines with inherently low elemental carbon emissions.[52] Data from locomotive testing (Figure 12) confirms a relatively low elemental carbon fraction and relatively high organic fraction for PM emissions from medium-speed Tier 2 locomotive engines.[27] The use of a highly oxidizing PGM catalyst coated directly to the CPDF combined with a highly oxidizing DOC mounted upstream of the CDPF can provide 95% or greater removal of HC, including the semi-volatile organic compounds that contribute to PM.

A functional schematic of a metal-CDPF is shown in Figure 13. In this particular example, flow restrictions divert a portion of the particle laden exhaust flow through the porous sintered metal walls. The openings in the flow restrictions are sufficient to allow accumulated ash to migrate through the CDPF substrate, either reducing or eliminating the need for periodic ash cleaning.[53] The metal-CDPF will most likely be used in combination with an upstream diesel oxidation catalyst (DOC). A diesel oxidation catalyst mounted upstream of the metal-CDPF improves NO to NO_2 oxidation for both passive soot regeneration within the CDPF and to increase the NO_x reduction efficiency of the SCR system, particularly during light-load and/or under cold ambient conditions. The DOC can also assist with oxidation of organic carbon PM, particularly at lower notch positions. The DOC effectively becomes mass transport limited for NO_2 oxidation at notch 6 and above (approximately $80{,}000^{-hr}$ space velocity), but at that point exhaust temperatures at the location of the metal-CDPF would be sufficient for NO to NO_2 oxidation and thus for passive soot regeneration and also for oxidation of organic carbon. Some or all of the DOC volume can be installed in a close-coupled position within the exhaust manifold, immediately downstream of the exhaust ports and upstream of the turbocharger's exhaust turbine (Figure 14) and within the “vee” of V-type locomotive and marine engines. Air-gapped construction can be used to provide faster warm-up and retention of heat within exhaust components. Thermal insulation that is similar to what is already in common use with dry exhaust manifold configurations in

Category 2 marine applications can be used to increase exhaust and catalyst temperatures (Figure 15).

Figure 16 and Figure 17 shows the expected line-haul locomotive PM reductions for the following scenarios:

- A 4-stroke line-haul Tier 2 locomotive due to reducing fuel sulfur content to 15 ppm
- A 4-stroke line-haul Tier 3 locomotive with oil consumption reduced approximately 50% relative to Tier 2 via improvements to the power assembly and closed-crankcase ventilation system
- A 4-stroke line-haul Tier 4 locomotives with application of a DOC and metal-CDPF to the Tier 3 engine
- A 4-stroke line-haul Tier 4 locomotives with application of a DOC and wall-flow-CDPF to the Tier 3 engine

Figure 18 and Figure 19 shows the expected marine PM reductions (on the E3 General Marine Duty Cycle) for the following scenarios:

- A 2-stroke medium-speed Category 2 marine diesel engine due to reducing fuel sulfur content to 15 ppm[E]
- A 2-stroke medium-speed Category 2 marine diesel engine with oil consumption reduced approximately 50% relative to Tier 2 via improvements to the power assembly and closed-crankcase ventilation system
- A 2-stroke medium-speed Category 2 marine diesel engine with application of a DOC and metal-CDPF to the Tier 3 engine

For both the 4-stroke line-haul locomotive and 2-stroke Category 2 marine examples, post-control PM was calculated using both AAR and EPA speciated PM test results. The relative contributions of elemental carbon and organic carbon to PM mass differed between the EPA and AAR test results, but the level of expected PM control was similar for the emissions control systems that were evaluated. Due to the relatively high organic carbon fraction and low elemental carbon fraction in the PM emissions, the difference in PM emissions between the metal-CDPF and the wall-flow-CDPF is less than 0.01 g/bhp-hr . The

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[E] For this specific example, speciated data from an EMD 16-710G3C-T2 2-stroke medium speed locomotive engine was used. This engine is offered in both Category 2 marine and line-haul locomotive applications. The locomotive application has a slightly higher speed rating and lower NOx emissions. A fit of the data to E3 points for the lower 4000 bhp @ 900 rpm EMD 16-710G7C-T2 marine rating was used to model PM emissions instead of the 4300 bhp @ 950 rpm rating. The G3C-T2 and G7C-T2 engines are remarkably similar, if not identical, designs with very similar NOx and PM emissions and appear to differ only with respect to rated power and rated speed.

advantages of the metal-CDPF relative to the wall-flow-CDPF are greatly reduced maintenance requirements and reduced exhaust back-pressure. We estimate that the use of a metal CDPF will result in PM emissions of approximately 0.020 to 0.022 g/bhp-hr over the line-haul cycle. The results from a ceramic wall-flow trap would be simlilar at 0.015 to 0.17 g/bhp-hr. Either system would provide sufficient compliance margin to meet the 0.03 g/bhp-hr Tier 3 line-haul locomotive standard. We expect comparable PM reductions from Category 2 marine engines and locomotive engines that utilize similar CDPF technology due to similarities in PM composition between these engines.

Fig 4-20 shows the expected PM removal efficiency of going from Tier 3 to Tier 4 plotted vs. exhaust temperature for all notch positions. The Tier 3 levels were calculated based on a 4-stroke Tier 2 locomotive engine with improved lubricating oil control. The Tier 4 levels were calculated based on the efficiency of a DOC and metal-CDPF combination at the end of useful life and taking into account removal efficiency for elemental and organic carbon and expected sulfate make from fuel and lubricant sulfur. Efficiency is similar or higher for Category 2 marine applications due to a narrower range of exhaust temperatures (approximately 250 °C to 350 °C over the E3 cycle) that are generally above the light-off temperatures for HC and NO oxidation for typical precious-metal DOC and CDPF formulations and yet are largely below the temperatures at which peak sulfate-make occurs.

Figure 12: Brake-specific PM emissions speciated into soluble organic, soluble sulfate, and insoluble elemental carbon over the Federal Line-Haul duty cycle.

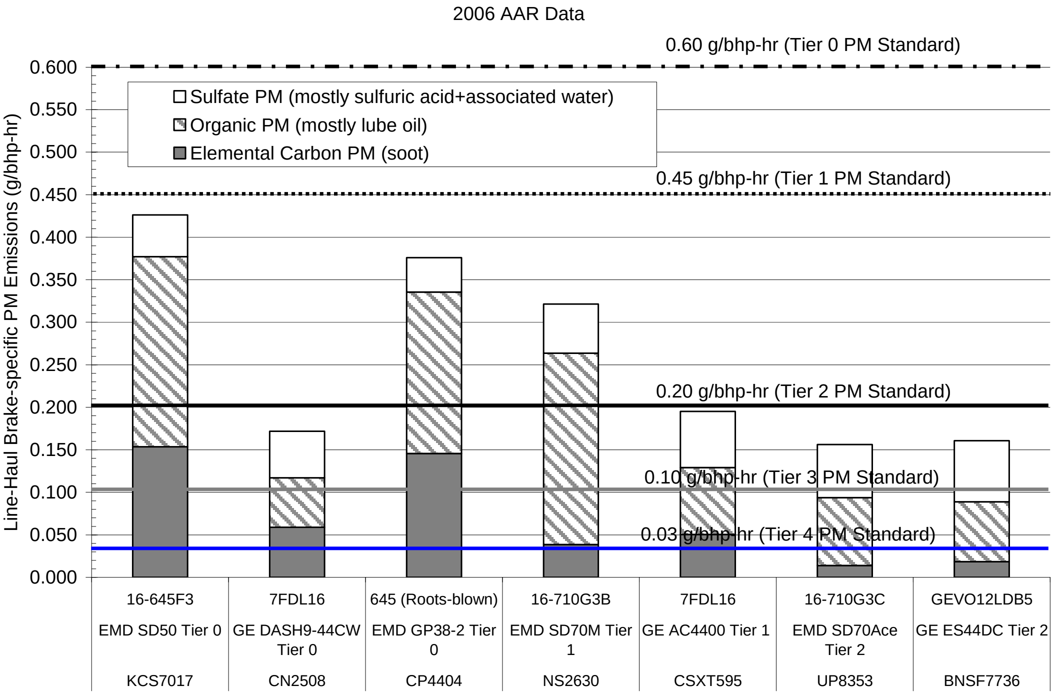


Figure 13: Cross-sectional functional schematic for a metal-CDPF (not to scale). Flow restrictions force part of the particle laden exhaust flow through the porous sintered metal layers. High efficiencies are possible with engines having relatively low elemental carbon PM emissions.

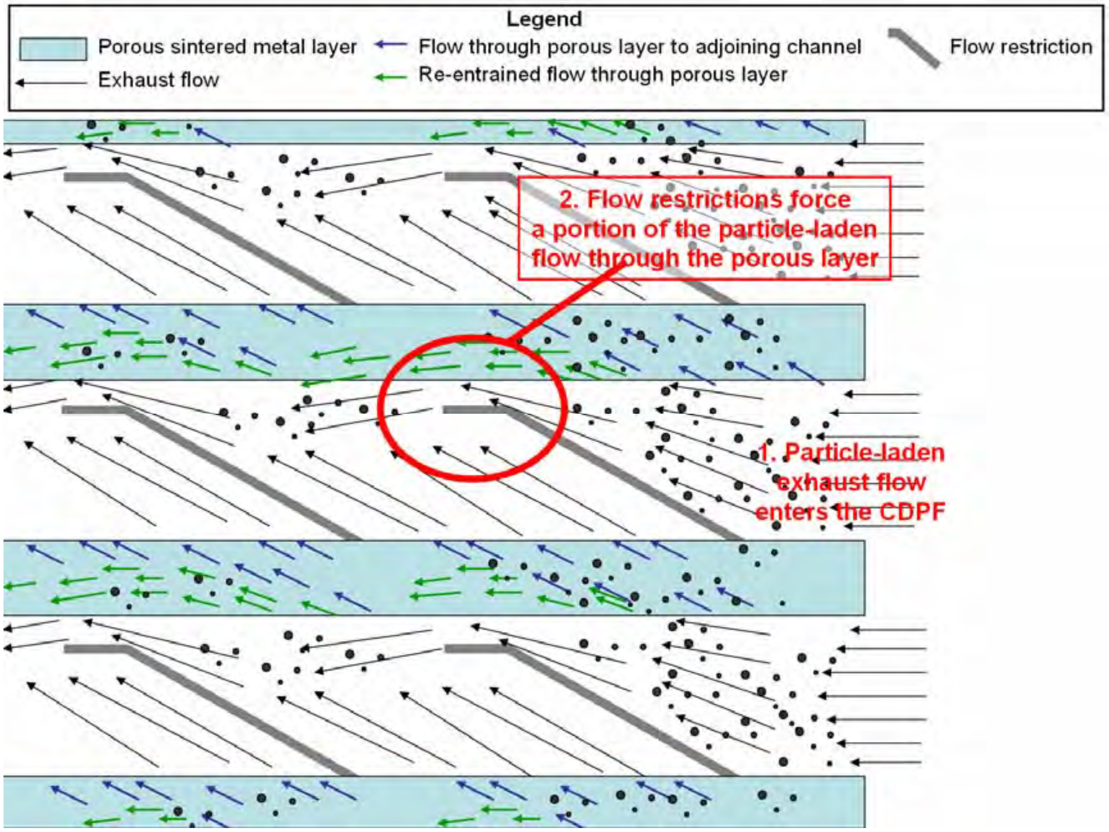


Figure 14: Metal-monolith diesel oxidation catalysts (DOC) mounted within the exhaust manifold of an EMD 710-series locomotive diesel engine. Use of a close-coupled DOC extends the range of light-load operation where NO to NO_2 oxidation can occur. Oxidation of engine-out NO to NO_2 assists with passive regeneration of the CDPF and increases the low temperature performance of the urea SCR system. The system also improves oxidation of organic carbon PM at light load conditions (locomotive notches 1 through 6).

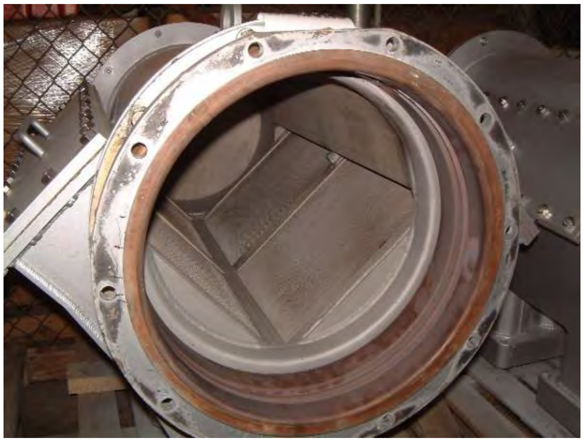


Figure 15: A two-stroke medium-speed Category 2 marine diesel engine with an insulated exhaust manifold and exhaust turbine in use in New York Harbor.

Figure 16: Brake-specific PM emissions over the line-haul duty cycle for a Tier 2 locomotive and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls. PM composition based on 2006 AAR testing.[27]

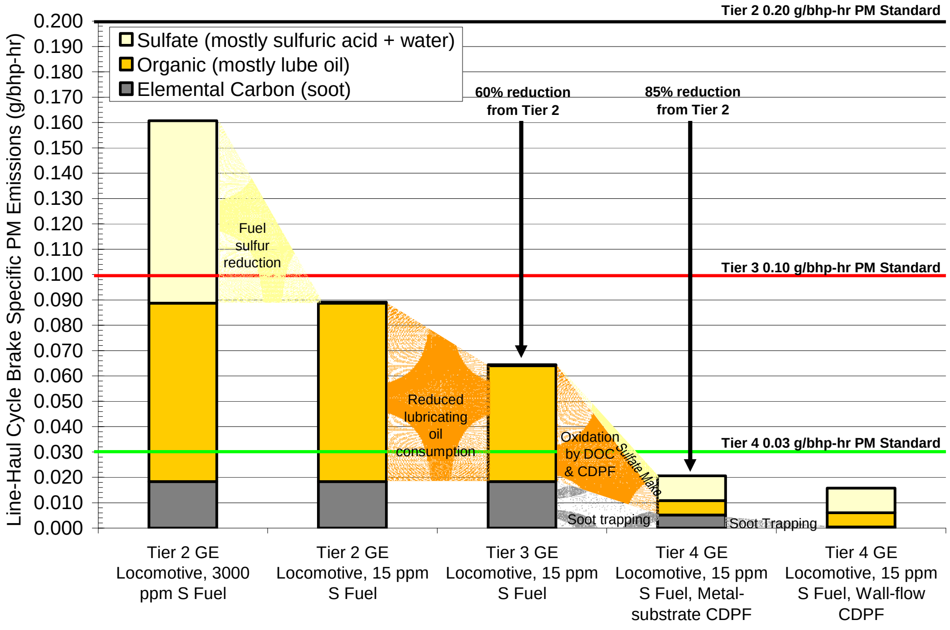


Figure 17: Brake-specific PM emissions over the line-haul duty cycle for a Tier 2 locomotive and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls. PM composition based on 2007 EPA Testing.[28]

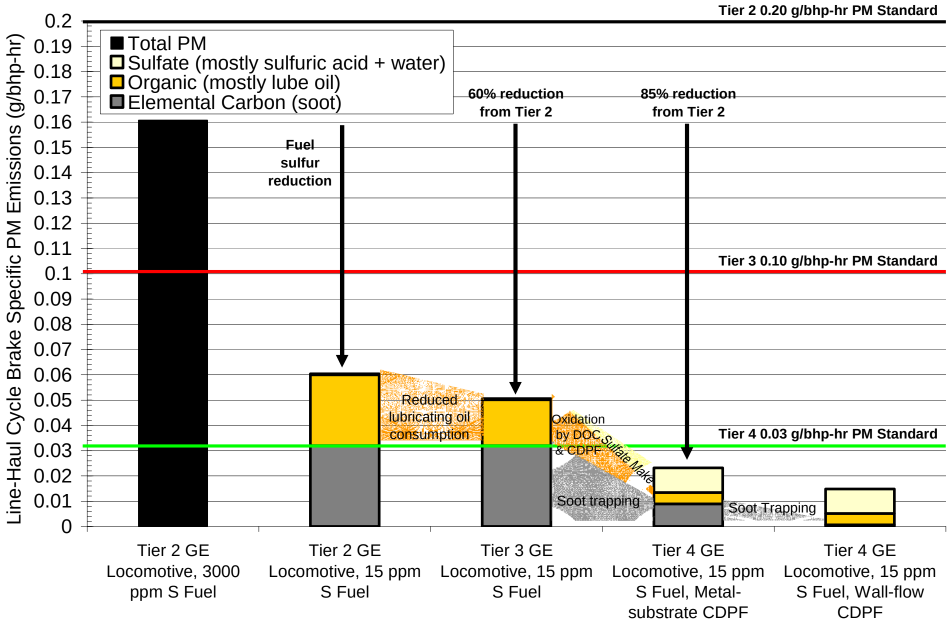


Figure 18: Brake-specific PM emissions over the E3 General Marine Duty Cycle for a Tier 2 medium-speed Category 2 diesel engine[E] and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls. PM composition based on 2006 AAR testing.[27]

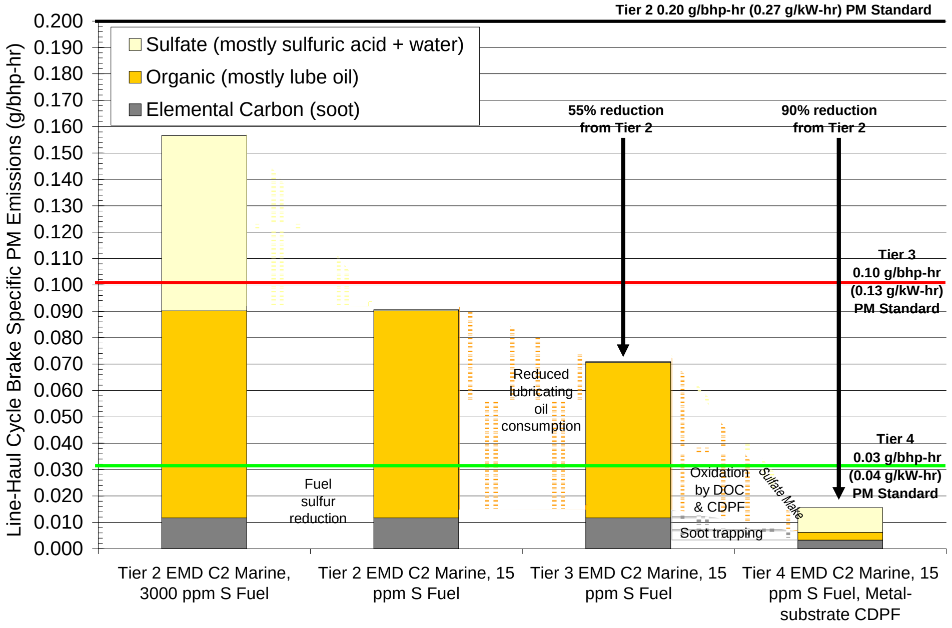


Figure 19: Brake-specific PM emissions over the E3 General Marine Duty Cycle for a Tier 2 medium-speed Category 2 diesel engine[E] and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls. PM composition based on 2007 EPA Testing.[28]

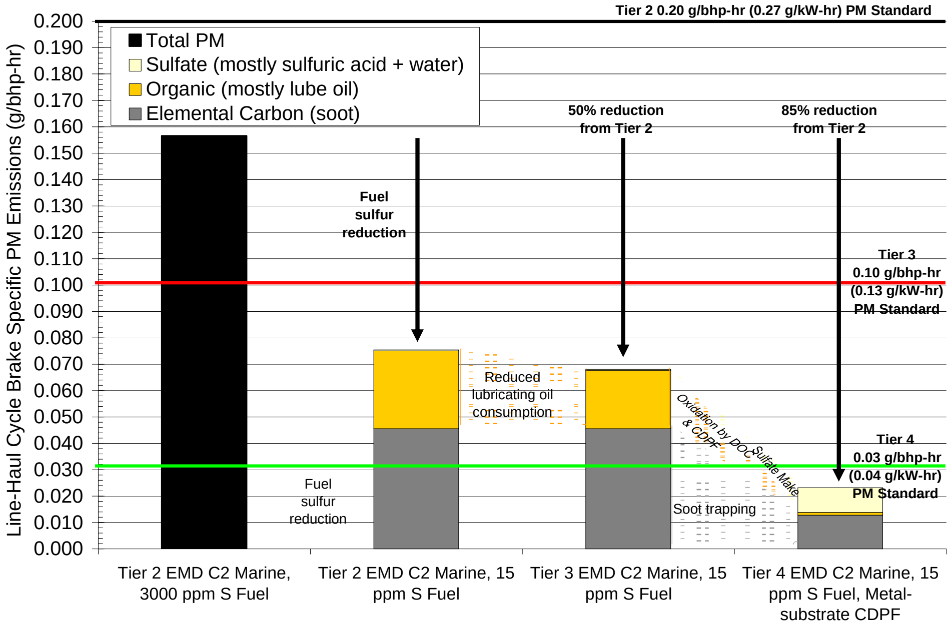
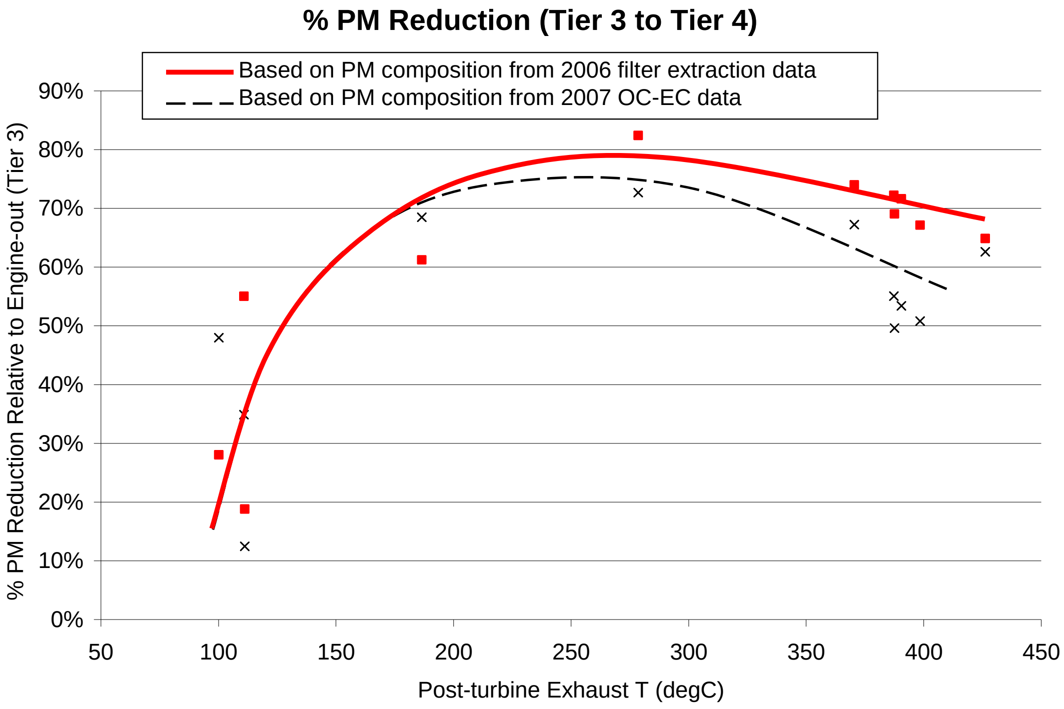


Figure 20: Expected PM reduction versus exhaust temperature for a combined DOC and Metal-CDPF system using 15 ppm sulfur fuel when applied to a Tier 3 locomotive. Below 200 °C, PM is dominated by organic carbon emissions, which can only be removed via catalytic oxidation and not by filtration since they are in the gas-phase in the raw exhaust. Thus (organic) PM removal is limited by the kinetically-limited HC oxidation rates over the precious metal catalyst applied to the DOC and the CDPF. The level of PM control is reduced at temperatures between 300 and 450 °C due to the formation of sulfate PM over the CDPF. Note that the percentage reduction is relative to the emissions of a Tier 3 locomotive, not a Tier 2 locomotive.



4.3.3 SCR and CDPF Packaging Feasibility

We expect that locomotive and marine manufacturers will design exhaust, turbocharger, and intake air aftercooling systems to accommodate the aftertreatment components. It is acknowledged that the existing overall length, width, and height dimensions of the locomotive are constrained by the existing infrastructure such as tunnel height, but our analysis shows the packaging requirements are such that they can be accommodated within the constraints of a locomotive. For commercial marine vessels, our discussions with marine architects and engineers, along with our review of vessel characteristics, leads us to conclude for engines >600 kW on-board commercial marine vessels, adequate engine room space can be made available to package aftertreatment components. Packaging of these components, and analyzing their mass/placement effect on vessel characteristics, will become part of design process undertaken by naval architecture and marine engineering firms.[54]

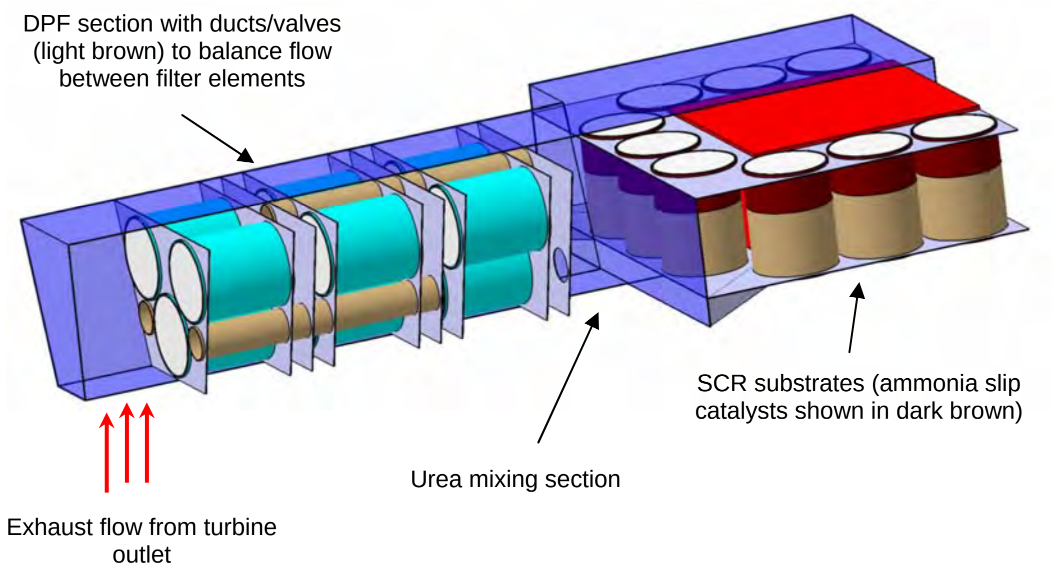
To achieve an acceptable balance between SCR performance and exhaust system backpressure, we estimate the volume of the SCR will need to be approximately 2.5 times the engine displacement. This volume includes the volume required for an ammonia-slip-catalyst zone coated to the final 15% of the volume of the SCR monoliths. The SCR volume is determined by sizing the device so that pollutants/reductants have adequate residence time within catalyst to complete the chemical reactions under peak exhaust flow (maximum power) conditions. The term used by the exhaust aftertreatment industry to describe the relationship between exhaust flow rate and catalyst residence time is "space velocity". Space velocity is the ratio of an engine's peak exhaust flow (in volume units-per-hour) to the volume of the aftertreatment device - this ratio is expressed as "inverse hours", or $^{-hr}$. For example, an engine with a displacement of 200 liters (L), 300,000 L/min of exhaust flow, and a 450 L SCR would have a space velocity of 40,000^{-hr} and a catalyst-to-engine displacement ratio of 2.25:1.[F] Typical space velocities for SCR on existing Euro 5 heavy-duty truck applications range from 60,000 to 80,000^{-hr}.

To achieve acceptable elemental carbon PM capture efficiency, organic carbon PM oxidation efficiency and exhaust system backpressure, the volume of a metal-CDPF for locomotive applications will need to be approximately 1.7 times the engine displacement, which results in a maximum space velocity of approximately 60,000^{-hr}. The exhaust-manifold-mounted DOC located upstream of the metal CDPF will need to be approximately 0.8 times the engine displacement with a maximum space velocity of approximately 80,000^{-hr} in notch 6 (approximately 120,000^{hr} in notch 8). Typical space velocity for combined DOC/CDPF systems for Euro 4, Euro 5, and U.S. 2007 heavy-duty truck applications range from approximately 60,000 to 80,000^{-hr}.

The volume of the space above the engine available for packaging of exhaust aftertreatment components on a locomotive is approximately 2300 L. For a 200L engine, with DOC, DPF, and SCR volume-to-displacement ratios of 0.8, 1.7, and 2.5 respectively, approximately 1000-L of space would be occupied by these aftertreatment components, leaving 1300 L of space available for the ducts, urea dosing/mixing hardware, and catalyst support structures. An example of an aftertreatment system design concept which satisfies the packaging space and volume criteria was developed by Tenneco® and is shown in Figure 21.

[F] Space Velocity =300,000 L/min * 1/450 L * 60 min/hr, Catalyst-to-Engine Displacement Ratio = 450 L/200 L.

Figure 21: Tenneco® DPF + SCR aftertreatment concept for line-haul locomotive applications.



One commenter stated that the EPA projections for space requirements of aftertreatment components was underestimated by a factor of 2. Our projection for catalyst/component volume was based on assigning a “reasonable” space velocity (one which provided a good balance between emissions reduction and exhaust backpressure) to each component – $120{,}000^{-hr}$ for the DOC, $60{,}000^{-hr}$ for the DPF, and $40{,}000^{-hr}$ for the SCR. In our analysis, we used engine data from the AAR’s locomotive in-use emissions test program to calculate the exhaust flow rate in units of “standard” cubic feet per minute (or SCFM, the conventional unit for volumetric flow used by catalyst manufacturers to calculate space velocity). In the commenter’s analysis, the “actual” exhaust flow rate instead of one corrected to “standard” conditions, as is industry practice. This method of analysis resulted in a flow rate which was approximately twice that of the value used in the EPA analysis, resulting in a space velocity which was two times greater as well. Once corrected to “standard” conditions, the commenter’s results for space velocity (and by extension, component volume) are very close to the EPA analysis.

4.3.4 Mechanical Durability of Aftertreatment Components

The exhaust components in any diesel application are subject to stresses from thermal expansion, vibration, and shock loads – all of which can affect the durability of the aftertreatment system. These stresses – and their associated affect on component durability - can be managed through the selection of proper materials and the design of support and mounting structures which are capable of withstanding them throughout the exected useful life and service conditions of a particular engine application. One commenter to our NPRM stated that shock loading for a locomotive catalyst is estimated to be 10-12 g. This level of shock loading is consistent with the levels that catalyst substrate manufacturers, catalyst canners, and exhaust system manufacturers are currently designing to (for OEM aftertreatment systems and components subject to the durability requirements of on-highway, marine, and nonroad applications). Nonroad applications such as logging equipment are subject to shock loads in excess of 10 g and on-highway applications can exceed 30 g (with some OEM applications specifying a 75 g shock load requirement).[55] In addition, the American Bureau of Shipping (ABS) specification for exhaust manifolds on diesel engines states that these parts may need to withstand vibration levels as high as +/-10 g at 600 °C for 90 minutes.[56] Given these examples of shock and vibration requirements for today's nonroad, on-highway, and marine environments , we believe that appropriate support structures can be designed and developed for the aftertreatment devices we expect to be used on Tier 4 locomotives.

4.3.5 Stakeholder Concerns Regarding Locomotive NO_x Standard Feasibility

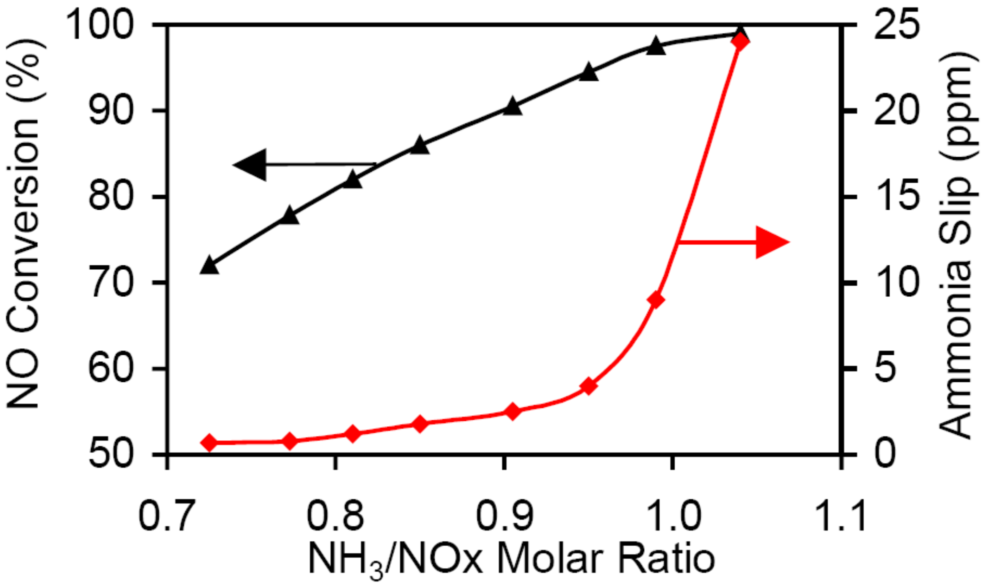
One stakeholder has expressed a number of concerns regarding the feasibility of the 1.3 g/bhp-hr Tier 4 locomotive NO_x standard. The issues raised by the stakeholder can be summarized into three broad areas of concern:

1. Ammonia (urea) dosing
2. Deterioration of SCR catalyst NO_x control
3. Locomotive parity with the marine Tier 4 NO_x standard

4.3.5.1 Ammonia/Urea dosing

The dosing concern specified that variability in urea quality (concentration), urea delivery (dosing), and engine-out NO_x level limits the maximum NO_x reduction potential of the SCR system in order to control ammonia slip to a level <20 ppm. This concern is valid only if urea dosing is controlled in an "open-loop" manner (or operated without consideration of - or inputs from – actual conditions present in the exhaust system and within the SCR catalysts.) If the urea dosing is controlled in a "closed-loop" manner, where feedback from NO_x and exhaust gas temperature sensors before/after the SCR catalyst is used to adjust the urea dosing rate, the SCR catalyst can operate at near-peak NO_x conversion efficiency while minimizing NH_3 slip. The use of an NH_3 slip catalyst can clean up any ammonia released from the SCR to levels less than 10 ppm, providing an additional level of robustness to the closed-loop urea dosing system.[36] For example, if exhaust gas and SCR temperature conditions at a particular engine speed/load point allowed for a maximum of 60% NO_x conversion efficiency, it is not be necessary to dose urea at an NH_3-to-NO_x ratio (α) of 1:1 (which could allow up to 40% of the NH_3 to slip) when an α of ~0.6 could achieve nearly the same level of NO_x control while minimizing NH_3 slip.[57] As shown in Figure 22, the relationship between dosing ratio and NO_x conversion is linear up to a ratio of ~0.95 (i.e. an α of 0.7 yields a NO_x conversion of 70%, an α of 0.8 yields a NO_x conversion of 80%, and so on). If the dosing ratio is increased beyond 0.95, the additional NH_3 injected will not produce a corresponding increase in NO_x conversion, but will begin to result in NH slip. An effective urea dosing system will operate at this "knee" in curve to maximize NO_x conversion while keeping slip below a designated target value.

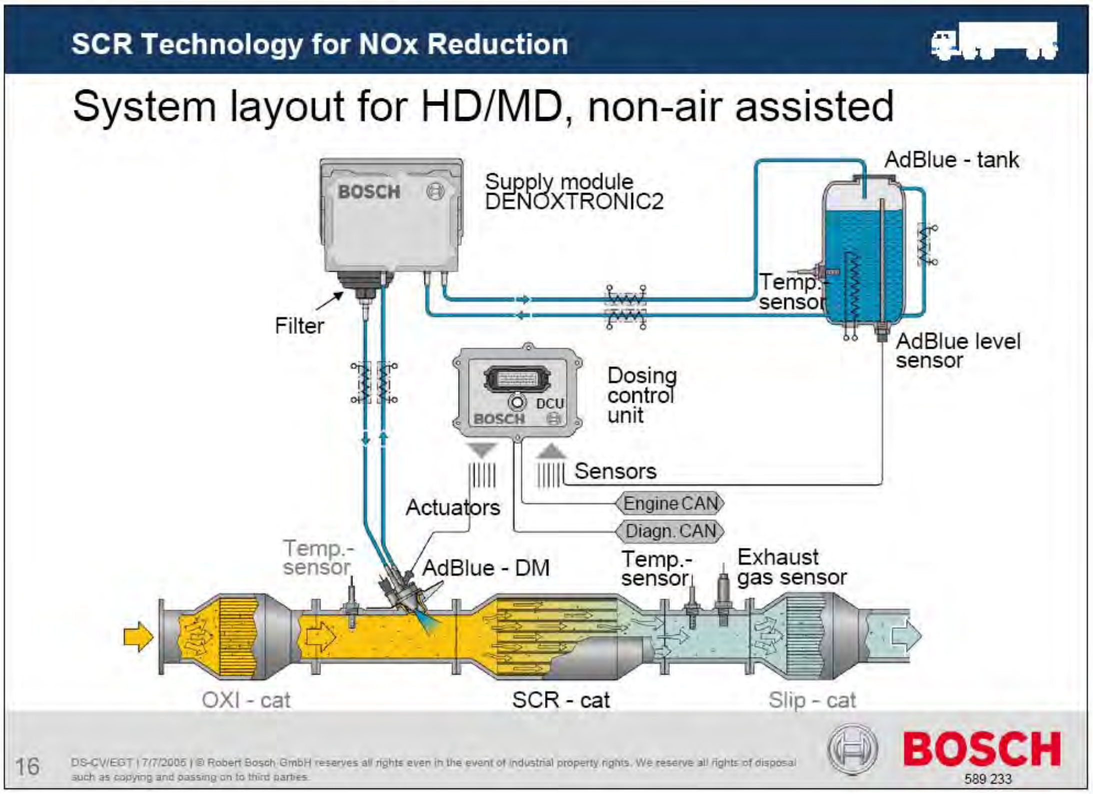
Figure 22: Effect of dosing ratio on NO_x conversion efficiency and NH3 slip.[57]



A NO_x sensor before (or upstream of) the SCR can be used as a "feed forward" control input to set the target urea dosing rate and a sensor after (or downstream of) the SCR can be used as "feedback" to fine-tune the dosing rate for optimum NO_x reduction while limiting ammonia slip. In addition, the feedback control provided by a closed-loop urea dosing system also mitigates any variation in concentration of the urea-water solution and engine-out NO_x levels by adjusting the control sytem to compensate by increasing/decreasing the urea dosing rate. The closed-loop system can also adjust to changes in the NO_x conversion efficiency as the SCR ages – as efficiency drops, the α can adapt downward, preventing excessive ammonia slip.

Closed-loop urea injection systems are already under development for 2010 U.S. heavy-duty highway diesel engines, U.S. and European light-duty diesel vehicles, and Euro V on-highway diesel trucks, and these applications have similar—if not more dynamic—engine operation as compared to locomotive and marine engine operation. Figure 23 illustrates a closed-loop urea-SCR control system for onroad diesel applications.[58] Figure 24 illustrates a urea-SCR system concept developed by Volkswagen to meet U.S Tier 2, Bin 5 passenger car emission standards.[59]

Figure 23: Adapted from “SCR Technology for NO_x Reduction: Series Experience and State of Development”.[58]



SCR Technology for NOx Reduction

System layout for HD/MD, non-air assisted

16 DS-CV/EGT | 7/7/2005 | © Robert Bosch GmbH reserves all rights even in the event of industrial property rights. We reserve all rights of disposal such as copying and passing on to third parties.

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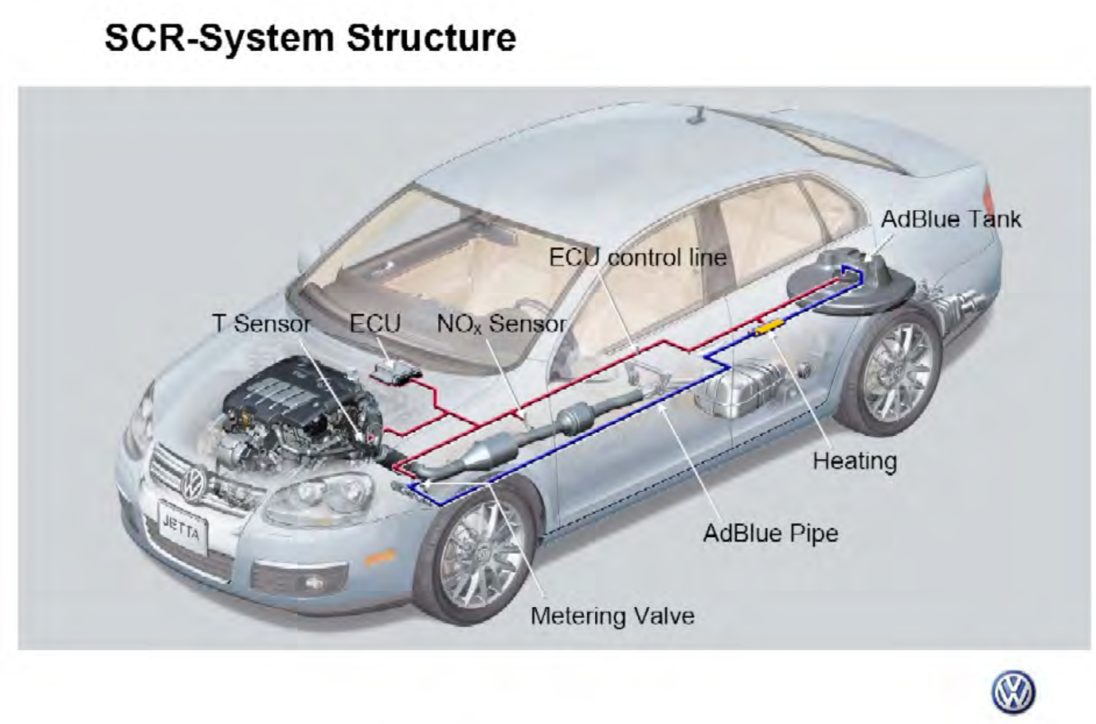
Figure 24: Adapted from "LNT or Urea SCR Technology: Which is the right technology for TIER 2 BIN 5 passenger vehicles?"[59]



To ensure accurate urea injection across all engine operating conditions, these systems utilize NO$_x$ sensors to maintain closed-loop feedback control of urea dosing. These NO$_x$-sensor-based feedback control systems are similar to oxygen-sensor-based systems that are used with three-way catalytic converters on virtually every gasoline vehicle on the road today. The control logic to which the sensors provide input allows for correction of urea dosing to adequately compensate for both production variation and in-use catalyst degradation. We believe these NO$_x$–sensor-based control systems are directly applicable to locomotive and marine engines.

Urea dosing systems under development to meet the light-duty Tier 2 and Heavy-duty 2010 diesel emissions standards also use sophisticated models that predict the mass of NH_3 stored within the catalyst system and continuously adjust dosing while taking into account NH_3 storage and release. Prediction of stored NH_3 reduces NH_3 slip and allows additional NO$_x$ reduction to occur by using stored NH_3 for NOx reduction at light load and idle conditions where exhaust temperatures are typically too low for urea injection and hydrolysis. EPA's analysis of SCR NOx efficiency in section 4.3.1.2 is thus somewhat conservative since the ability to reduce NO$_x$ emissions using stored NH_3 under many conditions where urea injection and urea hydrolysis are problematic (e.g., operation in notch one and under dynamic brake conditions) was not taken into consideration. Internal EPA engine testing shows that using a closed-loop controlled urea dosing system with prediction of stored NH_3 can allow sustained operation at exhaust conditions equivalent to notch 1 operation with 40 to 50% NO$_x$ control.[60]

Ammonia emissions, which are already minimized through the use of closed-loop feedback urea injection, can be all-but-eliminated with an ammonia slip catalyst downstream of the SCR catalyst. Such catalysts are in use today and have been shown to be 95% effective at reducing ammonia emissions. Ammonia slip catalysts that have been developed for Euro V and U.S. 2010 truck applications have reduced selectivity for NO_x formation from ammonia oxidation and can provide additional SCR NO_x conversion via reaction with ammonia within the slip catalyst itself.

4.3.5.2 Deterioration of NO_x Control with Urea-SCR Systems

A concern has been raised by the stakeholder that the iron-zeolite catalysts (as compared to the vanadium-based catalyst used in trucks in Europe) age rapidly in the presence of real exhaust and when exposed to elevated temperatures. Part of this concern is related to data provided by the stakeholder that had originally been presented by researchers at Ford and General Motors.[35,61] The data was characterized as reaching two conclusions:

1. Fe-zeolite catalysts have NO_x reduction efficiency of only 55% to 65% when NO_x emissions are predominantly NO.[61]

2. The NO to NO_2 conversion efficiency of PGM-based DOC's would rapidly degrade to zero, and thus could not be relied upon to provide any degree of NO to NO_2 oxidation to improve the efficiency of Fe-zeolite SCR catalysts.

The first point may be the case for some Fe-zeolite catalysts when operated at catalyst space velocities much higher than those that would be used for locomotive applications (see Figure 25). The research cited intentionally undersized the SCR catalyst to accentuate the impact of $NO:NO_2$ ratio on NO_x conversion When comparing the Fe-Zeolite SCR catalyst example in Figure 25 to a similar, aged Fe-Zeolite system at a lower space velocity (Figure 26), the NO_x conversion efficiency increases to approximately 80% to 90% over the exhaust temperature range for a line-haul locomotive application for the lower space velocity example with no conversion of NO to NO_2. There are two likely reasons for the differences seen between the results in Figure 25 and the results in Figure 26:

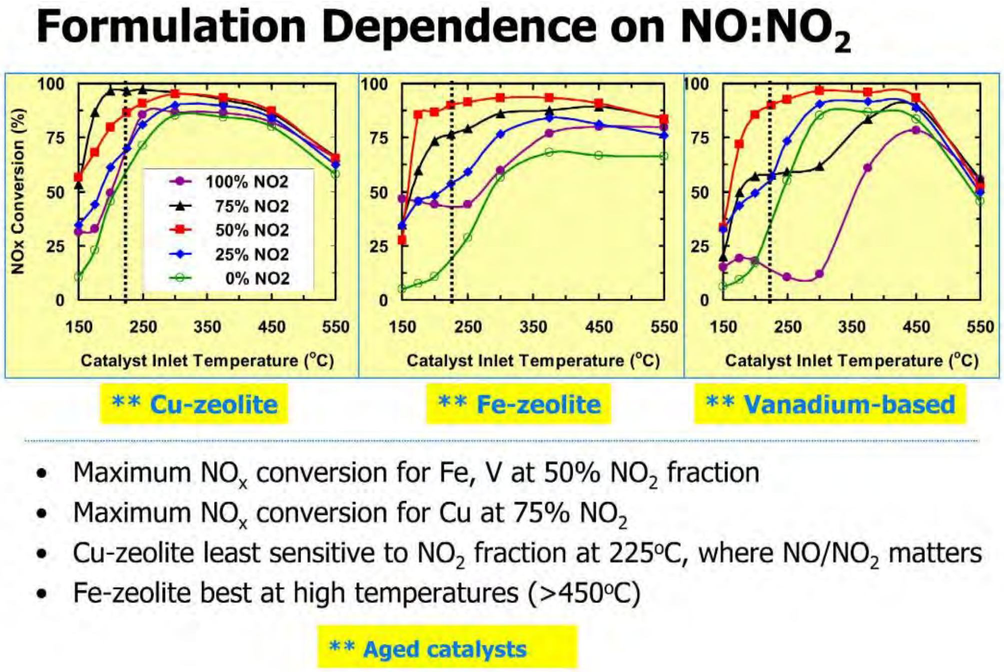
1. Differences in space velocity between the two SCR catalyst systems.
2. Differences in catalyst formulation and/or the supplier of the SCR catalyst system.

For an appropriately sized locomotive SCR system, >80% NO_x conversion for notches 2 through 8 is still possible even with no oxidation of NO to NO2 upstream of the SCR catalyst. Even when taking into consideration that the catalyst in Figure 25 is undersized, it was capable of greater than 75% NO_x conversion with NO_2 as 25% of NO_x and greater than 90% NO_x conversion with NO_2 as 50% of NO_x.

The second point cites NO_2 conversion of only 5-30% at the end of life for a passenger car and then further extrapolates this conversion to near-zero over the life of a locomotive.

Upon reviewing the research in question, it was apparent that the 5 to 30% range referred to average conversion over the light-duty FTP cycle, and that the lower end of the range (5%) referred to results achieved when saturating the catalyst with fuel-hydrocarbons. The graph in Figure 27 is from the same research cited by the stakeholder, and shows the level of reduced effectiveness for NO to NO2 of the up-front DOC in a compact-SCR system. The four conditions plotted on the curve all represent NO to NO_2 oxidation performance at the same level of thermal aging but with increasing injection of hydrocarbons. The lowest NO_2 oxidation levels reported are for a condition during which the catalyst is completely saturated with hydrocarbons from direct fuel injection into the exhaust. Once fuel injection ceased, NO_2 oxidation returned to the efficiency represented by the upper curve on the chart. The test was meant to show how NO_2 oxidation degrades if the catalyst becomes temporarily hydrocarbon saturated during PM trap forced-regeneration or during cold start, and does not represent aged vs. non-aged DOC results for NO_2 oxidation since all of the conditions shown represent approximately the same thermally-aged condition. Furthermore, in the range of post-turbine exhaust temperatures encountered by 4-stroke line-haul locomotive engines in notches 2 through 8 (approximately 275 °C to 450 °C), NO to NO_2 oxidation ranged from approximately 20% to 50%.

Figure 25: A comparison of zeolite-based and vanadium based urea-SCR catalyst formulations at a space velocity of 50,000 hr^{-1} while varying NO_2 as a percentage of NO_x. Adapted from "Evaluation of Supplier Catalyst Formulations for the Selective Catalytic Reduction of NO_x with Ammonia".[61]



Formulation Dependence on NO:NO$_2$

- Maximum NO$_x$ conversion for Fe, V at 50% NO$_2$ fraction
- Maximum NO$_x$ conversion for Cu at 75% NO$_2$
- Cu-zeolite least sensitive to NO$_2$ fraction at 225°C, where NO/NO$_2$ matters
- Fe-zeolite best at high temperatures (>450°C)

** Aged catalysts

Figure 26: NO_x conversion efficiency for an Fe-Zeolite urea-SCR catalyst system while varying NO_2 as a percentage of NO_x.[62] Note that the black line represents the case of NO_x that is 100% NO (0% NO_2).

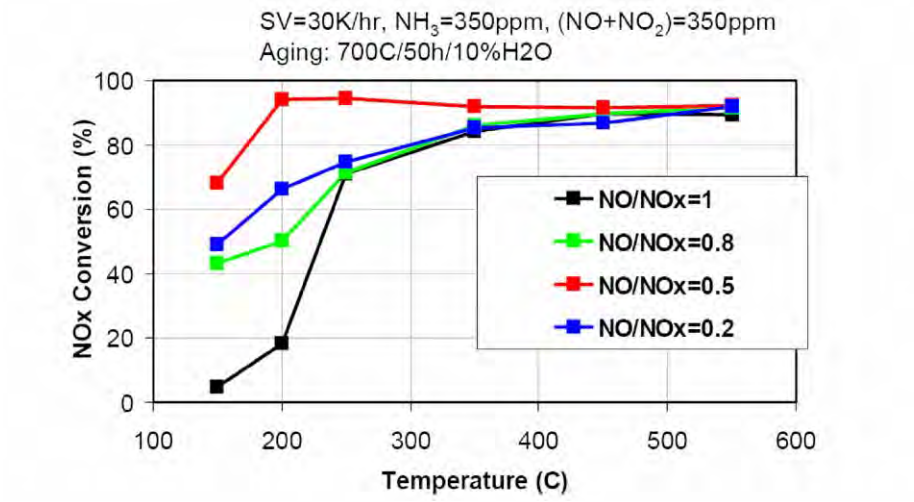


Figure 27: Oxidation of NO to NO_2 using a PGM-containing DOC and increasing levels of direct fuel hydrocarbon injection into the exhaust. Exhaust temperatures representative of operation of a 4-stroke line-haul locomotive are marked in red. Adapted from "Urea SCR and DPF System for Tier 2 Diesel Light-Duty Truck".[35]

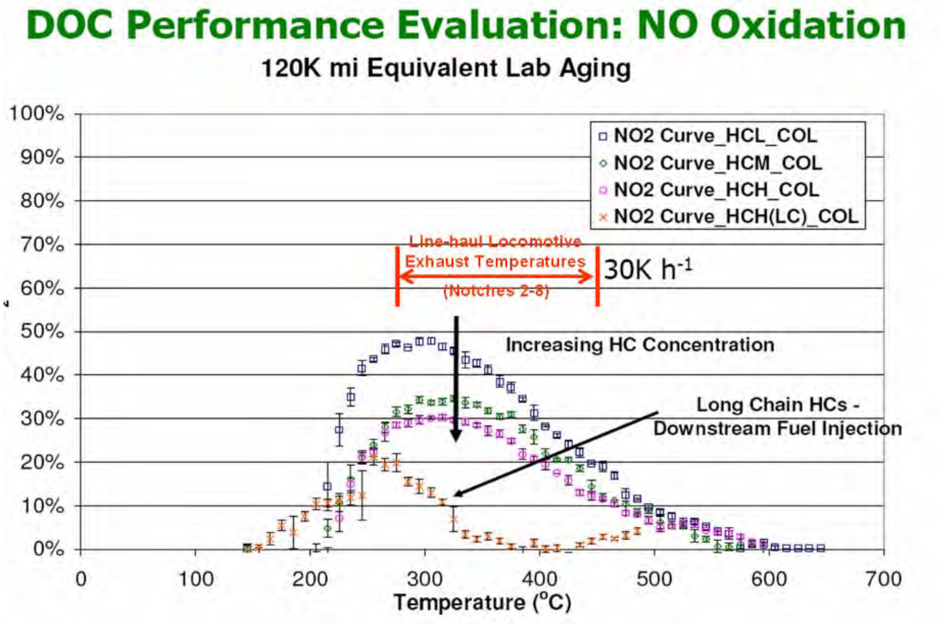


Figure 28 shows SCR system performance from the same work by Ford researchers, which shows greater than 90% NO_x control over exhaust temperatures consistent with locomotive operation in notches 2 through 8. The results shown following 20 hours of thermal aging at 700 °C are approximately representative of the maximum thermal aging that a stakeholder claimed could be encountered during the useful life of a locomotive. The results for 40 hours of thermal aging at 700 °C (or roughly double the thermal conditions encountered due to locomotive consist operation in tunnels) still shows nearly identical NO_x performance to the 20 hour results in the range of temperatures representative of locomotive notches 2 through 8 and are generally consistent with the results shown in Figure 26 at comparable NO_2 as a percentage of NO_x. However, the temperature used for aging is still much higher than what could be achieved even under the most severe locomotive operation. The typical maximum exhaust temperature for a locomotive is 450 °C. During tunnel operation in a consist, a stakeholder claimed that this temperature can reach 700 °C. Recent work by EPA has shown that the peak exhaust temperature encountered during consist operation in non-ventilated tunnels will not exceed 560 °C – 140 degrees less that previously stated.[39] Futhermore, the peak temperature achieved during the EPA testing was limited by the locomotives electronic controls to prevent damage to the engine or locomotive, thus it represents a self-limiting upper bound to in-use post-turbine exhaust temperatures.

Under this lower peak temperature scenario, thermal sintering of the SCR catalyst is diminished, and durability of the system is enhanced, relative to on-highway applications of this technology. Therefore, we do not believe that deterioration of the PM and NOx aftertreatment technologies will be any greater than that stated in our NPRM. Given this recent information, we are confident that locomotive manufacturers will be able to meet the Tier 4 standards by the 2015 implementation date.

Comments from a locomotive manufacturer claimed that operation in tunnels for limited numbers of locomotives could be as high as 50 hours per year.[63] Figure 29 shows NOx conversion and ammonia slip for a combined DPF and Fe-zeolite SCR system before and after 400 hours of engine dynamometer aging. Engine exhaust temperatures at the SCR inlet were elevated to 650 °C using the DPF's forced regeneration system for the entire 400 hour duration.[36] The truck engine used for the tests was a Euro IV configuration with higher engine-out NOx emissions than that of a Tier 2 line-haul locomotive. NOx efficiencies of approximately 85 to 95% were achieved at the end of aging. This would represent thermal degradation beyond the end of useful life even for the limited number of locomotives that operate in unventilated tunnels for 50 hours per year, especially when considering that the temperatures during the aging tests exceeded what could be attained during locomotive operation.

A stakeholder also provided citations to recent SCR durability data generated by the Ford Motor Company during development of combined base-metal zeolite SCR and CDPF emission control systems under development to meet Tier 2 bin 5 standards with future light-duty diesel vehicles. This recent data provided useful insight into the performance characteristics of some base-metal zeolite SCR formulations at temperatures more severe than those that could be attained during locomotive operation.[64,65,66] High temperature hydrothermal aging and aging that combined hydrothermal and wet urea injection effects showed virtually little or no degradation from the fresh condition for temperatures of 670 °C and below.[64,65] Engine durability testing to high hours showed that oil poisoning via deposition of phosphorus, zinc, and calcium compounds was limited to the first 1” to 1.5” from the catalyst face, which is the catalyst substrate region often impacted by direct oil deposition via turbulent diffusion.[66] NOx efficiency downstream of this region was effectively maintained for the duration of the aging tests. The use of a CH-4 lubricant with no limits on chemical properties during the engine durability testing was confirmed for the Ford engine tests at the 2007 DEER Conference in Detroit, Michigan.[67] Considering the chemical limits on zinc, phosphorus, and sulfonated ash specified within the current LMOA-approved locomotive lubricating oils and within the API CJ-4 service category specifications developed for use with aftertreatment-equipped heavy-duty diesels engines, EPA expects even less impact from oil poisoning than was seen during the Ford testing using CH-4 lubricant. The physical layout of the Ford system necessitated by the stringent light-duty Tier 2 cold-start NOx requirements (DOC followed by SCR with CDPF at the rear) also accentuated the impact of oil poisoning on the SCR substrates in a manner that would not occur with systems under development for heavy-duty, nonroad, locomotive or marine applications that typically place the less oil sensitive DOC and CDPF components upstream of the SCR monoliths. Such heavy-duty diesel engine system configurations have demonstrated good durability following extended engine aging using CJ-4 type lubricants.[36,37]

With respect to combined thermal and lubricating oil consumption effects, EPA recently conducted engine dynamometer emissions tests with four different combined DPF and base-metal zeolite SCR systems following engine dynamometer aging for approximately 700 to 1200 hours (hour levels differed among the four systems) at conditions equivalent to locomotive “notch 8”. The operation also included over 100 hours of operation at 580 °C using a forced regeneration system and either 600 to 1100 hours of operation with oil ash accumulation accelerated by a factor of six relative to the ash accumulation expected from normal oil consumption. Modifications were made to the electronic engine management system of a heavy-duty truck engine to provide exhaust temperature and gaseous composition equivalent to that of a Tier 2 GE 7FDL “GEVO” engine at each of the 8 loaded locomotive “throttle notch” positions. SCR catalyst volume for the four systems tested was sized for a maximum space velocity of approximately 40,000 hr^{-1} at the simulated locomotive “throttle notch 8” condition, and exhaust flow was scaled relative to “ throttle notch 8” for the remaining loaded conditions. The tested systems were each configured with a DOC and partial-flow, metal-substrate DPF immediately downstream of the exhaust turbine, followed by a urea dosing system, static mixer, SCR substrates, and an ammonia slip catalysts. SCR NO_x efficiency was assumed to be negligible for the dynamic brake and idle conditions. NOx efficiencies of 85% to 98% were observed for the simulated “notch 2” through “notch 8” conditions following the engine-dynamometer aging procedures (see Figure 30 and Figure 31). This corresponded to emissions of 0.4 to 0.6 g/bhp-hr NOx emissions over the line-haul cycle for the tested systems.[60] Ammonia slip in the exhaust stack outlet did not exceed 10 ppm for any of the tested conditions (Figure 32).

Figure 28: NO_x conversion efficiency with 20% conversion of NO to NO_2 for Fe-Zeolite SCR following different thermal aging conditions. The condition of 20 hours at 700 °C represents a condition with considerably higher temperatures than highest temperatures encountered during line-haul locomotive tunnel operation as part of a consist. Adapted from "Urea SCR and DPF System for Tier 2 Diesel Light-Duty Truck". [35]

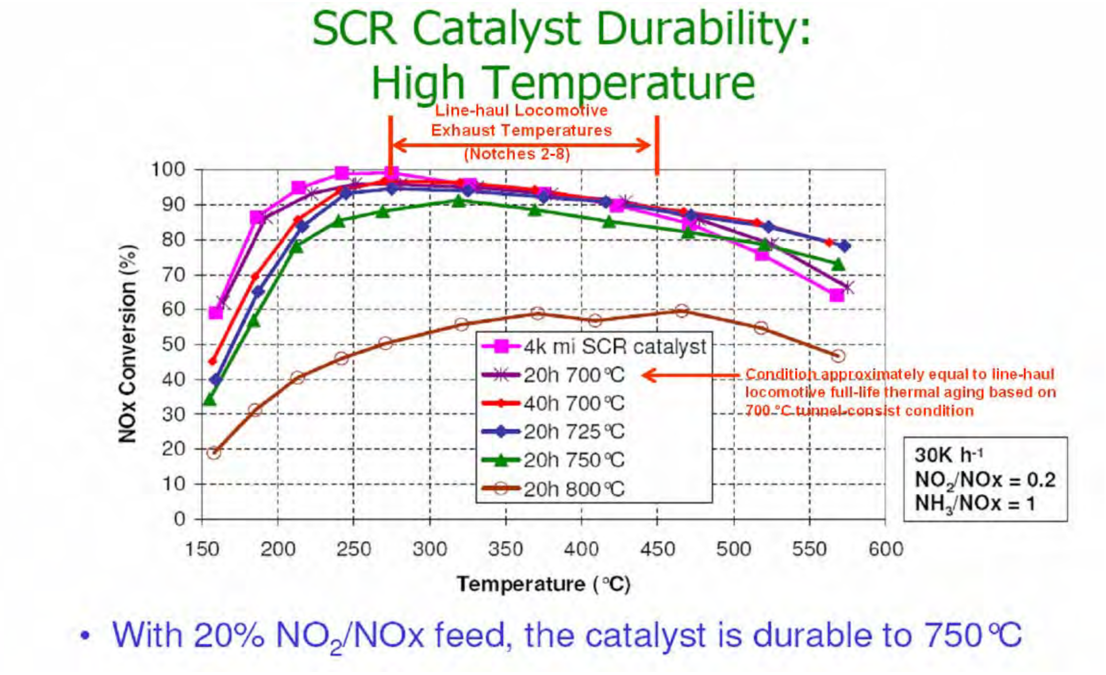


Figure 29: NOx conversion efficiency and NH_3 slip before and after 400 hours of engine dynamometer aging at the SCR inlet of 650 °C using forced DPF regeneration to increase the exhaust temperature, adapted from G. Smedler's presentation at the 2007 SAE Heavy Duty Diesel Emissions Symposium, Gothenburg, Sweden.[36] Testing was conducted with a maximum SCR space velocity of 60,000 hr^{-1} using a high-engine-out NOx Euro IV HD truck engine.

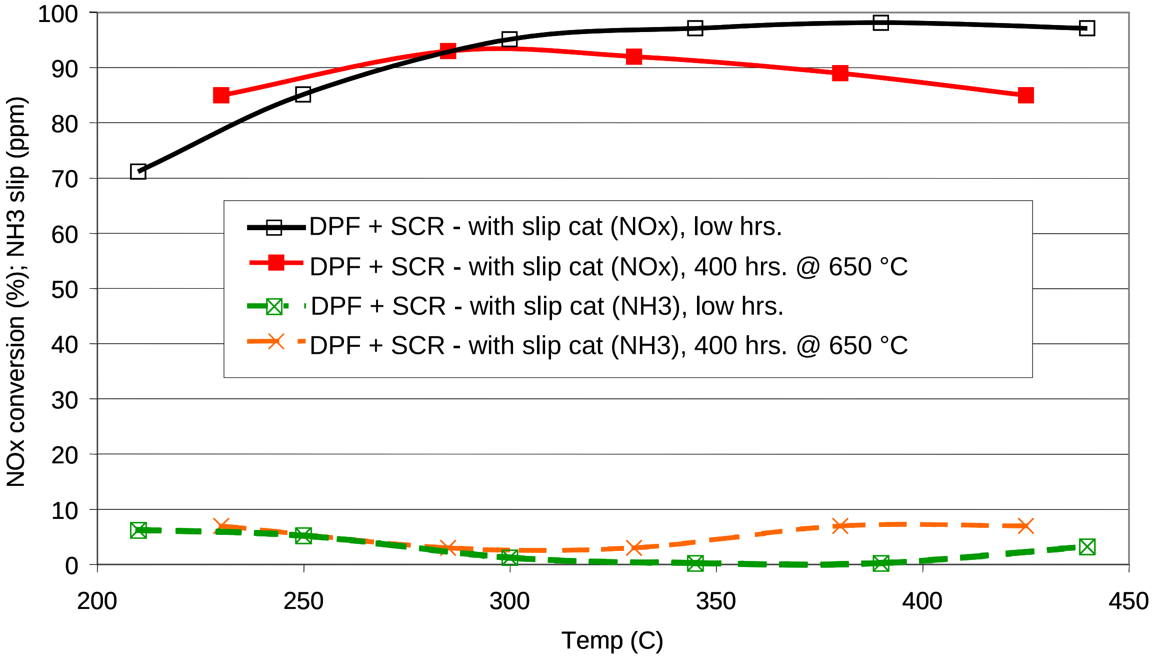


Figure 30: NO_x reduction efficiency for an Fe-zeolite urea SCR systems. Simulated throttle-notch, space velocity and turbine outlet temperature are shown on the X-axis. The 1270-hour point corresponds to 1160 hours of notch 8 operation (390 °C, ~40,000 hr^{-1} space velocity) with oil consumption and ash poisoning accelerated 6-fold and 110 cumulative hours of operation at an elevated temperature of 580 °C. Urea was dosed throughout the hour accumulation. No significant change in line-haul cycle brake specific NO_x emissions was observed for the Fe-zeolite system during hour accumulation.

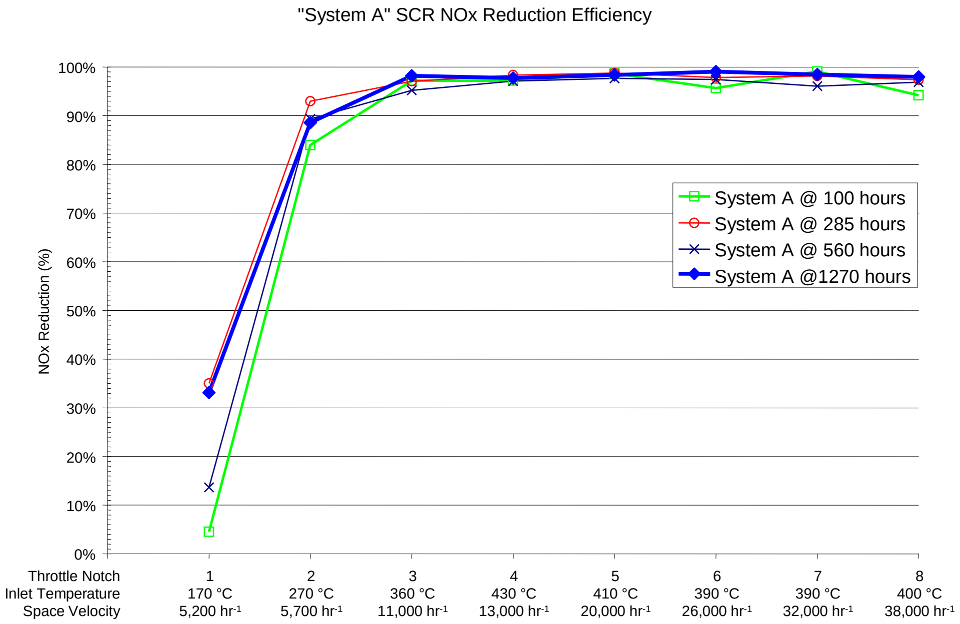


Figure 31: NO_x reduction efficiency for Cu-zeolite urea SCR systems. The 730-hour point corresponds to 610 hours of notch 8 operation (390 °C, ~40,000 hr^{-1} space velocity) with oil consumption and ash poisoning accelerated 6-fold and 100 cumulative hours of operation at an elevated temperature of 580 °C. Urea was dosed throughout the hour accumulation. A significant NOx reduction was observed at the "notch 1" condition at low hours. Reduction at this condition was dependent on NH_3 storage on the catalyst sufaces since urea dosing was only used at conditions of "notch 2" and above. The ability to reduce NOx with stored ammonia at "Notch 1" was less at high hours. NOx reduction over the line-haul cycle at high hours was comparable to the Fe-Zeolite formulation even though SCR catalyst volume was 20% smaller for the Cu-zeolite formulation (note the higher maximum space velocity in Throttle Notch 8).

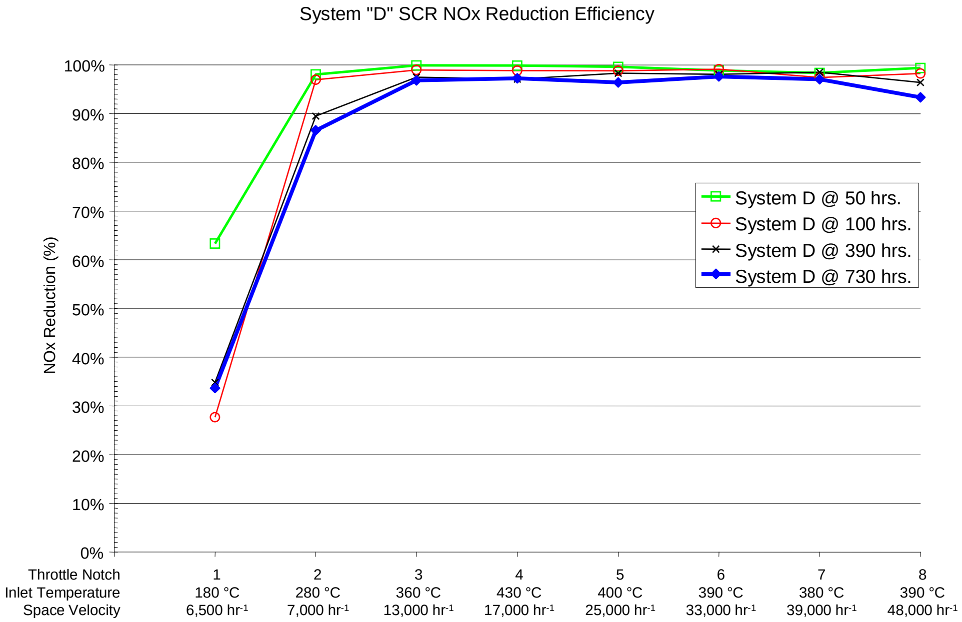
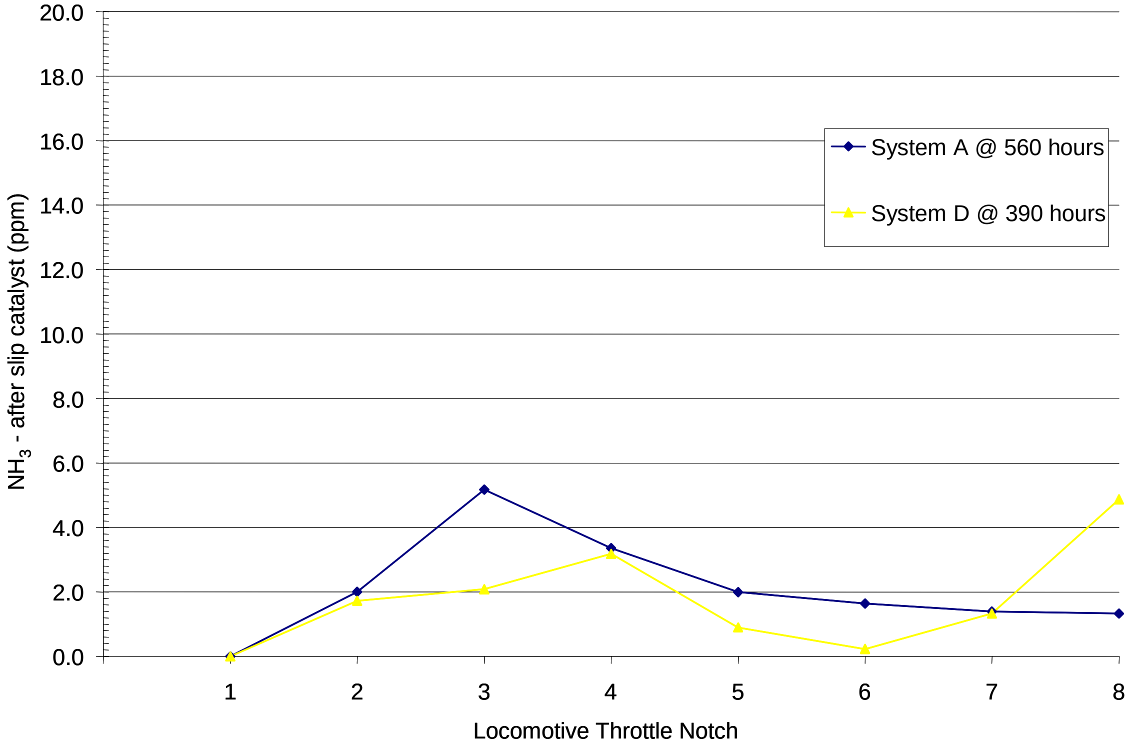


Figure 32: Ammonia slip for each locomotive "throttle notch" condition following hour accumulation for the Fe-zeolite urea SCR system (A) and the Cu-zeolite urea SCR system (D). Each system was configured with an ammonia slip catalyst.



4.3.5.3 Locomotive Parity with the Marine Tier 4 NO_x Standard

The stakeholder also expressed concern that with everything else being equal, a marine engine capable of achieving the 1.3 g/bhp-hr NO_x when tested to the marine duty cycle would only meet 1.7 g/bhp-hr NO_x when tested to the locomotive duty cycle. This would be due primarily to the way that the respective duty cycles used for emissions testing are conducted and weighted. The E3 Marine Duty Cycle operational points have exhaust temperatures that correspond to relatively high NO_x reduction efficiency with urea-SCR catalyst systems. The line-haul locomotive test cycle includes some operational points with exhaust temperatures that may be too low for high SCR NO_x reduction efficiency (low idle, high idle, dynamic brake and Notch 1). But, all things aren't equal. The locomotive emissions test cycle allows adjustments for reduced idle emissions from the new electronic control systems such as "automated start/stop" that we expect to be used by all manufacturers. The Category 2 marine engines that are comparable to, or larger than, line-haul locomotive engines will meet the same 1.3 Tier 4 NO_x standard with SCR three years sooner. They will also be meeting the Tier 4 NO_x standard from a higher engine-out NO_x emissions baseline since many Category 2 Tier 2 Marine engines are currently meeting a 7.3 g/bhp-hr NO_x standard versus current Tier 2 locomotive standard at 5.5 g/bhp-hr NO_x. Thus the Tier 4 standards actually represent a slightly higher 82% NO_x reduction for Tier 4 marine engines vs. 77% for Tier 4 locomotives. Therefore we believe that the Tier 4 NO_x standards for marine diesel engines are appropriate and represent roughly the same level of emissions stringency.

4.4 Feasibility of Marine NTE Standards

Changes to the marine diesel engine NTE standards based upon our understanding of in-use marine engine operation and based upon the underlying Tier 3 and Tier 4 duty cycle emissions standards that we are finalizing. As background, we determine NTE compliance by first applying a multiplier to the corresponding duty-cycle emission standard, and then we compare to that value an emissions result that is recorded when an engine runs within a certain range of engine operation. This range of operation is called an NTE zone. Refer to 40 CFR 94.106 for details on how we currently define this zone and how we currently apply the NTE multipliers within that zone.

Based upon our best information of in-use marine engine operation, we will broaden certain regions of the marine NTE zones, while narrowing other regions. It should be noted that the first regulation of ours that included NTE standards was the commercial marine diesel regulation, finalized in 1999. After we finalized that regulation, we promulgated other NTE regulations for both heavy-duty on-highway and nonroad diesel engines. We also finalized a regulation that requires heavy-duty on-highway engine manufacturers to conduct field testing to demonstrate in-use compliance with the on-highway NTE standards. Throughout our development of these other regulations, we have learned many details about how best to specify NTE zones and multipliers that help ensure the greatest degree of in-use emission control, while at the same time help avoid disproportionately stringent requirements for engine operation that has only a minor contribution to an engine's overall impact on the environment. Specifically, we are broadening the NTE zones in order to better control emissions in regions of engine operation where an engine's emissions rates (i.e. grams/hour, tons/day) are greatest; namely at high engine speed and high engine load. This is especially important for controlling emissions from commercial marine engines because they typically operate at steady-state at high-speed and high-load. This also will make our marine NTE zones much more similar to our on-highway and nonroad NTE zones.

Additionally, we analyzed different ways to define the marine NTE zones, and we determined a number of ways to improve and simplify the way we define and calculate the borders of these zones. We feel that these improvements will help clarify when an engine is operating within a marine NTE zone. We are also finalizing NTE zones for auxiliary marine engines for both Tier 3 and Tier 4 standards. Because these engines are very similar to constant-speed nonroad engines, we will adopt the same NTE provisions for auxiliary marine engines that have already been adopted for constant-speed nonroad engines. Note that we currently specify different duty cycles to which a marine engine may be certified, based upon the engine's specific application (e.g., fixed-pitch propeller, controllable-pitch propeller, constant speed, etc.). Correspondingly, we also have a unique NTE zone for each of these duty cycles. These different NTE zones are intended to best reflect an engine's real-world range of operation for that particular application. Refer to the figures in 40 CFR Part 1042, Appendix III, for illustrations of the changes we are finalizing as part of this rulemaking.

We are also including changes to the NTE multipliers. We have analyzed how the Tier 3 and Tier 4 emissions standards will affect the stringency of our current marine NTE standards, especially in comparison to the stringency of the underlying duty cycle standards. We recognized that in certain sub-regions of our NTE zones, slightly higher multipliers are necessary because of the way that our more-stringent Tier 3 and Tier 4 emissions standards affect the stringency of the NTE standards. For comparison, our current marine NTE standards contain multipliers that range in magnitude from 1.2 to 1.5 times the corresponding duty cycle standard. In the changes we have finalized, the new multipliers range from 1.2 to 1.9 times the standard. Refer to the figures in 40 CFR Part 1042, Appendix III, for illustrations of the changes we are finalizing.[68]

We are also adopting other NTE provisions for marine engines that are similar to our existing heavy-duty on-highway and nonroad diesel NTE standards. These particular changes to account for the implementation of catalytic exhaust aftertreatment devices on marine engines and to account for when a marine engine rarely operates within a limited region of the NTE zone.

Aftertreatment systems generally utilize metallic catalysts, which become highly efficient at treating emissions above a minimum exhaust temperature. For the most commonly used metallic catalysts, this minimum temperature occurs in the range of about (150 to 250) °C. In our recent on-highway and nonroad regulations, we identified NO_x adsorber-based aftertreatment technology as the most likely type of technology for on-highway and nonroad NO_x aftertreatment. This NO_x adsorber technology utilizes barium carbonate metals that become active and efficient at temperatures at or above 250 °C. Also, in our on-highway and nonroad rulemakings we identified platinum and platinum/palladium diesel oxidation catalyst technology for hydrocarbon emission control. This technology also becomes active and efficient at temperatures at or above 250 °C. Therefore, in our on-highway and nonroad rulemakings for NO_x and hydrocarbons emissions, we set a lower exhaust temperature NTE limit of 250 °C, as measured at the outlet of the last aftertreatment device. We only considered engine operation at or above this temperature as potential NTE operation.

For marine applications we have hydrocarbon aftertreatment emission control technology similar to that used in on-highway engines (i.e. diesel oxidation catalyst or DOC). However, we have identified different aftertreatment technology for NO_x control, as compared to our on-highway and nonroad rulemakings. Specifically, we have identified selective catalytic reduction (SCR) NO_x control technology, which we discussed in detail earlier in this chapter. We believe that the performance of this different technology needs to be considered in setting the proper exhaust temperature limits for the marine NTE standards. While some testing has shown that it is possible to dose urea when exhaust temperatures are as low as 150 °C, the majority of SCR applications require a minimum exhaust gas temperature of 250 °C for effective urea hydrolysis.[50] That is why our NTE standards for both NO_x and HC will remain consistent with our on-highway and nonroad regulations (see 40 CFR 86.1370-2007 (g)) and apply only when exhaust gas temperatures are equal to or greater than 250 °C, as measured within 12 inches of the outlet of the aftertreatment device.

4.5 Lead Time

In selecting the models years for which each of the new standards will begin, we sought to apply them as soon as possible considering the amount of lead time needed by the manufacturers to design, evaluate, and certify the modified or new engines. For marine engines, this was relatively straightforward, since most marine engines have land-based counterparts that are already scheduled to be subject to new standards. In general, the marine standards closely follow the land-based standards.

With respect to the amount of lead time needed to develop new locomotive designs, it is helpful to consider how locomotive development compares to the development process for highway truck engines and high-speed nonroad diesel engines. For these other categories, we generally provide the manufacturers at least four years of lead time to develop new engines, and even more when it requires a major technological shift. For both categories, when adopting our Tier 4 standards that required the addition of catalysts, we provided approximately nine years of lead time between the time the standards were adopted and the first model year the NOx and PM standards had to be fully met (from 2001 to 2010 for heavy-duty trucks and from 2004 to 2014 for nonroad equipment).

While locomotive manufacturers will benefit to some degree from the transfer of technologies from these categories, there are two key factors that will offset these advantages. First, locomotive manufacturers have more limited engineering resources and testing facilities, and they will need to use these resources to redesign their locomotives to meet the Tier 4 standards at the same time that they are developing lower emission kits for their Tier 0, 1 and 2 locomotives. Locomotive manufacturers generally have research staffs of a few dozen engineers and have a handful of test cells. For comparison, highway truck engine manufacturers typically have thousands of engineers and dozens of test cells. Equally important, the long useful lives and heavy normal use patterns for locomotives means that merely proving the durability of new designs can take more than three years even in the best case.

For these reasons, we believe that 2015 is the earliest that we can apply catalyst-based Tier 4 standards for locomotives. Moreover, we believe that by requiring compliance this soon, we also need to adopt the interim flexibilities described in §1033.150. This timing will allow manufacturers to finalize their designs over the next few years and perform field testing before 2015. Since manufacturers are much closer to having their Tier 3 locomotive designs ready for field testing, those standards can begin in 2012, and those technologies can be retrofitted to Tier 2 locomotives the following year. Finally, we do not believe that field testing will be required for the Tier 0 and Tier 1 technologies, so those standards can begin by 2010.

4.6 Conclusions

Even though this rulemaking covers a wide range of engines - and thus requires the implementation of a range of emission controls technologies - we believe we have identified a range of technologically feasible emission control technologies that likely will be used to meet standards. Some of these technologies are incremental improvements to existing engine components, and many of these improved components have already been applied to similar engines. The other technologies we identified involve catalytic exhaust aftertreatment systems. For these technologies we carefully examined the catalyst technology, its applicability to locomotive and marine engine packaging constraints, its durability with respect to the lifetime of today’s locomotive and marine engines, its impact on the infrastructure of the rail and marine industries, and the safety of its use. From our analysis, based upon numerous data from automotive, truck, locomotive, and marine industries, we conclude that incremental improvements to engine components and the implementation of catalytic PM and NO_x exhaust aftertreatment technology are technologically feasible for locomotive and marine applications, and thus can be used to meet the emissions standards finalized in this rulemaking.

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[57] Ming, C. et al., "Modelling and Optimization of SCR-Exhaust Aftertreatment Systems," SAE 2005-01-0969, 2005.

[58] "SCR Technology for NOx Reduction: Series Experience and State of Development," presented by Manuel Hesser, 11th DEER Conference, August 2005.

[59] "LNT or Urea SCR Technology: Which is the right technology for TIER 2 BIN 5 passenger vehicles?," presented by Richard Dorenkamp, 12th DEER Conference, August 2006.

[60] McDonald, J. "EPA Evaluation of Base-metal Zeolite Urea SCR Systems." This document is available in Docket EPA-HQ-OAR-2003-0190.

[61] "Evaluation of Supplier Catalyst Formulations for the Selective Catalytic Reduction of NOx with Ammonia", Presented by Steven J. Schmieg and Jong H. Lee at the U.S. DOE 9th CLEERS Workshop, May 2-5, 2006.

[62] Data provided to the U.S. EPA by Johnson Matthey Catalytic Systems Division, November 6, 2006.

[63] "Comments of General Electric Transportation on Proposed Rule Regarding Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder," page A-9. This document is available in Docket EPA-HQ-OAR-2003-0190-0590.1

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[67] Lambert, C. "Post-Mortem of DOC-SCR-DPF System for Tier 2 Light-Duty Diesel Truck." Presentation at the 2007 Diesel Engine-Efficiency & Emissions Research Conference, August 14, 2007.

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CHAPTER 5: Engineering Cost Estimates

This chapter presents the engine and equipment engineering costs we have estimated for meeting the new engine emissions standards.[A] Section 5.1 includes a brief outline of the methodology used to estimate the engine and equipment costs. Sections 5.2 and 5.3 present the projected costs of the individual technologies we expect manufacturers to use to comply with the new emissions standards, along with a discussion of fixed costs such as research, tooling, certification, and equipment/vessel redesign. Section 5.4 presents our estimate of changes in the operating costs that would result from the program and section 5.5 presents costs associated with the locomotive and marine remanufacturing programs. Section 5.6 summarizes these costs and presents the total program costs. Section 5.7 presents our analysis of the potential of costs and savings associated with idle reduction technology. Section 5.8 presents our analysis of energy effects and section 5.9 presents our cost-effectiveness calculations associated with the costs presented in sections 5.2 through 5.6.

To maintain consistency in the way our emission reductions, costs, and cost-effectiveness estimates are calculated, our cost methodology relies on the same projections of locomotive and marine engine growth as those used in our emissions inventory projections. Our emission inventory analyses for marine engines and for locomotives include estimates of future engine populations that are consistent with the future engine sales used in this cost analysis.

Note that the costs here do not reflect changes to the fuel used to power locomotive and marine engines. Our Nonroad Tier 4 rule controlled the sulfur level in all nonroad fuel, including that used in locomotives and marine engines.[B] The sulfur level in the fuel is a critical element of the locomotive and marine program. However, since the costs of controlling locomotive and marine fuel sulfur have been considered in our Nonroad Tier 4 rule, they are not considered here. This analysis considers only those costs associated with the locomotive and marine program.

Additionally, the costs presented here do not reflect any savings that are expected to occur because of the engine ABT program and the various flexibilities included in the program. These program features have the potential to provide savings for both engine and locomotive/vessel manufacturers. While we fully expect companies to use them to reduce compliance costs, we do not factor them into the cost analysis because they are voluntary programs. This analysis of compliance costs relates to regulatory requirements that are part of the final rule for Tiers 3 and 4 emissions standards for locomotive and marine engines. Unless noted otherwise, all costs are in 2005 dollars.

[A] We use the term "engineering costs" to differentiate from "social costs." Social costs are discussed in Chapter 7 of this final RIA. For simplicity, the terms "cost" and "costs" throughout the discussion in this Chapter 5 should be taken as referring to "engineering costs."

[B] See the Regulatory Impact Analysis for the Nonroad Tier 4 final rule, EPA420-R-04-007, May 2004.

5.1 Methodology for Estimating Engine and Equipment Engineering Costs

This analysis makes several simplifying assumptions regarding how manufacturers will comply with the new emission standards. First, for each tier of emissions standards within a given category of engine, we assume a single technology recipe. For example, all Tier 4 engines in the locomotive category are estimated to be fitted with a selective catalytic reduction (SCR) system, a diesel particulate filter (DPF), and a diesel oxidation catalyst (DOC). However, we expect that each manufacturer will evaluate all possible technology avenues to determine how to best balance costs while ensuring compliance. As noted, for developing cost estimates, we have assumed that the industry does not make use of the averaging, banking, and trading program, even though this program offers industry the opportunity for significant cost reductions. Given these simplifying assumptions, we believe the projections presented here overestimate the costs associated with different compliance approaches manufacturers may ultimately take.

Through our background work for this locomotive and marine rule, our past locomotive and marine rules, and our recent highway and nonroad diesel rules, we have sought input from a large section of the regulated community regarding the future costs of applying the emission control technologies expected for diesel engines within the context of this final program. Under contract with EPA, ICF International (formerly ICF Consulting) provided questions to several engine and parts manufacturers regarding costs associated with emission control technologies for diesel engines. The responses to these questions were used to estimate costs for "traditional" engine technologies such as EGR, fuel-injection systems, and for marinizing systems for use in a marine environment.[1,2]

Costs for exhaust emission control devices (e.g., catalyzed DPFs, SCR systems, and DOCs) were estimated using the methodology used in our 2007 heavy-duty highway rulemaking. In that rulemaking effort, surveys were provided to nine engine manufacturers seeking information relevant to estimating the costs for and types of emission-control technologies that might be enabled with low-sulfur diesel fuel. The survey responses were used as the first step in estimating the costs for advanced emission control technologies anticipated for meeting the 2007 heavy-duty highway standards. We then built upon these costs based on input from members of the Manufacturers of Emission Controls Association (MECA). We also used this approach as the basis for estimating costs for our recent nonroad tier 4 (NRT4) rulemaking effort. Because the anticipated emission control technologies for use on locomotive and marine engines are the same as, or similar to, those expected for highway and nonroad engines, and because the suppliers of the technologies are the same for of these engines, we have used that analysis as the basis for estimating the costs of these technologies in this rulemaking.[3]

Costs of control include variable costs (for new hardware, its assembly, and associated markups) and fixed costs (for tooling, research, redesign efforts, and certification). For technologies sold by a supplier to the engine manufacturers, costs are either estimated based on a direct cost to manufacture the system components plus a 29 percent markup to account for the supplier's overhead and profit or, when available, based on estimates from suppliers on expected total costs to the manufacturers (inclusive of markups).[4] Estimated variable costs for new technologies include a markup to account for increased warranty costs. Variable costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer carrying cost—estimated to be four percent of the direct costs—accounts for the capital cost of the extra inventory and the incremental costs of insurance, handling, and storage. The dealer carrying cost—estimated to be three percent of their direct costs—accounts for the cost of capital tied up in extra inventory. We adopted this same approach to markups in the 2007 heavy-duty highway rule and the NRT4 rule, based on industry input.[5]

We have also identified various factors that cause costs to decrease over time, making it appropriate to distinguish between near-term and long-term costs. Research on 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. This analysis incorporates the effects of this learning curve as described in Section 5.2.2.[6]

Fixed costs for engine research are estimated to be incurred over the five-year period preceding introduction of the engine. Fixed costs for engine tooling and certification are estimated to be incurred one year ahead of initial production. Fixed costs for equipment redesign are also estimated to be incurred one year ahead of production. We have also included lifetime operating costs where applicable. These include costs associated with fuel consumption impacts and urea use, and increased maintenance demands resulting from the addition of new emission-control hardware. We have also included incremental costs associated with an increase in remanufacturing costs due to the inclusion of additional hardware as part of the remanufactured engine.

A simplified overview of the methodology used to estimate engine and equipment costs is as follows:

- For engine research, we have estimated the total dollars that we believe each engine manufacturer will spend on research to make DPF and SCR systems work together. We refer to such efforts as corporate research. Also for engine research, we have estimated the dollars spent to tailor the corporate research to each individual engine line in the manufacturer’s product mix. We refer to such efforts as engine-line research.

- For engine-related tooling costs, we have estimated the dollars that we believe each engine manufacturer will spend on tooling for each of its engine lines. This amount varies depending on whether the manufacturer makes only locomotive and/or marine engines or also makes highway and/or nonroad engines. This amount also varies depending on the emissions standards to which the engine line is certified (i.e., Tier 3 or 4).

- For engine variable costs (i.e., emission-control hardware), we use a three-step approach:

- First, we estimate the cost per piece of technology/hardware. As described in detail in Section 5.2.2, emission-control hardware costs tend to be directly related to engine characteristics—for example, most emission control devices are sized according to engine displacement so costs vary by displacement. Because of this relationship, we are able to determine a variable cost equation as a function of engine displacement.

- Second, we determine a sales weighted baseline technology package using a database from Power Systems Research of all locomotive and marine engines sold in the United States.[7] That database lists engine characteristics for every one of over 40,000 locomotive and marine engines sold in the United States in any given year. Using the baseline engine characteristics of each engine, the projected technology package for that engine, and the variable cost equations described in Section 5.2.2, we calculate a variable cost for the sales weighted average engine in each of several different engine categories.

- Third, this weighted average variable cost is multiplied by the appropriate projected sales in each year after the new standards take effect to give total annual costs for each engine category. The sum total of the annual costs for all engines gives the fleetwide variable costs per year.

- Equipment related costs—i.e., marine vessels or locomotives—are generated using the same methodology to estimate the fixed costs for equipment redesign efforts and the variable costs for new brackets, bolts, and sheet metal that we expect will be required.

This chapter addresses a number of costs including: Engine costs – fixed costs then variable costs; equipment costs – fixed costs then variable costs; and, operating costs – urea, maintenance, and fuel consumption impacts; and, remanufacturing program costs. A summation of these costs is presented in Section 5.6. Variable cost estimates for both engines and equipment represent an expected incremental cost of the engine or piece of equipment in the model year of introduction. Variable costs per engine decrease in subsequent years as a result of several factors, as described below, although these factors do not apply to equipment variable costs. All costs are presented in 2005 dollars.

5.2 Engineering Costs for Freshly Manufactured Engines

5.2.1 Fixed Engineering Costs

Engine fixed costs consist of research, tooling, and certification. For these costs, we have made a couple of simplifying assumptions with regard to the timing of marine-related expenditures due to the complexity of the roll out of the marine engine standards. We have estimated that, in general, the marine engine fixed costs would be incurred during the years prior to 2012 (for Tier 3 related costs) and 2016 (for Tier 4 related costs). While this approach impacts the timing of marine-related expenditures and, thus, the annual costs during the early years of implementation, it has no impact on the total costs we would estimate in association with the new standards. However, while having no impact on the total costs we estimate would be incurred, this approach does have a very minor impact on the net present value of costs since some early costs (e.g., those for <75 kW Tier 3 engines and >3,700 kW Tier 4 NO_x) are effectively pushed back a couple of years. We believe that the approach taken makes it easier to follow the presentation of costs while having no impact on the results of the analysis.

5.2.1.1 Engine and Emission Control Device Research

As noted, we estimate costs for two types of engine research—corporate research, or that research conducted by manufacturers using test engines to learn how NO_x and PM control technologies work and how they work together in a system; and, engine line research, or that research done to tailor the corporate knowledge to each particular engine line. For the Tier 3 standards, we are estimating no corporate research since the technologies expected for Tier 3 are "existing" technologies and are well understood. However, we have estimated engine-line research associated with Tier 3 since those technologies will still need to be tailored to each engine-line. For Tier 4, we have estimated considerable corporate research since the technologies expected for Tier 4 are still considered "new" technologies in the diesel engine market. We have also estimated more engine-line research for Tier 4 so that the corporate research may be tailored to each engine.

We start this discussion with the more global corporate research. The technologies described in Chapter 4 represent those technologies we believe will be used to comply with the new emission standards. These technologies are also part of an ongoing research and development effort geared toward compliance with the 2007 heavy-duty highway and the nonroad Tier 4 standards and, to some extent, the current and future light-duty diesel vehicle standards in the US and Europe. Those engine manufacturers making research expenditures toward compliance with either highway or nonroad emission standards will have to undertake some research effort to transfer emission-control technologies to engines they wish to sell into the locomotive and/or marine markets. These research efforts will allow engine manufacturers to develop and optimize these new technologies for maximum emission control effectiveness, while continuing to design engines with good performance, durability, and fuel efficiency characteristics. However, many engine manufacturers are not part of the ongoing research effort toward compliance with highway and/or nonroad emission standards because they do not sell engines into the highway or nonroad markets. These manufacturers–i.e., the locomotive/marine-only manufacturers–are expected to learn from the research work that has already occurred and will continue through the coming years through their contact with highway and nonroad manufacturers, emission-control device manufacturers, and the independent engine research laboratories conducting relevant research. Despite these opportunities for learning, we expect the research expenditures for these loco/marine-only manufacturers to be higher than for those manufacturers already conducting research in response to the highway and nonroad rules.

We are projecting that SCR systems and DPFs will be the most likely technologies used to meet the new Tier 4 emission standards. Because these technologies are being researched for implementation in the highway and nonroad markets well before the locomotive and marine emission standards take effect, and because engine manufacturers will have had several years complying with the highway and nonroad standards, we believe that the technologies used to comply with the locomotive and marine Tier 4 standards will have undergone significant development before reaching locomotive and marine production. This ongoing research will likely lead to reduced costs in three ways. First, we expect research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission-control technologies than we would predict today, given the current state of development. Second, we anticipate that the continuing efforts to improve the emission-control technologies will include innovations that allow lower-cost production. And finally, we believe manufacturers will focus research efforts on any drawbacks, such as fuel economy impacts or maintenance costs, in an effort to minimize or overcome any potential negative effects.

We anticipate that manufacturers will introduce a combination of primary technology upgrades to meet the new emission standards. Achieving very low NO_x emissions requires basic research on NO_x emission-control technologies and improvements in engine management. Manufacturers are expected to address this challenge by optimizing the engine and exhaust emission-control system to realize the best overall performance. This will entail optimizing the engine and emission control system for both emissions and fuel economy performance in light of the presence of the new exhaust emission control devices and their ability to control pollutants previously controlled only via in-cylinder means or with exhaust gas recirculation. The NO_x control technology in particular is expected to benefit from re-optimization of the engine management system to better match the NO_x catalyst's performance characteristics. The majority of the dollars we have estimated for corporate engine research is expected to be spent on developing this synergy between the engine and NO_x exhaust emission-control systems. Therefore, for engines where we project use of exhaust aftertreatment devices, we have attributed two-thirds of the research expenditures to NO_x+NMHC control, and one-third to PM control. This approach is consistent with that taken in our 2007 heavy-duty highway and NRT4 rules.

To estimate corporate research costs, we begin with our 2007 heavy-duty highway rule. In that rule, we estimated that each engine manufacturer would expend $35 million for corporate research toward successfully implementing diesel particulate filters (DPF) and NO_x control catalysts. For this locomotive/marine analysis, we express all monetary values in 2005 dollars which means our starting point equates to just under $39 million.[8] For their locomotive/marine research efforts, engine manufacturers that also sell into the highway and/or nonroad markets will incur some level of research expense but not at the level incurred for the highway rule. In many cases, the engines used by highway/nonroad manufacturers in marine products are based on the same engine platform as those engines used in their highway/nonroad products. This is also true for locomotive switchers. However, power and torque characteristics are often different, so manufacturers will need to expend some effort to accommodate those differences. For these manufacturers, we assume that they will incur an average corporate research expense of roughly $4 million. This $4 million expense allows for the transfer of learning from highway/nonroad research to their locomotive/marine engines. For reasons noted above, two-thirds of this money is attributed to NO_x+NMHC control and one-third to PM control.

For those engine manufacturers that sell engines only into the locomotive and/or marine markets, and where those engines will be meeting the new Tier 4 standards, we believe they will incur a corporate research expense approaching that incurred by highway manufacturers for the 2007 highway rule although not quite at the same level. These manufacturers will be able to learn from the research efforts already underway for both the

2007 highway and nonroad Tier 4 rules (66 FR 5002 and 69 FR 38958, respectively), and for the Tier 2 light-duty highway rule (65 FR 6698) and analogous rules in Europe. This learning may come from seminars, conferences, technical publications regarding diesel engine technology (e.g., Society of Automotive Engineers technical papers), and contact with highway manufacturers, emission-control device manufacturers, and the independent engine research laboratories conducting relevant research. In the NRT4 rule, we estimated that this learning would result in nonroad-only manufacturers incurring 70 percent of the expenditures as highway manufacturers for the 2007 highway rule. Similarly, we would expect that locomotive/marine-only manufacturers would incur that same 70 percent of the expenditures incurred by highway manufacturers for the 2007 highway rule. This number—roughly $27 million versus $39 million in the highway rule—reflects the transfer of knowledge to locomotive/marine-only manufacturers from the many stakeholders in the diesel industry. Two-thirds of this corporate research is attributed to NO_x+NMHC control and one-third to PM control.

The $4 million and $27 million estimates represent our estimate of the average corporate research expenditures for engine manufacturers. Any particular manufacturer may incur more or less than these average figures.

These corporate research estimates are outlined in Table 5-1.

Table 5-1 Estimated Corporate Research Expenditures by Type of Engine Manufacturer Totals per Manufacturer over Five Years ($Million, 2005 dollars)

	Manufacturer sells only Tier 3 engines	Manufacturer sells Tier 4 engines
Manufacturer sells into highway and/or nonroad markets	$0	$4
Manufacturer sells only into locomotive and/or marine markets	$0	$27
% allocated to PM	n/a	33%
% allocated to NO_X+NMHC	n/a	67%

Note: Since we expect that the majority of the costs we have estimated for corporate engine research would be spent on developing the synergy between the engine and NO_X exhaust emission-control systems, we have attributed two-thirds of the corporate research expenditures to NO_X+NMHC control and one-third to PM control.

The PSR database shows that there were 47 engine manufacturers that sold engines into the locomotive and marine markets in 2002. Of these 47, 12 sold engines into the market segments required to meet the Tier 4 standards (i.e., expected to need exhaust aftertreatment devices and, therefore, need to conduct this research). Of those 12, three sold exclusively into the locomotive and/or marine markets, while the other nine sold engines into the highway and/or nonroad markets in addition to the locomotive and/or marine markets. As a result, we estimate that three manufacturers will need to spend the full $27 million conducting research and nine will spend $4 million, for a total corporate research expenditure of just under $117 million.

Further, six of these 12 manufacturers sold into both the locomotive and marine markets and, therefore, will spend a portion of their corporate research dollars during the five years prior to 2015 (to support locomotive engines), and a portion during the five years prior to 2016 (to support marine engines). Of the six remaining manufacturers, five sold only into the marine market so will spend their dollars during the five years prior to 2016. The remaining manufacturer sold only into the locomotive switcher market and will spend its corporate research dollars during the five years prior to 2015. Further allocation of corporate research into marine C1, marine C2, locomotive switcher, and locomotive line-haul segments based on the segments into which each manufacturer sold in 2002 results in the total corporate research expenditures by market segment shown in Table 5-2. We then spread these costs over the five years in advance of the applicable standards to get the annual costs shown in Table 5-3. Note that the corporate research expenditures for manufacturers that sell into both the locomotive line-haul and marine C2 categories are split equally between those two categories. The same approach is taken for those manufacturers that sell engines across other categories.

Table 5-2 Estimated Corporate Research Expenditures Allocated by Market Segment ($Million, 2005 dollars)

Market Segment	Total Corporate Research Expenditure	PM	NO_X+NMHC
Locomotive Switcher/Passenger	$ 10.4	$ 3.4	$ 7.0
Locomotive Line-Haul	$ 27.2	$ 9.0	$ 18.2
Marine C1	$ 45.4	$ 15.0	$ 30.4
Marine C2	$ 33.7	$ 11.1	$ 22.6
Total Industry Expenditure	$ 116.6	$ 38.5	$ 78.1

Notes: Since we expect that the majority of the dollars we have estimated for corporate engine research would be spent on developing the synergy between the engine and NO_X exhaust emission-control systems, we have attributed two-thirds of the corporate research expenditures to NO_X+NMHC control and one-third to PM control.

Table 5-3 Estimated Corporate Research Expenditures by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive Switchers			Locomotive Line-Haul			Marine C1			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006															
2007															
2008															
2009															
2010	$0.7	$1.4	$2.1	$1.8	$3.6	$5.4							$7.5	$2.5	$5.0
2011	$0.7	$1.4	$2.1	$1.8	$3.6	$5.4	$3.0	$6.1	$9.1	$2.2	$4.5	$6.7	$23.3	$7.7	$15.6
2012	$0.7	$1.4	$2.1	$1.8	$3.6	$5.4	$3.0	$6.1	$9.1	$2.2	$4.5	$6.7	$23.3	$7.7	$15.6
2013	$0.7	$1.4	$2.1	$1.8	$3.6	$5.4	$3.0	$6.1	$9.1	$2.2	$4.5	$6.7	$23.3	$7.7	$15.6
2014	$0.7	$1.4	$2.1	$1.8	$3.6	$5.4	$3.0	$6.1	$9.1	$2.2	$4.5	$6.7	$23.3	$7.7	$15.6
2015							$3.0	$6.1	$9.1	$2.2	$4.5	$6.7	$15.8	$5.2	$10.6
2016															
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Total	$3.4	$7.0	$10.4	$9.0	$18.2	$27.2	$15.0	$30.4	$45.4	$11.1	$22.6	$33.7	$116.6	$38.5	$78.1
NPV at 7%	$2.1	$4.3	$6.5	$5.6	$11.4	$17.0	$8.8	$17.8	$26.5	$6.5	$13.2	$19.7	$69.7	$23.0	$46.7
NPV at 3%	$2.8	$5.7	$8.4	$7.3	$14.8	$22.1	$11.8	$24.0	$35.8	$8.8	$17.8	$26.6	$93.0	$30.7	$62.3

As shown in Table 5-3, the net present value of the corporate research is estimated at $93 million using a three percent discount rate, and $70 million using a seven percent discount rate.[C] We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-4.

Table 5-4 Estimated Corporate Research per Engine (2005 dollars)

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 8.4	3,212	$ 2,630
Locomotive Line Haul	$ 22.1	19,453	$ 1,140
Marine C1 >600 kW	$ 35.8	20,039	$ 1,790
Marine C2	$ 26.6	6,647	$ 4,000
Total	$ 93.0	49,352	$ 1,880

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

For engine line research—those engine research efforts done to tailor the corporate research to each particular engine line—we have first determined the number of engine lines by considering that, typically, the same basic diesel engine design can be increased or decreased in size by simply adding or subtracting cylinders. As a result, a four-, six-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer's engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be one engine line. Doing this, we found there to be 88 engine lines that will need Tier 3 engine line research and 31 engine lines that will need Tier 4 engine line research. Of the 88 Tier 3 engine lines, eight are locomotive switcher lines, two are locomotive line haul lines, 13 are C2 marine lines, and 65 are other marine lines which, due to their size, generally span at least two of the three categories of C1 marine, recreational, and small commercial marine. For these 65 marine lines, we have weighted each manufacturer's estimated engine line research costs according to total engine lines sold into each of these three categories by the particular manufacturer. Of the 31 Tier 4 engine lines, four engine lines had sales in both the locomotive and the marine markets, so we have split evenly the engine line research between the appropriate segments; two of these four

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[C] Throughout Chapter 5 of this RIA, net present value (NPV) calculations are based on the period 2006-2040, reflecting the period when the NPRM analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a slightly smaller NPV of engineering costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV). The same convention applies for the emission inventories as shown in Table 5-66. We have used 2006 because we intended to publish the proposal in 2006. For the final analysis, we have chosen to continue with 2006 to make comparisons between proposal and final analyses more clear.

were marine-C1/locomotive-switcher engine lines, while the other two were marine-C2/locomotive-line haul engine lines.

Consistent with our NRT4 rule, for those engine lines adding aftertreatment devices (i.e., the Tier 4 engine lines) we have estimated the engine line research at $3.2 million per line for those engines under 600 kW, $6.5 million per line for non-locomotive line-haul engines over 600 kW, and $55 million per line for locomotive line-haul engines. The locomotive line-haul estimate is considerably higher than the others because of the high cost of prototypes for that category. For engine line research associated with the Tier 3 standards, we have estimated the expenditure per locomotive line-haul engine line at $15 million and at $1.6 million for all other engine lines. These values are lower than the amount estimated for Tier 4 since the Tier 3 effort should amount to recalibration work which is less costly than the work expected for Tier 4 engine lines. The estimated engine line research expenditures by type of engine manufacturer are shown in Table 5-5 and by market segment for Tier 3 in Table 5-6 and for Tier 4 in Table 5-7.

Table 5-5 Estimated Engine Line Research Expenditures by Type of Engine Manufacturer Totals per Engine Line for Tiers 3 & 4 ($Million, 2005 dollars)

	Tier 3 engine line	Tier 4 engine line <600 kW	Tier 4 engine line >600 kW
Manufacturer sells into highway and/or nonroad markets	$ 1.6	$ 3.2	$ 6.5
Manufacturer sells only into locomotive and/or marine markets	$ 1.6	$ 3.2	$ 6.5
Locomotive Line-haul engine line	$ 15.0		$ 55.0
% allocated to PM	33%	33%	33%
% allocated to NO_X+NMHC	67%	67%	67%

Note: Since we expect that the majority of the dollars we have estimated for engine line research would be spent on developing the synergy between the engine and NO_X exhaust emission-control systems, we have attributed two-thirds of the engine line research expenditures to NO_X+NMHC control and one-third to PM control.

Table 5-6 Tier 3 Engine Line Research Expenditures by Market Segment ($Million, 2005 dollars)

Segment	Engine Lines <600 kW	Engine Lines >600kW	Tier 3 $/line	Total
Small Commercial Marine	65		$ 1.6	$ 104
Recreational Marine				
Marine C1				
Marine C2	0	13	$ 1.6	$ 20.8
Locomotive Switcher/Passenger	6[a]	2	$ 1.6	$ 12.8
Locomotive Line Haul	0	2	$ 15.0	$ 30.0
Total	63	25		$ 167.6

[a] Note that we have developed hardware costs for switchers based on a single large engine of, generally, over 2000 hp. However, many switchers are powered by several nonroad engines placed in series to arrive at a large horsepower locomotive. Perhaps it would have been more appropriate to assume research costs for those engines to be $0 since the effort is, presumably, being done for the nonroad Tier 4 rule. However, to be conservative, we have included engine line research costs for these engines.

Table 5-7 Tier 4 Engine Line Research Expenditures by Market Segment ($Million, 2005 dollars)

Segment	Engine Lines <600 kW	Engine Lines >600 kW	Tier 4 $/line	Total
Marine C1	n/a	10	$ 6.5	$ 65.0
Marine-C1/Loco-Switcher/Passenger	0	2	$ 6.5	$ 13.0
Locomotive Switcher/Passenger	6[a]	0	$ 3.2	$ 19.2
Marine C2	0	12	$ 6.5	$ 78.0
Loco-LineHaul	0	2	$ 55.0	$ 110.0
Total	6	25		$ 285.2

[a] Note that we have developed hardware costs for switchers based on a single large engine of, generally, over 2000 hp. However, many switchers are powered by several nonroad engines placed in series to arrive at a large horsepower locomotive. We could have assumed research costs for those engines to be $0 since the effort is, presumably, being done for the nonroad Tier 4 rule. However, to be conservative, we have included engine line research costs for these engines.

We estimate that these engine line research expenditures will be made over a five year period in advance of the standard for which the cost is incurred. Spreading the costs this way results in the annual cost streams shown in Table 5-8 for Tier 3 and Table 5-9 for Tier 4 and Table 5-10 for the final program (i.e., Tiers 3 and 4).[D]

[D] Note that we show the Tier 3 engine-line research costs beginning in calendar year 2007 even though this rule will not be final until the end of 2007 at the earliest. While we usually do not account for investments made prior to a rule being finalized, we understand that manufacturers have begun spending money that, arguably, could be considered costs associated with this rule and believe it is appropriate that this rule reflect those estimates.

Table 5-8 Estimated Tier 3 Engine Line Research Expenditures by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1; Recreational; Small Commercial			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006															
2007	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2008	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2009	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2010	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2011	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2012															
2013															
2014															
2015															
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Total	$4.2	$8.6	$12.8	$9.9	$20.1	$30.0	$34.3	$69.7	$104.0	$6.9	$13.9	$20.8	$167.6	$55.3	$112.3
NPV at 7%	$3.2	$6.6	$9.8	$7.6	$15.4	$23.0	$26.3	$53.4	$79.7	$5.3	$10.7	$15.9	$128.4	$42.4	$86.1
NPV at 3%	$3.8	$7.6	$11.4	$8.8	$17.9	$26.7	$30.5	$62.0	$92.5	$6.1	$12.4	$18.5	$149.0	$49.2	$99.9

Table 5-9 Estimated Tier 4 Engine Line Research Expenditures by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1 > 600 kW			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006															
2007															
2008															
2009															
2010	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0							$27.1	$9.0	$18.2
2011	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2012	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2013	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2014	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2015							$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$29.9	$9.9	$20.0
2016															
2017															
2018															
2019															
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Total	$8.5	$17.2	$25.7	$36.3	$73.7	$110.0	$23.6	$47.9	$71.5	$25.7	$52.3	$78.0	$285.2	$94.1	$191.1
NPV at 7%	$5.3	$10.8	$16.1	$22.7	$46.1	$68.8	$13.8	$28.0	$41.8	$15.0	$30.6	$45.6	$172.3	$56.9	$115.4
NPV at 3%	$6.9	$14.0	$20.9	$29.5	$60.0	$89.5	$18.6	$37.8	$56.5	$20.3	$41.3	$61.6	$228.6	$75.4	$153.1

Table 5-10 Estimated Tier 3 & Tier 4 Engine Line Research Expenditures by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1; Recreational; Small Commercial			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006															
2007	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2008	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2009	$0.8	$1.7	$2.6	$2.0	$4.0	$6.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$33.5	$11.1	$22.5
2010	$2.5	$5.2	$7.7	$9.2	$18.8	$28.0	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$60.7	$20.0	$40.6
2011	$2.5	$5.2	$7.7	$9.2	$18.8	$28.0	$11.6	$23.5	$35.1	$6.5	$13.2	$19.8	$90.6	$29.9	$60.7
2012	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2013	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2014	$1.7	$3.4	$5.1	$7.3	$14.7	$22.0	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$57.0	$18.8	$38.2
2015							$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$29.9	$9.9	$20.0
2016															
2017															
2018															
2019															
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Total	$12.7	$25.8	$38.5	$46.2	$93.8	$140.0	$57.9	$117.6	$175.5	$32.6	$66.2	$98.8	$452.8	$149.4	$303.4
NPV at 7%	$8.5	$17.3	$25.9	$30.3	$61.5	$91.8	$40.1	$81.4	$121.5	$20.3	$41.2	$61.5	$300.8	$99.2	$201.5
NPV at 3%	$10.7	$21.6	$32.3	$38.3	$77.9	$116.2	$49.2	$99.8	$149.0	$26.4	$53.7	$80.1	$377.6	$124.6	$253.0

Table 5-10 shows the total estimated costs associated with engine line research. This table combines the costs for Tier 3 (Table 5-8) and Tier 4 (Table 5-9). As shown in Table 5-10, the net present value of the engine line research is estimated at $378 million using a three percent discount rate and $301 million using a seven percent discount rate. We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-11.

Table 5-11 Estimated Engine Line Research per Engine (2005 dollars)

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 32.3	3,212	$ 10,050
Locomotive Line Haul	$ 116.2	19,453	$ 5,970
Small Commercial Marine	$ 7.1	228,857	$ 30
Recreational Marine	$ 23.8	561,291	$ 40
Marine C1 <600 kW	$ 44.5	303,024	$ 150
Marine C1 >600 kW	$ 73.6	20,039	$ 3,670
Marine C2	$ 80.1	6,647	$12,050
Total	$ 377.6	1,142,525	$ 330

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

5.2.1.2 Engine-Related Tooling Costs

Once engines are ready for production, new tooling will be required to accommodate the assembly of the freshly manufactured engines. In the 2007 heavy-duty highway rule, we estimated approximately $1.6 million per engine line for tooling costs associated with DPF/NO_x aftertreatment systems. For the NRT4 rule, we estimated that a manufacturer that sold only into the landbased nonroad market would incur the same amount – $1.65 million expressed in 2002 dollars – for each engine line that required a DPF/NO_x aftertreatment system. In this rule, we estimate the same level of tooling costs associated with DPF/NO_x aftertreatment for those manufacturers selling only into the locomotive/marine markets, or $1.8 million in 2005 dollars. We have estimated the same level of tooling costs as in the 2007 highway and NRT4 rules because we expect freshly manufactured locomotive/marine engines to use technologies with similar tooling needs (i.e., a DPF and a NO_x aftertreatment device). For those manufacturers that sell into the highway and/or nonroad markets and have, therefore, already made considerable tooling investments, we have estimated an expenditure of 25 percent of this amount, or $450,000, for those engine lines that will require DPF/NO_x aftertreatment systems for the locomotive/marine market. These costs are assigned equally to NO_x+NMHC control and PM control since the tooling for one should be no more costly than that for the other.

The tooling estimates discussed above represent our estimates, per engine line, for engine lines expected to meet the Tier 4 requirements. As noted above in our discussion of engine line research, we estimate 31 engine lines that will incur these costs. Of those 31 lines, we estimate that five belong to manufacturers selling exclusively into the locomotive and/or marine markets. The remaining 26 lines belong to manufacturers that also sell into the highway and/or nonroad markets. The resultant tooling expenditures associated with the Tier 4 standards are then $22.1 million.

For meeting the Tier 3 requirements, we have estimated lower costs per line because the engines will require far less in terms of new hardware and, in fact, are expected only to require upgrades to existing hardware (i.e., new fuel systems). As such, we have estimated that those manufacturers selling exclusively into the locomotive and/or marine markets will spend $450,000 per engine line, while manufacturers that also sell into the highway and/or nonroad markets will spend $180,000 per engine line. The PSR database shows 88 engine lines that we expect to meet the Tier 3 standards, 13 of which belong to manufacturers that sell only into the locomotive and/or marine markets. The resultant tooling expenditures associated with the Tier 3 standards are then $19.4 million. As with the Tier 4 tooling costs, these costs are assigned equally to NO_x control and PM control.

We have applied tooling costs by engine line assuming that engines in the same line are produced on the same production line. Typically, the same basic diesel engine design can be increased or decreased in size by simply adding or subtracting cylinders. As a result, a four-, six-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer's engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be built on the same production line. Note that a tooling expenditure for a single engine line may cover engines over several market segments. To allocate the tooling expenditure for a given production line to a specific market segment, we have divided costs equally among the segments (i.e., an engine line used in both the marine C1 and the locomotive switchers segments would have its tooling costs split evenly between those two segments).

We estimate that the tooling expenditures would be made one year in advance of meeting the standards for which the money is spent. A summary of the tooling costs per manufacturer are shown in Table 5-12. The tooling costs by market segment are shown in Table 5-13 and the annual cost streams are shown in Table 5-14.

Table 5-12 Estimated Tooling Expenditures by Type of Engine Manufacturer Totals per Engine Line ($Million, 2005 dollars)

	Tier 3 engine lines	Tier 4 engine lines
Manufacturer sells into highway and/or nonroad markets	$ 0.18	$ 0.45
Manufacturer sells only into locomotive and/or marine markets	$ 0.45	$ 1.8
% allocated to PM	50%	50%
% allocated to NO_X+NMHC	50%	50%

Note: We have attributed the tooling costs equally to NO_X+NMHC and PM control because we have no reason to believe that the tooling costs would be greater for one than the other.

Table 5-13 Estimated Engine Tooling Expenditures by Market Segment and Tier ($Million, 2005 dollars)

Segment	Tier 3	Tier 4	Total
Marine C1 <600 kW	$ 7.9	$ 0	$ 7.9
Marine C1 >600 kW	$ 1.9	$ 7.8	$ 9.7
Marine C2	$ 2.6	$ 8.9	$ 11.5
Recreational Marine	$ 4.2	$ 0	$ 4.2
Small Commercial Marine	$ 1.2	$ 0	$ 1.2
Locomotive Switcher	$ 1.0	$ 3.1	$ 4.1
Locomotive Line Haul	$ 0.6	$ 2.3	$ 2.8
Total	$ 19.4	$ 22.1	$ 41.4

Table 5-14 Estimated Tier 3 and Tier 4 Engine Tooling Expenditures by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive			Marine					Totals		
	Switchers	Line-Haul	Subtotal	Marine C1	Marine C2	Recreational	Small Commercial	Subtotal	Total Spent	PM	NO_X+ NMHC
2006											
2007											
2008											
2009											
2010											
2011	$1.0	$0.6	$1.6	$9.8	$2.6	$4.2	$1.2	$17.8	$19.4	$9.7	$9.7
2012											
2013											
2014	$3.1	$2.3	$5.4						$5.4	$2.7	$2.7
2015				$7.8	$8.9			$16.7	$16.7	$8.3	$8.3
2016											
2017											
2018											
2019											
2020											
2021											
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2037											
2038											
2039											
2040											
Total	$4.1	$2.8	$6.9	$17.6	$11.5	$4.2	$1.2	$34.5	$41.4	$20.7	$20.7
NPV at 7%	$2.4	$1.6	$4.0	$10.5	$6.2	$2.8	$0.8	$20.3	$24.3	$12.1	$12.1
NPV at 3%	$3.2	$2.2	$5.4	$14.0	$8.8	$3.5	$1.0	$27.3	$32.7	$16.4	$16.4

As shown in Table 5-14, the net present value of the engine tooling expenditures are estimated at $33 million using a three percent discount rate, and $24 million using a seven percent discount rate. We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-15.

Table 5-15 Estimated Engine Tooling Costs per Engine (2005 dollars)

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 3.2	3,212	$ 1,000
Locomotive Line Haul	$ 2.2	19,453	$ 110
Small Commercial Marine	$ 1.0	228,857	$ 4
Recreational Marine	$ 3.5	561,291	$ 10
Marine C1 <600 kW	$ 8.2	303,024	$ 30
Marine C1 >600 kW	$ 5.8	20,039	$ 290
Marine C2	$ 8.8	6,647	$ 1,320
Total	$ 32.7	1,142,525	$ 30

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

5.2.1.3 Engine Certification Costs

Manufacturers would incur more than the normal level of certification costs during the first few years of implementation because all engines would need to be fully certified to the new emission standards rather than using the normal practice of carrying certification data over from prior years.[E] Consistent with our past locomotive and marine standard setting regulations, we have estimated engine certification costs as shown in Table 5-16. These costs are consistent with past rulemakings, but have been updated to 2005 dollars. Certification costs (for engines in all market segments) apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells.

[E] Note that all engines are certified every year, but most annual certifications involve carrying over test data from prior years since the engine being certified has not changed in an "emissions-meaningful" way. Since new standards preclude use of carry-over data, we estimate new certification costs for all engines. Note that this is, effectively, a conservative estimate since some engines would have changed sufficiently absent our new standards to require new certification data.

Table 5-16 Certification Costs per Engine Family (2005 dollars)

	$/engine family	# of engine families
Locomotive	$ 42,000	46
Small Commercial Marine	$ 32,000	24
Marine C1 0.9<L/cyl<1.2	$ 32,000	7
Marine C1 1.2<L/cyl<2.5	$ 43,000	19
Marine C1 L/cyl>2.5	$ 54,000	13
Marine C2 L/cyl>5	$ 54,000	5

To determine the number of engine families to be certified, we looked at our certification databases for the 2004 model year. For marine engines, our database provides the number of engine families, the liters per cylinder for each, and specifies whether it is certified as a C1 or a C2 engine. For locomotive engines, the database provides the engine displacement. We have also split the Marine C1 certification costs evenly between the C1 Marine and Recreational Marine market segments in the Tier 3 timeframe. In the Tier 4 timeframe, only those C1 Marine engines over 600 kW would incur certification costs since those C1 engines under 600 kW will not be meeting the Tier 4 standards. For the small commercial marine segment, we have estimated the number of engine families at 24 based on an estimated two families per each of 10 manufacturers selling into that market, and then another four families sold by marinizers. The costs for small commercial marine would be incurred only in the Tier 3 timeframe since they will not be meeting the Tier 4 standards. Similarly, the locomotive certification costs have been split evenly between locomotive switchers and locomotive line haul for both Tiers 3 and 4. The resultant annual cost streams are shown in Table 5-17. As shown in the table, the Tier 3 certification costs are estimated at $4.7 million, while the Tier 4 certification costs are estimated at around $2.8 million.

The total certification expenditures are estimated at $7.4 million, or $6.0 million at a three percent discount rate and $4.6 million at a seven percent discount rate. The table also makes clear what portion of the costs are allocated to NO_x+NMHC and PM, with a 50/50 allocation.

We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-18.

Table 5-17 Estimated Engine Certification Costs by Year ($Millions, 2005 dollars)

Calendar Year	Locomotive		Marine				Totals		
	Switchers	Line-Haul	Marine C2	Marine C1	Recreational	Small Com-mercial	Total Spent	PM	NO_X+ NMHC
2006									
2007									
2008									
2009									
2010									
2011	$1.0	$1.0	$0.3	$0.9	$0.9	$0.8	$4.7	$2.4	$2.4
2012									
2013									
2014	$1.0	$1.0					$1.9	$1.0	$1.0
2015			$0.3	$0.4			$0.7	$0.4	$0.4
2016									
2017									
2018									
2019									
2020									
2021									
2022									
2023									
2024									
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2039									
2040									
Total	$1.9	$1.9	$0.5	$1.3	$0.9	$0.8	$7.4	$3.7	$3.7
NPV at 7%	$1.2	$1.2	$0.3	$0.8	$0.6	$0.5	$4.6	$2.3	$2.3
NPV at 3%	$1.5	$1.5	$0.4	$1.1	$0.7	$0.6	$6.0	$3.0	$3.0

Table 5-18 Estimated Engine Certification Costs per Engine (2005 dollars)

	Estimated Total Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 1.5	3,212	$ 480
Locomotive Line Haul	$ 1.5	19,453	$ 80
Small Commercial Marine	$ 0.7	228,857	$ 3
Recreational Marine	$ 0.7	561,291	$ 1
Marine C1	$ 1.1	323,064	$ 3
Marine C2	$ 0.4	6,647	$ 60
Total	$ 6.0	1,142,525	$ 10

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

Note that these certification costs may overestimate actual costs because they assume all engines would be certified as a result of the new emission standards. However, some engines would have been scheduled for new certification independent of the new standards due to design changes or power increases among other possible reasons. For such engines, the incremental certification cost would be zero. However, to remain conservative, here we have applied the certification costs to all engine families.

5.2.2 Variable Engineering Costs

Engine variable costs are those costs for new hardware required to meet the new Tier 4 emission standards. We have estimated no incremental hardware costs associated with the Tier 3 standards. Unlike the Tier 4 standards, the Tier 3 standards are not based on the introduction of new emission control technologies on locomotive or marine diesel engines. Rather, the Tier 3 standards represent the largest level of emission reductions possible from the emission control systems we project that locomotive and marine engines will already have in the timeframe of Tier 3 implementation. For example, the marine Tier 3 standards are predicated on the use of the most modern nonroad Tier 4 base engine technologies without the use of the nonroad Tier 4 aftertreatment based emission solutions. While these base engines may represent significant technical advances from the marine Tier 2 engines they replace—having better high pressure fuel systems, better injectors, improved turbochargers, and more sophisticated electronic control units—we do not expect the manufacturing costs for these individual components to increase over the cost of the Tier 2 components they will replace. In fact, the shift from the Tier 2 engine's electronic unit pump system to the Tier 3 engine's common rail fuel system may actually result in a fuel system that is cheaper to produce, not more expensive. Similarly, while the processing power of the Tier 3 engine control computer may increase significantly, the cost of the computer chip that makes this possible is likely to be lower. This does not mean that the Tier 3 emission controls come for free. We project there will be costs incurred to optimize the control strategies to meet the stringent Tier 3 standards and further to test and certify these engines. These costs are accounted for as fixed costs described further in section 5.2.1 of this RIA.[F]

For the variable cost estimates presented here, we have used the same methodology to estimate costs as was used in our 2007 highway and our NRT4 rules. Because of the wide variation of engine sizes in the locomotive and marine markets, we have chosen an approach that results not in a specific cost per engine for engines within a given power range or market segment, but rather a set of equations that can be used to determine the variable costs for any engine provided its displacement and number of cylinders are known. Using the equations

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[F] To clarify, we have analyzed the fixed costs associated with the switch from unit injectors to common rail fuel systems reflecting our belief that this transition will come in part because of our regulation. Because we estimate that common rail fuel systems will be no more expensive than unit injector systems, and may in fact be cheaper, we have made no estimate of an incremental increase in variable costs due to this switch. Similarly, we have not made an estimate of what savings (if any) might be realized from this switch.

presented in this section, we have then estimated the engine variable costs for the sales weighted average engine in different power ranges within each market segment.[G]

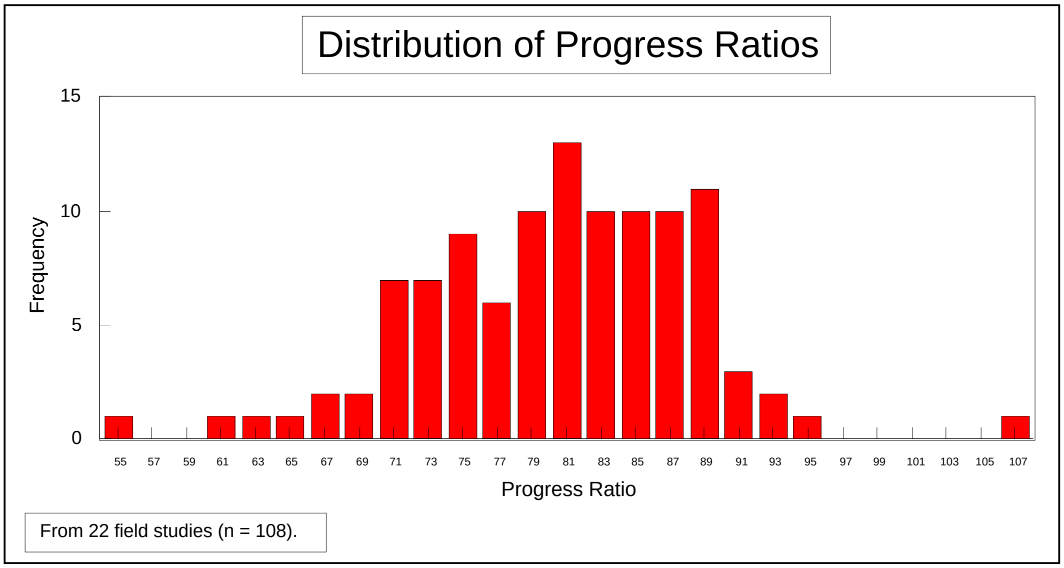
The discussion here considers both near-term and long-term cost estimates. We believe there are factors that cause hardware costs to decrease over time, making it appropriate to distinguish between near-term and long-term costs. Research in the costs of manufacturing has consistently shown that as manufacturers 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 which allows them to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve.[9]

The learning curve is a well documented phenomenon dating back to the 1930s. The general concept is that unit costs decrease as cumulative production increases. Learning curves are often characterized in terms of a progress ratio, where each doubling of cumulative production leads to a reduction in unit cost to a percentage "p" of its former value (referred to as a "p cycle"). Organizational learning, which brings about a reduction in total cost, is caused by improvements in several areas. Areas involving direct labor and material are usually the source of the greatest savings. Examples include, but are not limited to, a reduction in the number or complexity of component parts, improved component production, improved assembly speed and processes, reduced error rates, and improved manufacturing process. These all result in higher overall production, less scrappage of materials and products, and better overall quality. As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable plateau, beyond which increased production does not necessarily lead to markedly decreased costs.

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[10] The distribution of these progress ratios is shown in Figure 5-1. Except for one company that saw increasing costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

[G] For example, if two engines are sold with one being 100 hp and having 5 sales, the other being 200 hp and having 20 sales, the sales weighted horsepower of engines sold would not be 150 hp but would instead be 180 hp (100x5 + 200x20 = 4,500; 4,500/25 = 180).

Figure 5-1 Distribution of Progress Ratios (Dutton and Thomas 1984)



The learning curve is not the same in all industries. For example, the effect of the learning curve seems to be less in the chemical industry and the nuclear power industry where a doubling of cumulative output is associated with 11 percent decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

We believe the learning curve is appropriate to consider in assessing the cost impact of diesel engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. Neither locomotive nor marine diesel engines currently use any form of NO_x or PM aftertreatment except in very limited retrofit applications. Therefore, these are new technologies for these engines and will involve some new manufacturing operations, new parts, and new assembly operations beyond those anticipated in response to the 2007 highway and NRT4 rules. Since this will be a freshly manufactured product, we believe this is an appropriate situation for the learning curve concept to apply. Opportunities will exist to reduce unit labor and material costs and increase productivity as discussed above. We believe a similar opportunity exists for the new control systems that will integrate the function of the engine and emission-control technologies. While impacted diesel engines beginning with Tier 3 compliance are expected to have the basic components of this system—advanced engine control modules (computers), advanced engine air management systems (cooled EGR, and variable geometry turbocharging), and advanced electronic fuel systems including common rail systems—they will be applied in some new ways in response to the Tier 4 standards. Additionally some new components will be applied for the first time. These freshly manufactured parts and assemblies will involve new manufacturing operations. As manufacturers gain experience with these systems, comparable learning is expected to occur with respect to unit labor and material costs. These changes require manufacturers to start new production procedures, which will improve with experience.

We have applied a p value of 80 percent beginning with the first year of introduction of any new technology. That is, variable costs were reduced by 20 percent for each doubling of cumulative production following the year in which the technology was first introduced in a given market segment. Because the timing of the emission standards in this final rule follows that of the 2007 highway and NRT4 rules, we have used the first stage of learning done via those rules collectively as the starting point of learning for locomotive and marine engines. In other words, one learning phase is factored into the baseline costs for locomotive/marine engines. We have then applied one additional learning step from that baseline. In the 2007 highway rule, we applied a second learning step following the second doubling of production estimated to occur at the end of the 2010 model year. We could have chosen that point as our baseline case for this rule and then applied a single learning curve effect from there. Instead, to remain conservative, we have chosen to use only the first learning step from the highway/nonroad rules. The approach taken here is consistent with the approaches taken in our Tier 2 light-duty highway rule and the 2007 highway rule for heavy-duty gasoline engines. There, compliance was being met through improvements to existing technologies rather than the development of new technologies. We argued in those rules that, with existing technologies, there is less opportunity for lowering production costs. For that reason, we applied only one learning curve effect. The situation is similar for locomotive and marine engines. Because these will be existing technologies by the time they are introduced into the market, there would arguably be less opportunity for learning than there will be for the highway engines on which the technologies were first introduced.

Another factor that plays into our near-term and long-term cost estimates is that for warranty claim rates. In our 2007 highway rule, we estimated a warranty claim rate of one percent. Subsequent to that rule, we learned from industry that repair rates can be as much as two to three times higher during the initial years of production for a new technology relative to later years.[11] As a result, in our NRT4 rule, we applied a three percent warranty claim rate during the first two years and then one percent warranty claim rate thereafter. We have used the same approach here as used in the NRT4 rule. This difference in warranty claim rates, in addition to the learning effects discussed above, is reflected in the different long-term costs relative to near-term costs.

5.2.2.1 SCR System Costs

The NO_x aftertreatment system anticipated for the Tier 4 standards is the selective catalytic reduction (SCR) system. For the SCR system to function properly, a systems approach that includes a reductant metering system and control of engine-out NO_x emissions is necessary. Many of the new air handling and electronic system technologies developed to meet past locomotive and marine standards, and past highway and nonroad standards can be applied to accomplish the SCR system control functions as well. Some additional hardware for exhaust NO_x or oxygen sensing may also be required.

We have used the same methodology to estimate costs associated with SCR systems as was used in our 2007 highway and NRT4 rulemakings for other aftertreatment devices. The basic components of the SCR system are well known and include the following material elements:[H]

- a ceramic substrate upon which a NO_x catalyst washcoating is applied;
- a can to hold and support the substrate;
- a reductant injector and associated plumbing;
- an exhaust gas sensor (e.g., a NO_x sensor) used for control.

Examples of these material costs are summarized in Table 5-19 and represent costs to the engine manufacturers inclusive of supplier markups. The manufacturer costs shown in Table 5-19 include additional markups to account for both manufacturer and dealer overhead and carrying costs. The application of overhead and carrying costs is consistent with the approach taken in the 2007 highway and NRT4 rulemakings. In those rules, we estimated the markup for catalyzed emission-control technologies based on input from catalyst manufacturers. Specifically, we were told that device manufacturers could not mark up the cost of the individual components within their products because those components consist of basic commodities (for example, precious metals used in the catalyst could not be arbitrarily marked up because of their commodity status). Instead, manufacturing entities could mark up costs only where they add a unique value to the product. In the case of catalyst systems, the underlying cost of precious metals, catalyst substrates, PM filter substrates, and canning materials were well known to both buyer and seller and no markup or profit recovery for those component costs could be realized by the catalyst manufacturer. In essence, these are components to which the supplier provides little value-added engineering.

The one component that is unique to each catalyst manufacturer (i.e., the component where they add a unique value) is the catalyst washcoat support materials. This mixture (which is effectively specialized clays) serves to hold the catalytic metals in place and to control the surface area of the catalytic metals available for emission control. Although the price for the materials used in the washcoat is almost negligible (i.e., perhaps one or two dollars), we have estimated a substantial cost for washcoating based on the engineering value added by the catalyst manufacturer in this step. This is reflected in the costs presented for SCR systems and DPF systems. This portion of the cost estimate – the washcoating – is where the catalyst manufacturer recovers the fixed cost for research and development as well as realizes a profit. To these manufacturer costs, we have added a four percent carrying cost to account for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. A dealer carrying cost is also included to cover the cost of capital tied up in extra inventory. Considering input received from industry, we have adopted this

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[H] Note that our draft cost analysis included costs for the urea storage tank and computer controller in the SCR system costs. For our final cost analysis, we have removed those costs from the SCR system and are, instead, accounting for those costs in our discussion of equipment related variable costs. We have also made a corresponding reduction in the labor costs for SCR systems since the urea tank and controller labor is now being considered at the equipment level. That discussion is in section 5.3.2 of this RIA.

approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value each entity adds at various stages of the supply chain.[12] Also included is our estimate of warranty costs for the system.

Table 5-19 SCR System Costs (costs shown are costs per SCR system for the given engine power/displacement, 2005 dollars)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Catalyst Volume (Liter)	1.0	3.8	9.8	19.1	45.0	86.3	470.0
Substrate	$29	$113	$294	$573	$1,350	$2,588	$14,100
Washcoating and Canning	$423	$517	$721	$1,035	$1,910	$3,302	$16,258
Platinum	$0	$0	$0	$0	$0	$0	$0
Catalyst Can Housing	$12	$12	$13	$15	$20	$28	$100
Urea Injection Assembly	$500	$527	$585	$674	$922	$1,318	$5,000
Reductant Solution Tank & Controls (see section 5.3.2)	$0	$0	$0	$0	$0	$0	$0
NO$_X$ sensor (1 sensor/engine)	$200	$200	$200	$200	$200	$200	$200
DOC for cleanup	$236	$255	$297	$362	$543	$831	$3,511
Direct Labor Costs							
Estimated Labor hours	3	3	3	3	3	6	6
Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$54	$54	$54	$54	$54	$108	$108
Labor Overhead @ 40%	$22	$22	$22	$22	$22	$43	$43
Total Direct Costs to Mfr.	$1,476	$1,699	$2,186	$2,935	$5,021	$8,419	$39,321
Warranty Cost (3% claim rate)	$111	$128	$164	$220	$377	$626	$2,944
Mfr. Carrying Cost - Near term	$59	$68	$87	$117	$201	$337	$1,573
Total Cost to Dealer - Near term	$1,646	$1,895	$2,438	$3,273	$5,599	$9,382	$43,838
Dealer Carrying Cost - Near term	$49	$57	$73	$98	$168	$281	$1,315
Baseline Cost to Buyer - Near term	$1,695	$1,952	$2,511	$3,371	$5,767	$9,663	$45,153
Loco/Marine Cost to Buyer (includes highway learning) - Near term	**$1,356**	**$1,561**	**$2,009**	**$2,697**	**$4,613**	**$7,730**	**$36,122**
Warranty Cost (1% claim rate)	$37	$43	$55	$73	$126	$209	$981
Mfr. Carrying Cost - Long term	$59	$68	$87	$117	$201	$337	$1,573
Total Cost to Dealer - Long term	$1,572	$1,810	$2,329	$3,126	$5,348	$8,964	$41,875
Dealer Carrying Cost - Long term	$47	$54	$70	$94	$160	$269	$1,256
Baseline Cost to Buyer - Long term	$1,619	$1,864	$2,399	$3,220	$5,508	$9,233	$43,131
Baseline Cost to Buyer (includes Highway Learning) - Long term	$1,295	$1,491	$1,919	$2,576	$4,406	$7,387	$34,505
Loco/Marine Cost to Buyer (includes Loco/Marine learning) - Long term	**$1,036**	**$1,193**	**$1,535**	**$2,061**	**$3,525**	**$5,909**	**$27,604**

We have estimated the cost of this system based on information from several reports.[13, 14, 15] The individual estimates and assumptions used to estimate the cost for the system are touched upon in the following paragraphs.

SCR Catalyst Volume

During development of this rule, engine and aftertreatment device manufacturers have indicated that SCR catalyst volumes could be from one to three times engine displacement for locomotive and marine applications. As explained in Chapter 4 of this RIA, we have used a ratio of SCR volume to engine displacement equal to 2.5:1.

SCR Catalyst Substrate

The ceramic flow-through substrates used for the SCR catalyst were estimated to cost $30 per liter.

SCR Catalyst Washcoating and Canning

We have estimated a "value-added" engineering and material product, called washcoating and canning, based on feedback from members of the Manufacturers of Emission Control Association (MECA). By using a value-added component that accounts for fixed costs (including R&D), overhead, marketing and profits from likely suppliers of the technology, we can estimate this fraction of the cost for the technology apart from other components that are more widely available as commodities (e.g, precious metals and catalyst substrates). Based on conversations with MECA, we understand this element of the product to represent the catalyst manufacturer's value added and, therefore, their opportunity for markup. As a result, the washcoating and canning costs shown in Table 5-19 represent costs with manufacturer markups included. The washcoating and canning costs can be expressed as $34(x) + $390, where x is the catalyst volume in liters. This washcoating cost is higher than our past rulemakings because of dual washcoating process we anticipate will be used to "zone coat" the diesel oxidation function onto a portion of the SCR catalyst (as discussed below).

SCR Catalyst Precious Metals

We expect that the SCR catalysts used in locomotive and marine applications will contain no precious metals (e.g., the platinum group metals platinum, palladium, and rhodium). As a result, we have estimated zero costs associated with these commodities.

SCR Can Housing

The material cost for the can housing is estimated based on the catalyst volume plus 20 percent for transition (inlet/outlet) cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of $1 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2005.[16]

Reductant Injection Assembly

The costs for the reductant injection assembly are based in part on our past contractor report that estimated the costs at \$250 to \$300 for units meant for 12 to 26 liter catalysts. Here, we have adjusted the numbers based on recent conversations with industry by estimating the costs for the smallest engines at \$500 and the largest at \$5,000. We then used a linear interpolation to arrive at the costs for engines in between.

Reductant Solution Tank and Brackets

These costs are now addressed in section 5.3.2 where we present equipment-related hardware costs.

NO_x Sensor Cost

We believe that one sensor will be needed per catalyst and have used an estimated cost of \$200 per sensor based on today's cost of \$300 for use in retrofit applications (retrofit applications are typically considerably more costly than new). With increased NO_x sensor sales volumes in future locomotive, marine, highway, and nonroad markets, we believe that NO_x sensor costs may well be in the \$50 to \$100 range, if not lower. For this analysis, reflecting the relatively low sales volumes of locomotive and marine engines relative to highway engines, we have chosen to remain conservative by using the \$200 per sensor estimate.

DOC for Cleanup

Included in the costs for the SCR system are costs for a diesel oxidation catalyst (DOC) for clean-up of possible excess ammonia emissions that might occur as a result of excessive urea usage. The methodology used to estimate DOC costs is consistent with the SCR system cost methodology and is presented below in Table 5-20. These cost estimates use a DOC to engine displacement ratio of 0.8:1 because the low emissions conversion demand placed on the DOC is not expected to require a larger device. This ratio is higher than the ratio used in the draft cost analysis where we used a ratio of 0.5:1. The 0.8:1 ratio is consistent with our technological feasibility discussion in Chapter 4 of this RIA.

Table 5-20 Diesel Oxidation Costs (costs shown are costs per SCR system for the given engine power/displacement, 2005 dollars)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Catalyst Volume (liter)	0.3	1.2	3.1	6.1	14.4	27.6	150.4
Substrate	$0	$0	$0	$0	$0	$0	$0
Washcoating and Canning	$189	$201	$228	$270	$385	$568	$2,275
Platinum	$2	$6	$16	$31	$73	$141	$768
Catalyst Can Housing	$0	$0	$0	$0	$0	$0	$0
Direct Labor Costs							
Estimated Labor hours	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$9	$9	$9	$9	$9	$9	$9
Labor Overhead @ 40%	$4	$4	$4	$4	$4	$4	$4
Total Direct Costs to Mfr.	$203	$220	$257	$313	$471	$722	$3,056
Warranty Cost - Near Term (3% claim rate)	$17	$19	$21	$26	$37	$56	$231
Mfr. Carrying Cost - Near Term	$8	$9	$10	$13	$19	$29	$122
Total Cost to Dealer - Near Term	$229	$247	$289	$352	$527	$807	$3,409
Dealer Carrying Cost - Near Term	$7	$7	$9	$11	$16	$24	$102
Loco/Marine Cost to Buyer	**$236**	**$255**	**$297**	**$362**	**$543**	**$831**	**$3,511**

Important to note here is that we expect the DOC function to be fulfilled within the confines of the SCR catalyst using a process known as “zone coating” by which the DOC washcoat is applied to the tail end of the SCR catalyst substrate. By doing this, a physically separate DOC is not necessary. We have remained conservative in our cost analysis by including costs associated with canning of the DOC.

Direct Labor Costs

The direct labor costs for the catalyst are estimated based on an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor costs.

SCR Warranty Costs

We have estimated both near-term and long-term warranty costs. Near-term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long-term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident.[17] The labor rate is assumed to be $50 per hour with four hours required per claim, and parts costs are estimated to be 2.5 times the original manufacturing cost for the component. The calculation of near-term warranty costs for the 7 kW engine shown in Table 5-19 is as follows:

$$[(\$29+\$423+\$12+\$500+\$200+\$236)(2.5) + (\$50)(4\text{hours})](3\%) = \$111$$

Manufacturer and Dealer Carrying Costs

The manufacturer’s carrying cost was estimated at 4 percent of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer’s carrying cost was estimated at 3 percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

SCR System Cost Estimation Function

Using the example SCR system costs shown in the table, we calculated a linear regression to determine the SCR system cost as a function of engine displacement. This way, the function can be applied to the wide array of engines in the locomotive line haul and marine fleets to determine the total or per engine costs for SCR hardware. The functions calculated for SCR system costs in line-haul locomotives and marine applications are shown in Table 5-21.

For locomotive switcher applications, we have used the costs developed for our NRT4 rulemaking because locomotive switchers tend to be powered by land based nonroad engines. For this reason, it seemed most appropriate to use the same costs developed for that rule. These costs are also shown in Table 5-21.

Table 5-21 SCR System Costs as a Function of Engine Displacement, x, in Liters (2005 dollars)

		Linear Regression	R^2
Line haul locomotive; marine	Near-term cost function	\$185(x) + \$1,293	0.999
	Long-term cost function	\$142(x) + \$988	0.999
Switcher locomotive	Near-term cost function	\$103(x) + \$183	0.999
	Long-term cost function	\$83(x) + \$160	0.999

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

This table shows both a near-term and a long-term cost function for SCR system costs. The near-term function incorporates the near-term warranty costs determined using a three percent claim rate, while the long-term function incorporates the long-term warranty costs determined using a one percent claim rate. Additionally, the long-term function incorporates learning curve effects.

5.2.2.2 DPF System Costs

One means of meeting the Tier 4 PM standard is to use a diesel particulate filter (DPF) system like that expected to be used for highway and NRT4 applications. However, as explained in Chapter 4 of this RIA, here we are projecting a DPF volume to engine displacement ratio of 1.7:1. In the highway and nonroad rules, we projected ratios of 1.5:1. For the DPF to function properly, a systems approach that includes precise control of engine air-fuel ratio is also necessary. Many of the new air handling and electronic fuel system technologies developed in order to meet the highway, nonroad, and past locomotive/marine standards can be applied to accomplish the DPF control functions as well.

We have used the same methodology to estimate costs associated with DPF systems as was used in our 2007 highway and NRT4 rulemakings. The basic components of the DPF are well known and include the following material elements:

- An oxidizing catalyst, typically platinum;
- a substrate upon which the catalyst washcoating is applied and upon which PM is trapped;
- a can to hold and support the substrate.

Examples of these material costs are summarized in Table 5-22 and represent costs to the engine manufacturers inclusive of supplier markups. The total direct cost to the manufacturer includes an estimate of warranty costs for the DPF system. Hardware costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer’s carrying cost was estimated to be four percent of the direct costs accounting for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. The dealer’s carrying cost was marked up three percent reflecting the cost of capital tied up in inventory. We have adopted this approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value added at each stage of the supply chain based on industry input.[18] Note that our final costs for DPF systems are identical to those presented in the draft cost analysis.

Table 5-22 DPF System Costs (costs shown are costs per DPF system for the given engine power/displacement, 2005 dollars)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Filter Volume (Liter)	0.7	2.6	6.7	13.0	30.6	58.7	319.6
Filter Trap	$46	$176	$461	$898	$2,117	$4,057	$22,108
Washcoating and Canning	$96	$111	$143	$192	$328	$546	$2,571
Platinum	$41	$156	$408	$796	$1,874	$3,592	$19,575
Filter Can Housing	$9	$10	$11	$12	$16	$21	$74
Differential Pressure Sensor	$52	$52	$52	$52	$52	$52	$52
Direct Labor Costs							
Estimated Labor hours	4	4	4	4	4	8	8
Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$72	$72	$72	$72	$72	$145	$145
Labor Overhead @ 40%	$29	$29	$29	$29	$29	$58	$58
Total Direct Costs to Mfr.	$345	$606	$1,175	$2,051	$4,488	$8,471	$44,583
Warranty Cost -- Near Term (3% claim rate)	$21	$41	$84	$149	$332	$623	$3,332
Mfr. Carrying Cost -- Near Term	$14	$24	$47	$82	$180	$339	$1,783
Total Cost to Dealer -- Near Term	$380	$671	$1,306	$2,282	$4,999	$9,433	$49,698
Dealer Carrying Cost -- Near Term	$11	$20	$39	$68	$150	$283	$1,491
Savings by removing silencer	($52)	($52)	($52)	($52)	($52)	($52)	($52)
Baseline Cost to Buyer -- Near Term	$340	$640	$1,293	$2,298	$5,098	$9,664	$51,137
Loco/Marine Cost to Buyer (includes highway learning) - Near term	**$272**	**$512**	**$1,035**	**$1,839**	**$4,078**	**$7,731**	**$40,910**
Warranty Cost -- Long Term (1% claim rate)	$7	$14	$28	$50	$111	$208	$1,111
Mfr. Carrying Cost -- Long Term	$14	$24	$47	$82	$180	$339	$1,783
Total Cost to Dealer -- Long Term	$366	$644	$1,250	$2,182	$4,778	$9,017	$47,477
Dealer Carrying Cost -- Long Term	$11	$19	$38	$65	$143	$271	$1,424
Savings by removing muffler	($52)	($52)	($52)	($52)	($52)	($52)	($52)
Baseline Cost to Buyer -- Long Term	$325	$611	$1,236	$2,196	$4,870	$9,236	$48,849
Baseline Cost to Buyer (includes Highway Learning) - Long term	$260	$489	$989	$1,757	$3,896	$7,389	$39,080
Loco/Marine Cost to Buyer (includes Loco/Marine learning) - Long term	**$208**	**$391**	**$791**	**$1,405**	**$3,117**	**$5,911**	**$31,264**

DPF Volume

During development of this rule, engine manufacturers have suggested that DPF volumes could be up to three times engine displacement. The size of the DPF is based largely on the maximum allowable flow restriction for the engine. Generically, the filter size is inversely proportional to its resistance to flow (a larger filter is less restrictive than a similar smaller filter). In the 2007 highway and NRT4 rules, we estimated that the DPF would be sized to be 1.5 times the engine displacement based on the responses received from EMA and on-going research aimed at improving filter porosity control to give a better trade-off between flow restrictions and filtering efficiency. As explained in Chapter 4 of this RIA, here we have estimated a ratio of 1.7:1.

DPF Substrate

The DPF can be made from a wide range of filter materials including wire mesh, sintered metals, fibrous media, or ceramic extrusions. The most common material used for DPFs for heavy-duty diesel engines is cordierite. Here we have based our cost estimates on the use of silicon carbide (SiC) even though it is more expensive than other filter materials. In the 2007 highway rule, we estimated that DPFs would consist of a cordierite filter costing $30 per liter. To remain conservative in our cost estimates for nonroad applications, we assumed the use of silicon carbide filters costing double that amount, or $60 per liter, because silicon carbide filters are more durable. As discussed in Chapter 4 of this RIA, we believe that metal substrates may be choice for locomotive and marine DPFs, which would cost less than a silicon carbide substrate. Nonetheless, to be conservative in our cost estimates, we have assumed use of silicon carbide filters for locomotive and marine applications, so have based costs on the $60 per liter cost estimate. This cost is directly proportional to filter volume, which is proportional to engine displacement. We have converted the $60 value to $2005 using the Producer Price Index (PPI) for manufacturing industries; the end result being a cost of $62 per liter.[19]

DPF Washcoating and Canning

These costs are based on costs developed under contract for our 2007 highway rule.[20] We converted those costs to $2005 using the PPI for manufacturing industries. We then calculated a linear “best fit” to express the washcoating and canning costs as $8(x) + $91, where x is the DPF volume in liters.

DPF Precious Metals

The total precious metal content for DFPs is estimated to be 60 g/ft^3 with platinum as the only precious metal used in the filter. In our NRT4 rule, we used a price of $542 per troy ounce for platinum. Here we have used the 2005 average monthly price of $899 per troy ounce for platinum.[21]

DPF Can Housing

The material cost for the can housing is estimated based on the DPF volume plus 20 percent for transition (inlet/outlet) cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of $1 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2005.

DPF Differential Pressure Sensor

We believe that the DPF system will require the use of a differential pressure sensor to provide a diagnostic monitoring function of the filter. A contractor report to EPA estimated the cost for such a sensor at $45.[22] A PPI adjusted cost of $52 per sensor has been used in this analysis.

DPF Direct Labor

Consistent with the approach for SCR systems, the direct labor costs for the DPF are estimated based on an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor costs.

DPF Warranty

Consistent with the approach taken for SCR system costs, we have estimated both near-term and long-term warranty costs. Near-term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long-term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident. The labor rate is estimated to be $50 per hour with two hours required per claim, and parts cost are estimated to be 2.5 times the original manufacturing cost for the component.

DPF Manufacturer and Dealer Carrying Costs

Consistent with the approach for SCR systems, the manufacturer's carrying cost was estimated at four percent of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at three percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

Savings Associated with Silencer Removal

DPF retrofits are often incorporated in, or are simply replacements for, the silencer (muffler) for diesel-powered vehicles and equipment. We believe that the DPF could be mounted in place of the silencer, although it may have slightly larger dimensions. We have estimated that applying a DPF allows for the removal of the silencer due to the noise attenuation characteristics of the DPF. We have accounted for this savings and have estimated a silencer costs at $52. The $52 estimate is an average for all engines; the actual savings will be higher for some and lower for others.

DPF System Cost Estimation Function

Using the example DPF costs shown in Table 5-22, we calculated a linear regression to determine the DPF system cost as a function of engine displacement. This way, the function can be applied to the wide array of engines in the locomotive line haul and/or marine fleets to determine the total or per engine costs for DPF system hardware. The functions calculated for DPF system costs for locomotive line-haul and marine applications are shown in Table 5-23.

For locomotive switcher applications, we have used the costs developed for our NRT4 rulemaking because locomotive switchers tend to be powered by land based nonroad engines making it appropriate to use the same costs developed for that rule. These costs are also shown in Table 5-23.

Table 5-23 DPF System Costs as a function of Engine Displacement, x, in Liters (2005 dollars)

		Linear Regression	R^2
Line-haul locomotive; marine	Near-term cost function	\$217(x) + \$199	0.999
	Long-term cost function	\$166(x) + \$153	0.999
Switcher locomotive	Near-term cost function	\$146(x) + \$75	0.999
	Long-term cost function	\$112(x) + \$57	0.999

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

The near-term and long-term costs shown in Table 5-23 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

5.2.2.3 Aftertreatment Marinization Costs

For marine engines, the Tier 4 requirements will entail increased costs associated with marinizing the engines for the marine environment. Marine C1 and C2 engines are typically land based nonroad engines that are marinized for the marine environment. This marinization can take many forms, but is generally a matter of altering the cooling system to make use of sea or lake water rather than relying on ambient air since marine engines tend to be enclosed within vessels where ambient air radiators like those used in land based engines cannot operate efficiently. Such marinization efforts have been done for years and will continue but do not represent incremental costs associated with the new standards. Marinization costs associated with the new aftertreatment devices that would be added to comply with the Tier 4 standards—to control the surface temperatures in the typically tight space constraints onboard a vessel—do represent incremental costs associated with the final program and, thus, they must be considered.

Under contract to EPA, ICF International conducted a study that considered the costs associated with marinizing aftertreatment devices.[23] In their study, ICF looked at the costs associated with two methods of marinization: triple wall stainless steel; and, insulating blankets. Both methods could be used to control the surface temperature of the aftertreatment device such that accidental touching would not cause burns or otherwise compromise safety. The triple wall insulation method proved more cost efficient. Using this method, the device would, essentially, have three layers of stainless steel surrounding the substrate rather than the single layer normally used on land based engines. These layers would be separated by a few millimeters to provide an insulating air gap.

The ICF study looked at aftertreatment marinizing costs for a range of engine sizes in a manner similar to that discussed above for SCR and DPF systems. The details of these estimates are contained in the final report.[24] In the report, ICF calculated costs using a 1:1 or a 1.5:1 device volume to engine displacement ratio. However, as noted earlier, our analysis leads us to believe that a 2.5:1 ratio (SCR) and 1.7:1 ratio (DPF) are more applicable. As a result, we have adjusted the ICF results somewhat higher to reflect a larger sized device being insulated; these adjustments are reflected in Table 5-24 for marinization of SCR systems and in Table 5-25 for marinization of DPF systems. The resultant linear regression best fit curves for marinization costs as a function of engine displacement are shown in Table 5-26.

Table 5-24 SCR System Marinization Costs (2005 dollars)

Typical Engine Power (kW)	64	93	183	620	968	1425	1902	3805	5968
Typical Engine Displacement (L)	4.2	7	10.5	27	34.5	51.8	111	222	296
SCR Catalyst Marinization Hardware Cost	$23	$28	$29	$65	$77	$91	$173	$292	$350
Assembly	$0	$0	$0	$0	$0	$0	$0	$0	$0
Labor @ $28/hr	$3	$3	$3	$3	$3	$3	$3	$3	$3
Overhead @ 40%	$1	$1	$1	$1	$1	$1	$1	$1	$1
Total Assembly Cost	$4	$4	$4	$4	$4	$4	$4	$4	$4
Markup on Hardware and Assembly @ 29%	$8	$9	$9	$20	$24	$28	$51	$86	$103
Total SCR Catalyst Marinization Costs - Near term	$34	$42	$42	$90	$105	$123	$228	$382	$456
Total SCR Catalyst Marinization Costs - Long term	$27	$33	$34	$72	$84	$98	$182	$305	$365

Table 5-25 DPF System Marinization Costs (2005 dollars)

Typical Engine Power (kW)	64	93	183	620	968	1425	1902	3805	5968
Typical Engine Displacement (L)	4.2	7	10.5	27	34.5	51.8	111	222	296
DPF Marinization Hardware Cost	$15	$22	$29	$52	$61	$75	$112	$218	$262
Assembly	$0	$0	$0	$0	$0	$0	$0	$0	$0
Labor @ $28/hr	$3	$3	$3	$3	$3	$3	$3	$3	$3
Overhead @ 40%	$1	$1	$1	$1	$1	$1	$1	$1	$1
Total Assembly Cost	$4	$4	$4	$4	$4	$4	$4	$4	$4
Markup on Hardware and Assembly @ 29%	$6	$8	$9	$16	$19	$23	$34	$64	$77
Total DPF Marinization Costs - Near term	$25	$34	$42	$72	$84	$102	$150	$286	$343
Total DPF Marinization Costs - Long term	$20	$27	$34	$58	$67	$81	$120	$229	$274

Table 5-26 Marinization Costs as a function of Engine Displacement, x, in Liters (2005 dollars)

		Linear Regression	R^2
SCR System Marinization	Near-term cost function	\$1(x) + \$42	0.990
	Long-term cost function	\$1(x) + \$34	0.990
DPF System Marinization	Near-term cost function	\$1(x) + \$35	0.991
	Long-term cost function	\$1(x) + \$28	0.991

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

5.2.2.4 Summary of Engine Variable Cost Equations

Engine variable costs are discussed in detail in sections 5.2.2.1 through 5.2.2.3. As described in those sections, we have generated cost estimation equations for SCR systems, DPF systems, and aftertreatment marinization as a function of engine displacement. These equations are summarized in Table 5-27. Note that not all equations were used for all engines and all market segments; equations were used in the manner shown in the table. We have calculated the aggregate engine variable costs and present them later in this chapter.

Table 5-27 Summary of Cost Equations for Engine Variable Costs (x represents the dependent variable, 2005 dollars)

Engine Technology	Time Frame	Cost Equation	Dependent Variable	How Used
SCR System Costs	Near term Long term	\$185(x) + \$1,293 \$142(x) + \$988	Engine Displacement (Liters)	Tier 4 Locomotive Line-haul and Marine Engines
SCR System Costs	Near term Long term	\$103(x) + \$183 \$83(x) + \$160	Engine Displacement (Liters)	Tier 4 Locomotive Switcher Engines
DPF System Costs	Near term Long term	\$217(x) + \$199 \$166(x) + \$153	Engine Displacement (Liters)	Tier 4 Locomotive Line-haul and Marine Engines
DPF System Costs	Near term Long term	\$146(x) + \$75 \$112(x) + \$57	Engine Displacement (Liters)	Tier 4 Locomotive Switcher Engines
SCR Marinization Costs	Near term Long term	\$1(x) + \$42 \$1(x) + \$34	Engine Displacement (Liters)	Tier 4 Marine Engines
DPF Marinization Costs	Near term Long term	\$1(x) + \$35 \$1(x) + \$28	Engine Displacement (Liters)	Tier 4 Marine Engines

Using these equations, we can calculate the variable costs associated with the Tier 4 standards for any engine provided we know its displacement, power, and intended application. We could do this for every compliant engine expected to be sold in the years following implementation of the new standards, total the results, and we would have the total annual variable costs associated with the rule. We can achieve essentially the same thing by calculating a sales weighted variable cost. This could be done for a single engine that could represent the entire fleet provided we sales weighted the critical characteristics of that engine. Doing this for one engine would not provide a particularly good look at the impact of the new standards on costs since the sizes of engines, their power, and use varies so much. Therefore, we have broken the fleet first into the market segments according to our regulatory definitions (i.e., marine C1, marine C2, locomotive, etc.). We have further broken each market segment into several power ranges, some of which are arbitrary and meant only to provide more stratification of the results, and some of which are chosen to align properly with the structure of the new standards (e.g., marine C1 has a power cutpoint at 600 kW since the Tier 4 standards apply to marine engines above 600 kW).

The necessary engine characteristics for sales weighting are engine displacement, power, and application. We have used the PSR database and sales figures from 2002. The resultant sales weighted engines within given market segments and power ranges are shown in Table 5-28. For example, the sales weighted engine in the marine C1 segment, power range

800 to 2000 hp, has an engine displacement of 33.4 liters and is 1266 hp (944 kW). Empty cells in the table mean that there are no engines in that power range and market segment.

Table 5-28 Sales Weighted Engine Characteristics by Market Segment and Power Range

Power Range	Loco-LineHaul	Loco-Switcher	Marine C1	Marine C2	Marine Recreational	Small Commercial Marine
	Sales Weighted Displacement (Liters)					
0<hp<25						0.6
25<=hp<50						1.6
50<=hp<75		2.7	2.5		2.6	
75<=hp<200		5.8	5.5		5.0	
200<=hp<400		7.7	10.5		4.9	
400<=hp<800		18.9	17.6		8.8	
800<=hp<2000		51.8	33.4	93.0	28.9	
>=2000hp	174.2	69.0	61.0	176.4	60.6	
	Sales Weighted Horsepower					
0<hp<25						15.8
25<=hp<50						36.0
50<=hp<75		67.0	58.2		61.1	
75<=hp<200		157.7	149.6		159.1	
200<=hp<400		227.3	301.1		269.7	
400<=hp<800		660.0	553.2		457.2	
800<=hp<2000		1500.0	1266.3	1508.6	1226.1	
>=2000hp	4895.2	2000.0	2144.4	4014.5	2935.1	

Using these sales weighted engines shown in Table 5-28 and the variable cost equations shown in Table 5-27, we can calculate the individual piece costs for the various hardware elements expected to be added to engines to comply with the new standards. Those elements, as discussed above, being SCR systems, DPF systems, and costs associated with marinizing the SCR and the DPF systems (for marine engines only). The resultant piece costs are shown in Table 5-29. The table includes costs for engines in power ranges that are expected to add the new hardware or upgrade existing hardware. Empty cells reflect our belief that the technology will not be added as a result of our final rule. The rows containing data for “All engines” are costs for the sales weighted engine within each market segment. For Marine C1, we have also broken out the sales weighted costs for engines below and above 600 kW (805 hp). We use these values—those for “All engines” or, for the C1 marine segment, those for “<600 kW” or “>600 kW”—for our total cost calculations presented in section 5.6.

Table 5-29 Piece Costs for Engine Hardware by Market Segment and Power Range (2005 dollars)

Power Range	Line-Haul	Switchers	Marine C1	Marine C2	Rec Marine	Power Range	Line-Haul	Switchers	Marine C1	Marine C2	Rec Marine
	SCR System Costs - Near term						SCR System Costs - Long term				
0<hp<25						0<hp<25					
25<=hp<50						25<=hp<50					
50<=hp<75		$460				50<=hp<75		$381			
75<=hp<200		$778				75<=hp<200		$635			
200<=hp<400		$979				200<=hp<400		$796			
400<=hp<800		$2,140				400<=hp<800		$1,723			
800<=hp<2000		$5,532	$7,485	$18,527		00<=hp<2000		$4,431	$5,720	$14,158	
2000+	$33,567	$7,315	$12,591	$33,988		2000+	$25,651	$5,855	$9,622	$25,973	
All engines	$33,567	$1,639		$30,476		All engines	$25,651	$1,323		$23,290	
<800 hp only		$852				<800 hp only		$695			
>800 hp only		$6,449	$8,782			>800 hp only		$5,163	$6,711		
	SCR Marinization Costs - Near term						SCR Marinization Costs - Long term				
0<hp<25						0<hp<25					
25<=hp<50						25<=hp<50					
50<=hp<75						50<=hp<75					
75<=hp<200						75<=hp<200					
200<=hp<400						200<=hp<400					
400<=hp<800						400<=hp<800					
800<=hp<2000			$91	$178		800<=hp<2000			$73	$143	
2000+			$131	$300		2000+			$106	$242	
All engines				$272		All engines				$219	
<800 hp only						<800 hp only					
>800 hp only			$101			>800 hp only			$81		
	DPF System Costs - Near term					>2000kW only	DPF System Costs - Long term				
0<hp<25						0<hp<25					
25<=hp<50						25<=hp<50					
50<=hp<75		$467				50<=hp<75		$357			
75<=hp<200		$918				75<=hp<200		$702			
200<=hp<400		$1,203				200<=hp<400		$920			
400<=hp<800		$2,847				400<=hp<800		$2,177			
800<=hp<2000		$7,650	$7,437	$20,344		800<=hp<2000		$5,850	$5,684	$15,547	
2000+	$37,924	$10,175	$13,405	$38,416		2000+	$28,982	$7,781	$10,245	$29,358	
All engines	$37,924	$2,137		$34,312		All engines	$28,982	$1,634		$26,222	
<800 hp only		$1,023				<800 hp only		$782			
>800 hp only		$8,949	$8,953			>800 hp only		$6,843	$6,843		
	DPF Marinization Costs - Near term						DPF Marinization Costs - Long term				
0<hp<25						0<hp<25					
25<=hp<50						25<=hp<50					
50<=hp<75						50<=hp<75					
75<=hp<200						75<=hp<200					
200<=hp<400						200<=hp<400					
400<=hp<800						400<=hp<800					
800<=hp<2000			$71	$135		800<=hp<2000			$57	$108	
2000+			$101	$225		2000+			$80	$180	
All engines				$205		All engines				$163	
<800 hp only						<800 hp only					
>800 hp only			$79			>800 hp only			$63		

5.2.2.5 Annual Engine Variable Engineering Costs

Using the hardware piece costs shown in Table 5-29, we can calculate the annual costs for each market segment by multiplying piece costs by estimated future sales. Table 5-30 through Table 5-34 show these costs. These costs are associated with the Tier 4 standards since only Tier 4 engines are expected to incur new hardware costs. The PM/NO_x+NMHC cost allocations for engine variable costs used in this cost analysis are as follows: SCR systems including marinization costs on marine applications are attributed 100% to NO_x+NMHC control; and DPF systems including marinization costs on marine applications are attributed 100% to PM control.

Table 5-30 Annual Locomotive Line-haul Engine Variable Costs; Freshly Manufactured Tier 4 Engines Only ($Millions, 2005 dollars)

Calendar Year	Sales	DPF	SCR	Total	PM	NO_X+ NMHC
2006						
2007						
2008						
2009						
2010						
2011						
2012	767					
2013	765					
2014	780					
2015	816	$30.9	$27.4	$58.3	$30.9	$27.4
2016	854	$32.4	$28.7	$61.1	$32.4	$28.7
2017	877	$25.4	$22.5	$47.9	$25.4	$22.5
2018	894	$25.9	$22.9	$48.8	$25.9	$22.9
2019	917	$26.6	$23.5	$50.1	$26.6	$23.5
2020	948	$27.5	$24.3	$51.8	$27.5	$24.3
2021	979	$28.4	$25.1	$53.5	$28.4	$25.1
2022	1007	$29.2	$25.8	$55.0	$29.2	$25.8
2023	1034	$30.0	$26.5	$56.5	$30.0	$26.5
2024	1048	$30.4	$26.9	$57.2	$30.4	$26.9
2025	1078	$31.2	$27.6	$58.9	$31.2	$27.6
2026	1096	$31.8	$28.1	$59.9	$31.8	$28.1
2027	1119	$32.4	$28.7	$61.1	$32.4	$28.7
2028	1136	$32.9	$29.1	$62.1	$32.9	$29.1
2029	1150	$33.3	$29.5	$62.8	$33.3	$29.5
2030	1158	$33.6	$29.7	$63.3	$33.6	$29.7
2031	1173	$34.0	$30.1	$64.1	$34.0	$30.1
2032	1190	$34.5	$30.5	$65.0	$34.5	$30.5
2033	1209	$35.0	$31.0	$66.0	$35.0	$31.0
2034	1223	$35.5	$31.4	$66.8	$35.5	$31.4
2035	1231	$35.7	$31.6	$67.3	$35.7	$31.6
2036	1197	$34.7	$30.7	$65.4	$34.7	$30.7
2037	1172	$34.0	$30.1	$64.0	$34.0	$30.1
2038	1144	$33.2	$29.3	$62.5	$33.2	$29.3
2039	1112	$32.2	$28.5	$60.8	$32.2	$28.5
2040	1078	$31.2	$27.7	$58.9	$31.2	$27.7
NPV at 7%		$196.5	$173.9	$370.4	$196.5	$173.9
NPV at 3%		$426.6	$377.6	$804.2	$426.6	$377.6

Table 5-31 Annual Locomotive Switcher & Passenger Engine Variable Costs; Freshly Manufactured Tier 4 Engines Only ($Millions, 2005 dollars)

Calendar Year	Sales	DPF	SCR	Total	PM	NO_X+ NMHC
2006						
2007						
2008						
2009						
2010						
2011						
2012	92					
2013	92					
2014	93					
2015	93	$0.9	$0.7	$1.6	$0.9	$0.7
2016	94	$1.0	$0.7	$1.6	$1.0	$0.7
2017	94	$0.7	$0.5	$1.3	$0.7	$0.5
2018	94	$0.7	$0.5	$1.3	$0.7	$0.5
2019	94	$0.7	$0.6	$1.3	$0.7	$0.6
2020	94	$0.7	$0.6	$1.3	$0.7	$0.6
2021	94	$0.7	$0.6	$1.3	$0.7	$0.6
2022	95	$0.7	$0.6	$1.3	$0.7	$0.6
2023	160	$1.2	$0.9	$2.2	$1.2	$0.9
2024	183	$1.4	$1.1	$2.5	$1.4	$1.1
2025	201	$1.6	$1.2	$2.7	$1.6	$1.2
2026	212	$1.6	$1.2	$2.9	$1.6	$1.2
2027	227	$1.8	$1.3	$3.1	$1.8	$1.3
2028	239	$1.9	$1.4	$3.3	$1.9	$1.4
2029	247	$1.9	$1.4	$3.4	$1.9	$1.4
2030	263	$2.0	$1.5	$3.6	$2.0	$1.5
2031	281	$2.2	$1.6	$3.8	$2.2	$1.6
2032	292	$2.3	$1.7	$4.0	$2.3	$1.7
2033	296	$2.3	$1.7	$4.0	$2.3	$1.7
2034	305	$2.4	$1.8	$4.2	$2.4	$1.8
2035	302	$2.3	$1.8	$4.1	$2.3	$1.8
2036	294	$2.3	$1.7	$4.0	$2.3	$1.7
2037	287	$2.2	$1.7	$3.9	$2.2	$1.7
2038	278	$2.2	$1.6	$3.8	$2.2	$1.6
2039	269	$2.1	$1.6	$3.7	$2.1	$1.6
2040	263	$2.0	$1.5	$3.6	$2.0	$1.5
NPV at 7%		$8.6	$6.4	$15.0	$8.6	$6.4
NPV at 3%		$20.4	$15.3	$35.8	$20.4	$15.3

Table 5-32 Annual C2 Marine Engine Variable Costs; Freshly Manufactured Tier 4 Engines Only ($Millions, 2005 dollars)

Calendar Year	Sales	DPF	SCR	Marinization	Total	PM	NO_X+ NMHC
2006							
2007							
2008							
2009							
2010							
2011							
2012	299						
2013	301						
2014	304						
2015	307						
2016	309	$10.6	$9.4	$0.1	$20.2	$10.7	$9.5
2017	312	$10.7	$9.5	$0.1	$20.4	$10.8	$9.6
2018	315	$8.3	$7.3	$0.1	$15.7	$8.3	$7.4
2019	318	$8.3	$7.4	$0.1	$15.9	$8.4	$7.5
2020	321	$8.4	$7.5	$0.1	$16.0	$8.5	$7.5
2021	324	$8.5	$7.5	$0.1	$16.1	$8.5	$7.6
2022	327	$8.6	$7.6	$0.1	$16.3	$8.6	$7.7
2023	330	$8.6	$7.7	$0.1	$16.4	$8.7	$7.7
2024	332	$8.7	$7.7	$0.1	$16.6	$8.8	$7.8
2025	335	$8.8	$7.8	$0.1	$16.7	$8.9	$7.9
2026	338	$8.9	$7.9	$0.1	$16.9	$8.9	$7.9
2027	342	$9.0	$8.0	$0.1	$17.0	$9.0	$8.0
2028	345	$9.0	$8.0	$0.1	$17.2	$9.1	$8.1
2029	348	$9.1	$8.1	$0.1	$17.3	$9.2	$8.2
2030	351	$9.2	$8.2	$0.1	$17.5	$9.3	$8.2
2031	354	$9.3	$8.2	$0.1	$17.7	$9.4	$8.3
2032	357	$9.4	$8.3	$0.1	$17.8	$9.4	$8.4
2033	360	$9.5	$8.4	$0.1	$18.0	$9.5	$8.5
2034	364	$9.5	$8.5	$0.1	$18.1	$9.6	$8.5
2035	367	$9.6	$8.5	$0.1	$18.3	$9.7	$8.6
2036	370	$9.7	$8.6	$0.1	$18.5	$9.8	$8.7
2037	374	$9.8	$8.7	$0.1	$18.6	$9.9	$8.8
2038	377	$9.9	$8.8	$0.1	$18.8	$10.0	$8.9
2039	380	$10.0	$8.9	$0.1	$19.0	$10.0	$8.9
2040	384	$10.1	$8.9	$0.1	$19.1	$10.1	$9.0
NPV at 7%		$54.4	$48.3	$0.8	$103.4	$54.7	$48.7
NPV at 3%		$119.3	$106.0	$1.7	$227.0	$120.2	$106.8

Table 5-33 Annual C1 Marine (>600 kW/805 hp) Engine Variable Costs; Freshly Manufactured Tier 4 Engines Only ($Millions, 2005 dollars)

Calendar Year	Sales	DPF	SCR	Marinization	Total	PM	NO_X+ NMHC
2006							
2007							
2008							
2009							
2010							
2011							
2012	900						
2013	908						
2014	916						
2015	925						
2016	933	$8.4	$8.2	$0.2	$16.7	$8.4	$8.3
2017	941	$8.4	$8.3	$0.2	$16.9	$8.5	$8.4
2018	950	$6.5	$6.4	$0.1	$13.0	$6.6	$6.4
2019	958	$6.6	$6.4	$0.1	$13.1	$6.6	$6.5
2020	967	$6.6	$6.5	$0.1	$13.2	$6.7	$6.6
2021	976	$6.7	$6.5	$0.1	$13.4	$6.7	$6.6
2022	985	$6.7	$6.6	$0.1	$13.5	$6.8	$6.7
2023	993	$6.8	$6.7	$0.1	$13.6	$6.9	$6.7
2024	1002	$6.9	$6.7	$0.1	$13.7	$6.9	$6.8
2025	1011	$6.9	$6.8	$0.1	$13.9	$7.0	$6.9
2026	1020	$7.0	$6.8	$0.1	$14.0	$7.1	$6.9
2027	1030	$7.0	$6.9	$0.1	$14.1	$7.1	$7.0
2028	1039	$7.1	$7.0	$0.1	$14.2	$7.2	$7.0
2029	1048	$7.2	$7.0	$0.2	$14.4	$7.2	$7.1
2030	1058	$7.2	$7.1	$0.2	$14.5	$7.3	$7.2
2031	1067	$7.3	$7.2	$0.2	$14.6	$7.4	$7.2
2032	1077	$7.4	$7.2	$0.2	$14.7	$7.4	$7.3
2033	1086	$7.4	$7.3	$0.2	$14.9	$7.5	$7.4
2034	1096	$7.5	$7.4	$0.2	$15.0	$7.6	$7.4
2035	1106	$7.6	$7.4	$0.2	$15.2	$7.6	$7.5
2036	1116	$7.6	$7.5	$0.2	$15.3	$7.7	$7.6
2037	1126	$7.7	$7.6	$0.2	$15.4	$7.8	$7.6
2038	1136	$7.8	$7.6	$0.2	$15.6	$7.9	$7.7
2039	1146	$7.8	$7.7	$0.2	$15.7	$7.9	$7.8
2040	1157	$7.9	$7.8	$0.2	$15.8	$8.0	$7.8
NPV at 7%		$42.8	$41.9	$0.9	$85.6	$43.2	$42.4
NPV at 3%		$93.9	$92.1	$2.0	$187.9	$94.8	$93.0

Table 5-34 Total Annual Engine Variable Costs; Freshly Manufactured Tier 4 Engines Only ($Millions, 2005 dollars)

Calendar Year	Locomotive	Marine C1	Marine C2	Recreational Marine	Small Commercial Marine	Total	PM	NO_X+ NMHC
2006								
2007								
2008								
2009								
2010								
2011								
2012								
2013								
2014								
2015	$60.0					$60.0	$31.9	$28.1
2016	$62.7	$16.7	$20.2			$99.6	$52.5	$47.1
2017	$49.2	$16.9	$20.4			$86.4	$45.4	$41.0
2018	$50.1	$13.0	$15.7			$78.9	$41.5	$37.3
2019	$51.4	$13.1	$15.9			$80.4	$42.3	$38.1
2020	$53.1	$13.2	$16.0			$82.3	$43.4	$39.0
2021	$54.8	$13.4	$16.1			$84.3	$44.4	$39.9
2022	$56.3	$13.5	$16.3			$86.1	$45.4	$40.7
2023	$58.7	$13.6	$16.4			$88.7	$46.8	$41.9
2024	$59.7	$13.7	$16.6			$90.1	$47.5	$42.6
2025	$61.6	$13.9	$16.7			$92.2	$48.6	$43.6
2026	$62.8	$14.0	$16.9			$93.7	$49.4	$44.2
2027	$64.2	$14.1	$17.0			$95.4	$50.3	$45.0
2028	$65.3	$14.2	$17.2			$96.7	$51.1	$45.7
2029	$66.2	$14.4	$17.3			$97.9	$51.7	$46.2
2030	$66.9	$14.5	$17.5			$98.9	$52.2	$46.7
2031	$67.9	$14.6	$17.7			$100.2	$52.9	$47.3
2032	$69.0	$14.7	$17.8			$101.6	$53.6	$47.9
2033	$70.1	$14.9	$18.0			$102.9	$54.4	$48.6
2034	$71.0	$15.0	$18.1			$104.2	$55.0	$49.1
2035	$71.4	$15.2	$18.3			$104.8	$55.4	$49.5
2036	$69.4	$15.3	$18.5			$103.1	$54.5	$48.7
2037	$67.9	$15.4	$18.6			$102.0	$53.8	$48.1
2038	$66.3	$15.6	$18.8			$100.7	$53.1	$47.5
2039	$64.4	$15.7	$19.0			$99.1	$52.3	$46.8
2040	$62.5	$15.8	$19.1			$97.5	$51.4	$46.1
NPV at 7%	$385.5	$85.6	$103.4			$574.5	$303.1	$271.4
NPV at 3%	$839.9	$187.9	$227.0			$1,254.8	$662.1	$592.8

Table 5-34 shows the net present value of the annual engine variable costs through 2040 as $1.3 billion at a three percent discount rate or $0.6 billion at a seven percent discount rate. These costs are fairly evenly split between NO_x+NMHC and PM.

5.3 Engineering Costs for Freshly Manufactured Equipment

In this section, we present our estimated costs associated with the piece of equipment into which the freshly manufactured engines are placed—i.e., the locomotive itself or the marine vessel itself. In general, we refer generically to equipment rather than specifically to locomotives or vessels. Costs of control to equipment manufacturers include fixed costs (those costs for equipment redesign), and variable costs (for new hardware and increased equipment assembly time).

5.3.1 Fixed Engineering Costs

5.3.1.1 Equipment Redesign Costs

The projected modifications to equipment resulting from the new emission standards relate to the need to package emission control hardware that engine manufacturers will incorporate into their engines. As discussed above, the additional emission control hardware for equipment into which a Tier 4 engine is installed is proportional in size to engine displacement by roughly a 4:1 ratio (2.5x engine displacement for the SCR system and 1.7x engine displacement for the DPF system). We expect that equipment manufacturers will have to redesign their equipment to accommodate this new volume of hardware. As such, we would expect such costs for only those pieces of equipment that will be installing a Tier 4 engine since Tier 3 engines are expected to incorporate controls that will not result in a larger engine or otherwise require any more space within the piece of equipment.

To determine marine-related redesign costs, our first step was to determine the number of vessels sold each year. To estimate vessel sales, we looked first at the number of engines being sold as marine engines. Since only C2 engines and C1 engines >600 kW (805 hp) would be complying with the Tier 4 standards, we limited ourselves to those engines. Further, we eliminated those engines sold as auxiliary engines since we know that there exists a direct correlation between vessel sales and propulsion engine sales because every freshly manufactured vessel will have at least one propulsion engine while having anywhere from zero to many auxiliary engines. Based on the 2002 PSR database and our marine engine sales growth rates, our analysis estimates that, in the year 2015—one year before vessels would be adding engines equipped with aftertreatment devices and, hence, being redesigned—there will be 751 marine C1 propulsion engines >600 kW and 147 marine C2 propulsion engines.

We know that most vessels in these larger marine categories are fitted with more than one engine. In our draft cost analysis, we estimated 1.5 propulsion engines, on average, per vessel. For our final cost analysis, we have increased that to 2 propulsion engines per vessel based on our industry characterization work (see Chapter 1 of this RIA). This results in an estimated 375 marine C1 and 74 marine C2 vessels sold in 2015.

We believe that not every vessel will require a full redesign. Instead, we believe that, while some vessels truly are a one-design/one-vessel effort, many vessels are a one-design/five-vessel or even ten or more-vessel effort. To be conservative and as was done in our draft cost analysis, we have estimated that a redesign effort will accommodate two freshly manufactured vessels. That is, on average, a fleet of 74 freshly manufactured C2 vessels would require 37 redesign efforts. We have estimated the costs per redesign at $50,000 for C1 vessel redesigns and $100,000 for C2 vessel redesigns. These estimates are summarized in Table 5-35.

Table 5-35 Estimated Vessel Redesigns in 2015 and Costs per Redesign (2005 dollars)

	Power Range	Propulsion Engines in 2015	Engines / Vessel	Vessels	Vessels / Redesign	Redesigns	$/Redesign
Marine-C1 propulsion	>800hp	751	2	375	2	188	$50,000
Marine-C2 propulsion	All	147	2	74	2	37	$100,000
Total		898		449		225	

Using these estimates, we can estimate the annual total costs associated with vessel redesigns. But first it is important to note that we do not believe that the vessel fleets will require these redesign efforts every year. Nor will the need to redesign vessels cease once the Tier 4 standards are implemented. Instead, in the second year of implementation we would expect vessel sales to be similar but in many ways different than in year one. Such is the nature of the marine fleet in contrast to say, the automotive fleet where a freshly manufactured vehicle design is typically carried-over for four to six years with no significant redesign. Nonetheless, a first year redesign effort will no doubt make a second year redesign effort less costly given what was learned by redesign and construction firms during the first year. To estimate this effect, we considered year two to require half the effort of year one, year three half again, and year four half again. We then carried this effort forward until we had accumulated at least 1,000 redesigns which, we believe, is sufficient to have fully redesigned the applicable fleet. The number of marine redesign efforts and the annual total costs are shown in Table 5-36.

Table 5-36 Estimated Total Number of Vessel Redesigns and the Associated Annual Costs; Freshly Manufactured Tier 4 Equipment only (monetary entries are in $Millions, 2005 dollars)

Calendar Year	C1 Redesigns	C2 Redesigns	Annual Total Redesigns	Cumulative Redesigns	C1 Redesign Costs	C2 Redesign Costs	Annual Total Costs	PM	NO_X+NMHC
2006									
2007									
2008									
2009									
2010									
2011									
2012									
2013									
2014									
2015	188	37	224	224	$9.4	$3.7	$13.1	$6.5	$6.5
2016	90	20	110	334	$4.5	$2.0	$6.5	$3.3	$3.3
2017	50	10	60	394	$2.5	$1.0	$3.5	$1.8	$1.8
2018	30	10	40	434	$1.5	$1.0	$2.5	$1.3	$1.3
2019	30	10	40	474	$1.5	$1.0	$2.5	$1.3	$1.3
2020	30	10	40	514	$1.5	$1.0	$2.5	$1.3	$1.3
2021	30	10	40	554	$1.5	$1.0	$2.5	$1.3	$1.3
2022	30	10	40	594	$1.5	$1.0	$2.5	$1.3	$1.3
2023	30	10	40	634	$1.5	$1.0	$2.5	$1.3	$1.3
2024	30	10	40	674	$1.5	$1.0	$2.5	$1.3	$1.3
2025	30	10	40	714	$1.5	$1.0	$2.5	$1.3	$1.3
2026	30	10	40	754	$1.5	$1.0	$2.5	$1.3	$1.3
2027	30	10	40	794	$1.5	$1.0	$2.5	$1.3	$1.3
2028	30	10	40	834	$1.5	$1.0	$2.5	$1.3	$1.3
2029	30	10	40	874	$1.5	$1.0	$2.5	$1.3	$1.3
2030	30	10	40	914	$1.5	$1.0	$2.5	$1.3	$1.3
2031	30	10	40	954	$1.5	$1.0	$2.5	$1.3	$1.3
2032	30	10	40	994	$1.5	$1.0	$2.5	$1.3	$1.3
2033	30	10	40	1,034	$1.5	$1.0	$2.5	$1.3	$1.3
2034									
2035									
2036									
2037									
2038									
2039									
2040									
Total					$40.4	$22.7	$63.1	$31.5	$31.5
NPV at 7%					$14.3	$7.5	$21.8	$10.9	$10.9
NPV at 3%					$25.2	$13.7	$38.9	$19.4	$19.4

For locomotive redesign efforts, we believe that the cost per redesign should be roughly equivalent to that for a C2 marine vessel, or $100,000 dollars per redesign, since the engine sizes and corresponding aftertreatment sizes should be roughly the same. Unlike the marine industry, the locomotive industry generally sells many of units of the same design. In fact, we estimate that there are only seven locomotive models—two line haul and five switcher—that comprise the hundreds of locomotives sold each year. Therefore, we have estimated that one redesign effort per model will suffice. The number of locomotive redesign efforts and the annual total costs are shown in Table 5-37.

Table 5-37 Estimated Total Number of Locomotive Redesigns and the Associated Annual Costs; Freshly Manufactured Tier 4 Equipment only (monetary entries are in $Millions, 2005 dollars)

Calendar Year	Line haul Redesigns	Switcher Redesigns	Line haul Redesign Costs	Switcher Redesign Costs	Annual Total Costs	PM	NO_X+ NMHC
2006							
2007							
2008							
2009							
2010							
2011							
2012							
2013							
2014	2	5	$0.2	$0.5	$0.7	$0.4	$0.4
2015							
2016							
2017							
2018							
2019							
2020							
2021							
2022							
2023							
2024							
2025							
2026							
2027							
2028							
2029							
2030							
2031							
2032							
2033							
2034							
2035							
2036							
2037							
2038							
2039							
2040							
Total			$0.2	$0.5	$0.7	$0.4	$0.4
NPV at 7%			$0.1	$0.3	$0.4	$0.2	$0.2
NPV at 3%			$0.2	$0.4	$0.5	$0.3	$0.3

The net present value of the vessel redesign costs are estimated at $39 million using a three percent discount rate and at $22 million using a seven percent discount rate. The net present value of the locomotive redesign costs are estimated at $0.5 million using a three percent discount rate and at $0.4 million using a seven percent discount rate. In total, the net present value of the equipment redesign costs are estimated at $40 million using a three percent discount rate and at $22 million using a seven percent discount rate. These equipment redesign costs are split evenly between NO_x+NMHC and PM control.

5.3.2 Variable Engineering Costs

As discussed above, we are projecting that SCR systems and DPFs will be the most likely technologies used to comply with the Tier 4 standards. Upon installation in a freshly manufactured locomotive or a freshly manufactured marine vessel, these devices would require some new equipment related hardware in the form of brackets and/or new sheet metal. Based on engineering judgement, we estimated this cost as shown in Table 5-38. Since the equipment variable costs are linked closely with the size of aftertreatment devices being installed (i.e., the large the diesel engine being installed in the piece of equipment, the larger the aftertreatment devices and, therefore, the larger the necessary brackets and/or greater the necessary sheet metal), it makes sense to scale the equipment hardware costs accordingly. Note that these costs would be incurred by only those pieces of equipment required to comply with the Tier 4 standards. Note also that we termed these costs “equipment variable costs” in our draft cost analysis and have more precisely named them “aftertreatment housing” costs for our final cost analysis. This helps to distinguish them from the reductant system costs, discussed below, that were included as engine-related costs in our draft analysis but are considered equipment-related costs in the final analysis. These two cost elements – aftertreatment housing and reductant system – now constitute the overall equipment variable costs.

Table 5-38 Estimated Aftertreatment Housing Costs per Piece of Freshly Manufactured Equipment (2005 dollars)

	$/piece of equipment
Locomotive Line-haul	$4,000
Locomotive Switcher	$4,000
Marine C1 (600-1492 kW; 805-2000 hp)	$2,000
Marine C1 (>1492 kW; >2000 hp)	$4,000
Marine C2 (600-1492 kW; 805-2000 hp)	$2,000
Marine C2 (>1492 kW; >2000 hp)	$4,000

For our final cost analysis, we have removed reductant tank and controller costs from the engine-related SCR system costs and are accounting for these costs at the equipment level. We have chosen to do so because we believe it is most appropriate given that some equipment, especially vessels, would be equipped with more than one engine but probably only one reductant tank and dosing controller to accommodate all engines.

For the reductant tank, just as was done in our draft cost analysis, the estimated costs for the reductant solution tank and brackets is based on industry input that fuel tank size is roughly one gallon per engine horsepower and reductant dosing rate is roughly four percent of the fueling rate. We also estimated that a reductant tank would cost $60 per 10 gallons of capacity. Using these estimates, the needed reductant tank size and associated cost can be estimated.

We have increased the final cost estimates for the reductant dosing controller based on input from EMA, although we have not used all of the EMA estimates directly. In their comments, EMA estimated the cost of a dosing panel at $10,000 to ~$15,000 per vessel, depending on power, and the cost of the dosing controls at $20,000 per vessel. We believe that those estimates were based on discussions with retrofit companies who, we have no doubt, are today charging those types of prices for those items. However, we believe that once the 2007/2010 HD highway truck program is underway, control and dosing system hardware will be available at a small fraction of today's retrofit price. In our draft analysis, we estimated the cost of the controller and reductant injector at $500. After considering EMA's comments, we believe that cost estimate was more applicable to a higher production quantity market (i.e., highway/nonroad production). For our final analysis, while the reductant injector itself remains part of the SCR catalyst system (described in section 5.2.2.1), we have estimated that the reductant dosing panel and controller will cost 10% of the amounts estimated by EMA. We base that on the cost of new DPF and/or SCR systems being roughly 10% of the cost of typical retrofit systems. For the same reasons, we have applied the same 10% factor to EMA's estimates for a reductant tank heater (EMA estimated at $500) and a reductant pump (EMA estimated at $4,400), neither of which were included in our draft cost analysis but are included in our final cost analysis. We used the same methodology as described in section 5.2.2 (with the exception that we have not estimated any learning from the highway program that will reduce costs in the locomotive and marine program) to determine the final cost of the reductant system including labor and markups, etc., and these are shown in Table 5-39.

Table 5-39. Estimated Reductant Tank and Dosing System Cost per Piece of Freshly Manufactured Equipment (2005 dollars)

Typical Equipment Power (kW)	1400	10000
Material and Component Costs		
Reductant Solution Tank & Brackets	$450	$3,217
Reductant Tank Heaters & Pumps	$490	$490
Reductant dosing panel & controls	$3,000	$3,518
Direct Labor Costs		
Estimated Labor hours	$2	$2
Labor Rate ($/hr)	$18	$18
Labor Cost	$36	$36
Labor Overhead @ 40%	$14	$14
Total Direct Costs to Mfr.	$3,991	$7,276
Warranty Cost (3% claim rate)	$302	$548
Mfr. Carrying Cost - Near term	$160	$291
Total Cost to Dealer - Near term	$4,452	$8,115
Dealer Carrying Cost - Near term	$134	$243
Baseline Cost to Buyer - Near term	$4,586	$8,358
L/M Cost to Buyer (includes no Highway Learning) - Near term	**$4,586**	**$8,358**
Warranty Cost (1% claim rate)	$101	$183
Mfr. Carrying Cost - Long term	$160	$291
Total Cost to Dealer - Long term	$4,251	$7,749
Dealer Carrying Cost - Long term	$128	$232
Baseline Cost to Buyer - Long term	$4,379	$7,982
Baseline Cost to Buyer (includes no Highway Learning) - Long term	$4,379	$7,982
L/M Cost to Buyer (includes Loco/Marine Learning) - Long term	**$3,503**	**$6,385**

We have used the lower costs shown in Table 5-39 for locomotive switchers and vessels equipped with propulsion engines in the 800 to 2000 horsepower range (~600-1500kW) and the higher costs for locomotive line-haul and vessels equipped with propulsion engines over 2000 horsepower. Note that, for marine, we estimate two Tier 4 propulsion engines per vessel in those power ranges and nearly two (1.9 on average) auxiliary engines per vessel.[25] For vessels in the 800 to 2000 horsepower range, we anticipate that Tier 3 auxiliary engines will be used which will not require reductant tank capacity. Looking at the sales weighted horsepowers shown in Table 5-28 we can estimate total vessel power requiring urea which, for vessels powered by 800 to 2000 horsepower engines, we estimate at just under 2000 kW for C1 vessels and just under 2300 kW for C2 vessels. For the over 2000 horsepower vessels, we similarly anticipate two Tier 4 propulsion engines and nearly two Tier 4 auxiliary engines (rather than Tier 3) which will require urea tank capacity. Looking at the sales weighted horsepowers shown in Table 5-28 we can estimate total vessel power requiring reductant which, for vessels powered by over 2000 horsepower engines, we estimate at just under 6300 kW for C1 vessels and just under 12,000 kW for C2 vessels. Therefore, the costs shown in Table 5-39 are roughly appropriate.

Using these costs and estimated future sales of locomotives and vessels, we can estimate the annual costs for the fleet. These costs are shown in Table 5-40 for locomotives, Table 5-41 for C1 marine, and Table 5-42 for C2 marine. Table 5-43 summarizes these costs and presents the total costs. As shown, we estimate the net present value of annual equipment variable costs at $220 million using a three percent discount rate and $100 million using a seven percent discount rate. These costs are split evenly between NO_x+NMHC and PM control.

Table 5-40 Annual Locomotive Variable Costs; Freshly Manufactured Tier 4 Equipment Only ($Millions, 2005 dollars)

Calendar Year	Locomotive Line Haul				Locomotive Switcher			
	Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal	Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal
2006								
2007								
2008								
2009								
2010								
2011								
2012								
2013								
2014								
2015	816	$3.3	$6.8	$10.1	93	$0.4	$0.4	$0.8
2016	854	$3.4	$7.1	$10.6	94	$0.4	$0.4	$0.8
2017	877	$3.5	$5.6	$9.1	94	$0.4	$0.3	$0.7
2018	894	$3.6	$5.7	$9.3	94	$0.4	$0.3	$0.7
2019	917	$3.7	$5.9	$9.5	94	$0.4	$0.3	$0.7
2020	948	$3.8	$6.1	$9.8	94	$0.4	$0.3	$0.7
2021	979	$3.9	$6.2	$10.2	94	$0.4	$0.3	$0.7
2022	1,007	$4.0	$6.4	$10.5	95	$0.4	$0.3	$0.7
2023	1,034	$4.1	$6.6	$10.7	160	$0.6	$0.6	$1.2
2024	1,048	$4.2	$6.7	$10.9	183	$0.7	$0.6	$1.4
2025	1,078	$4.3	$6.9	$11.2	201	$0.8	$0.7	$1.5
2026	1,096	$4.4	$7.0	$11.4	212	$0.8	$0.7	$1.6
2027	1,119	$4.5	$7.1	$11.6	227	$0.9	$0.8	$1.7
2028	1,136	$4.5	$7.3	$11.8	239	$1.0	$0.8	$1.8
2029	1,150	$4.6	$7.3	$11.9	247	$1.0	$0.9	$1.9
2030	1,158	$4.6	$7.4	$12.0	263	$1.1	$0.9	$2.0
2031	1,173	$4.7	$7.5	$12.2	281	$1.1	$1.0	$2.1
2032	1,190	$4.8	$7.6	$12.4	292	$1.2	$1.0	$2.2
2033	1,209	$4.8	$7.7	$12.6	296	$1.2	$1.0	$2.2
2034	1,223	$4.9	$7.8	$12.7	305	$1.2	$1.1	$2.3
2035	1,231	$4.9	$7.9	$12.8	302	$1.2	$1.1	$2.3
2036	1,197	$4.8	$7.6	$12.4	294	$1.2	$1.0	$2.2
2037	1,172	$4.7	$7.5	$12.2	287	$1.1	$1.0	$2.2
2038	1,144	$4.6	$7.3	$11.9	278	$1.1	$1.0	$2.1
2039	1,112	$4.4	$7.1	$11.6	269	$1.1	$0.9	$2.0
2040	1,078	$4.3	$6.9	$11.2	263	$1.1	$0.9	$2.0
NPV at 7%		$26.1	$43.3	$69.4		$4.3	$3.9	$8.2
NPV at 3%		$57.4	$94.0	$151.4		$10.3	$9.2	$19.5

Table 5-41 Annual C1 Marine Vessel Variable Costs; Freshly Manufactured Tier 4 Equipment Only ($Millions, 2005 dollars)

Calendar Year	C1 800-2000hp				C1 >2000hp			
	Vessel Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal	Vessel Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal
2006								
2007								
2008								
2009								
2010								
2011								
2012								
2013								
2014								
2015								
2016	268	$0.5	$1.2	$1.8	111	$0.4	$0.9	$1.4
2017	270	$0.5	$1.2	$1.8	112	$0.4	$0.9	$1.4
2018	272	$0.5	$1.0	$1.5	113	$0.5	$0.7	$1.2
2019	275	$0.5	$1.0	$1.5	114	$0.5	$0.7	$1.2
2020	277	$0.6	$1.0	$1.5	115	$0.5	$0.7	$1.2
2021	280	$0.6	$1.0	$1.5	116	$0.5	$0.7	$1.2
2022	282	$0.6	$1.0	$1.6	117	$0.5	$0.7	$1.2
2023	285	$0.6	$1.0	$1.6	118	$0.5	$0.8	$1.2
2024	287	$0.6	$1.0	$1.6	119	$0.5	$0.8	$1.2
2025	290	$0.6	$1.0	$1.6	120	$0.5	$0.8	$1.3
2026	293	$0.6	$1.0	$1.6	122	$0.5	$0.8	$1.3
2027	295	$0.6	$1.0	$1.6	123	$0.5	$0.8	$1.3
2028	298	$0.6	$1.0	$1.6	124	$0.5	$0.8	$1.3
2029	301	$0.6	$1.1	$1.7	125	$0.5	$0.8	$1.3
2030	303	$0.6	$1.1	$1.7	126	$0.5	$0.8	$1.3
2031	306	$0.6	$1.1	$1.7	127	$0.5	$0.8	$1.3
2032	309	$0.6	$1.1	$1.7	128	$0.5	$0.8	$1.3
2033	312	$0.6	$1.1	$1.7	129	$0.5	$0.8	$1.3
2034	314	$0.6	$1.1	$1.7	131	$0.5	$0.8	$1.4
2035	317	$0.6	$1.1	$1.7	132	$0.5	$0.8	$1.4
2036	320	$0.6	$1.1	$1.8	133	$0.5	$0.8	$1.4
2037	323	$0.6	$1.1	$1.8	134	$0.5	$0.9	$1.4
2038	326	$0.7	$1.1	$1.8	135	$0.5	$0.9	$1.4
2039	329	$0.7	$1.2	$1.8	137	$0.5	$0.9	$1.4
2040	332	$0.7	$1.2	$1.8	138	$0.6	$0.9	$1.4
NPV at 7%		$3.4	$6.3	$9.7		$2.8	$4.8	$7.6
NPV at 3%		$7.6	$13.8	$21.4		$6.3	$10.4	$16.8

Table 5-42 Annual C2 Marine Vessel Variable Costs; Freshly Manufactured Tier 4 Equipment Only ($Millions, 2005 dollars)

Calendar Year	C2 800-2000hp				C2 >2000hp			
	Vessel Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal	Vessel Sales	Aftertreatment Housing Costs	Reductant System Costs	Subtotal
2006								
2007								
2008								
2009								
2010								
2011								
2012								
2013								
2014								
2015								
2016	3	$0.0	$0.0	$0.0	71	$0.3	$0.6	$0.9
2017	3	$0.0	$0.0	$0.0	71	$0.3	$0.6	$0.9
2018	3	$0.0	$0.0	$0.0	72	$0.3	$0.5	$0.7
2019	3	$0.0	$0.0	$0.0	73	$0.3	$0.5	$0.8
2020	4	$0.0	$0.0	$0.0	73	$0.3	$0.5	$0.8
2021	4	$0.0	$0.0	$0.0	74	$0.3	$0.5	$0.8
2022	4	$0.0	$0.0	$0.0	75	$0.3	$0.5	$0.8
2023	4	$0.0	$0.0	$0.0	75	$0.3	$0.5	$0.8
2024	4	$0.0	$0.0	$0.0	76	$0.3	$0.5	$0.8
2025	4	$0.0	$0.0	$0.0	77	$0.3	$0.5	$0.8
2026	4	$0.0	$0.0	$0.0	77	$0.3	$0.5	$0.8
2027	4	$0.0	$0.0	$0.0	78	$0.3	$0.5	$0.8
2028	4	$0.0	$0.0	$0.0	79	$0.3	$0.5	$0.8
2029	4	$0.0	$0.0	$0.0	80	$0.3	$0.5	$0.8
2030	4	$0.0	$0.0	$0.0	80	$0.3	$0.5	$0.8
2031	4	$0.0	$0.0	$0.0	81	$0.3	$0.5	$0.8
2032	4	$0.0	$0.0	$0.0	82	$0.3	$0.5	$0.8
2033	4	$0.0	$0.0	$0.0	83	$0.3	$0.5	$0.9
2034	4	$0.0	$0.0	$0.0	83	$0.3	$0.5	$0.9
2035	4	$0.0	$0.0	$0.0	84	$0.3	$0.5	$0.9
2036	4	$0.0	$0.0	$0.0	85	$0.3	$0.5	$0.9
2037	4	$0.0	$0.0	$0.0	86	$0.3	$0.5	$0.9
2038	4	$0.0	$0.0	$0.0	86	$0.3	$0.6	$0.9
2039	4	$0.0	$0.0	$0.0	87	$0.3	$0.6	$0.9
2040	4	$0.0	$0.0	$0.0	88	$0.4	$0.6	$0.9
NPV at 7%		$0.0	$0.1	$0.1		$1.8	$3.0	$4.8
NPV at 3%		$0.1	$0.2	$0.3		$4.0	$6.7	$10.7

Table 5-43 Annual Equipment Variable Costs; Freshly Manufactured Tier 4 Equipment Only ($Millions, 2005 dollars)

Calendar Year	Locomotive	Marine	Annual Total Costs	PM	NO_X+ NMHC
2006					
2007					
2008					
2009					
2010					
2011					
2012					
2013					
2014					
2015	$10.9		$10.9	$5.4	$5.4
2016	$11.4	$4.0	$15.4	$7.7	$7.7
2017	$9.8	$4.1	$13.9	$6.9	$6.9
2018	$10.0	$3.4	$13.4	$6.7	$6.7
2019	$10.2	$3.5	$13.7	$6.9	$6.9
2020	$10.6	$3.5	$14.1	$7.0	$7.0
2021	$10.9	$3.5	$14.4	$7.2	$7.2
2022	$11.2	$3.6	$14.7	$7.4	$7.4
2023	$11.9	$3.6	$15.5	$7.8	$7.8
2024	$12.3	$3.6	$15.9	$7.9	$7.9
2025	$12.7	$3.7	$16.4	$8.2	$8.2
2026	$13.0	$3.7	$16.7	$8.3	$8.3
2027	$13.3	$3.7	$17.1	$8.5	$8.5
2028	$13.6	$3.8	$17.4	$8.7	$8.7
2029	$13.8	$3.8	$17.6	$8.8	$8.8
2030	$14.0	$3.8	$17.8	$8.9	$8.9
2031	$14.3	$3.9	$18.2	$9.1	$9.1
2032	$14.6	$3.9	$18.5	$9.2	$9.2
2033	$14.8	$3.9	$18.7	$9.4	$9.4
2034	$15.0	$4.0	$19.0	$9.5	$9.5
2035	$15.0	$4.0	$19.1	$9.5	$9.5
2036	$14.6	$4.0	$18.7	$9.3	$9.3
2037	$14.3	$4.1	$18.4	$9.2	$9.2
2038	$14.0	$4.1	$18.1	$9.0	$9.0
2039	$13.6	$4.2	$17.7	$8.9	$8.9
2040	$13.2	$4.2	$17.4	$8.7	$8.7
NPV at 7%	$77.6	$22.3	$99.9	$49.9	$49.9
NPV at 3%	$170.9	$49.1	$220.0	$110.0	$110.0

5.4 Operating Costs for Freshly Manufactured Tier 4 Engines

We anticipate an increase in costs associated with operating locomotives and marine vessels. We anticipate three sources of increased operating costs: urea use; DPF maintenance; and a fuel consumption impact. Increased operating costs associated with urea use would occur only in those locomotives/vessels equipped with a urea SCR engine. Maintenance costs associated with the DPF (for periodic cleaning of accumulated ash resulting from unburned material that accumulates in the DPF) would occur in those locomotives/vessels that are equipped with a DPF engine. The fuel consumption impact is anticipated to occur more broadly—we expect that a one percent fuel consumption increase would occur for all freshly manufactured Tier 4 locomotive and marine engines due to higher exhaust backpressure resulting from aftertreatment devices. We also expect a one percent fuel consumption increase would occur for remanufactured Tier 0 locomotives and two percent for C2 marine engines due to our expectation that the tighter NO_x standard may in part be met using retarded fuel injection timing. The operating costs associated with the remanufacturing program are presented in section 5.5

5.4.1 Increased Operating Costs Associated with Urea Use

Freshly manufactured Tier 4 engines are expected to be equipped with SCR systems. The costs associated with the SCR system, including the reductant tank and dosing system, are discussed in section 5.2.2.1 of this chapter. To estimate the costs associated with reductant use, we first considered the dosage rate. For this analysis, we have used a dosing rate of four percent reductant to every gallon of fuel burned. Using our marine and locomotive emissions analysis work (see Chapter 3 of this RIA), we can determine the gallons of fuel burned every year by SCR equipped pieces of equipment. The amount of reductant used each year is then four percent of those gallons.

The cost per gallon of reductant would be dependent on the volume dispensed at each facility, with smaller refueling sites experiencing higher costs. The type of reductant storage/dispensing equipment, and the ultimate cost-per-gallon, for railroad and marine industries will depend on the volume of fuel and reductant dispensed at each site. We expect that the most common reductant will be urea and estimate that high-volume fixed sites may choose to mix emissions-grade dry urea (or urea liquor) and de-mineralized water on-site, whereas others may choose bulk or container delivery of a pre-mixed 32.5 percent urea-water solution.[I] In 2015, one source suggests that urea cost is expected to be ~$0.75/gallon for retail facilities dispensing 200,000 - 1,000,000 gallons/month, and ~$1.00/gallon for those dispensing 80,000 - 200,000 gallons/month.[26] With the implementation of SCR for the on-highway truck fleet in 2010, the economic factors for each urea supply option will be well-known prior to implementation of the 2015 and 2016 NO_x standards for locomotive and

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[I] While the discussion here is focussed on urea as a reductant, other reductants may be used and, if used, we would expect them to be used only if they result in lower costs than urea. As such, we believe our estimates, based on urea as the reductant, are conservative.

marine engines, respectively.[J] In our draft cost analysis, we used a value of $1.00/gallon of urea. To remain conservative and based on input from comments, for the final cost analysis we have used a urea cost of $1.34/gallon. This cost should cover the costs associated with distributing urea to the necessary point of transfer to locomotive and/or vessel (i.e., the necessary infrastructure). The resultant increased operating costs associated with urea use are presented in section 5.4.4. The costs associated with urea use are attributed solely to NO_x+NMHC control.

5.4.2 Increased Operating Costs Associated with DPF Maintenance

The maintenance demands associated with the addition of DPF hardware are discussed in Chapter 4 of this RIA. For this analysis, we have estimated a maintenance interval of 200,000 gallons of fuel burned between DPF ash maintenance events. For a typical locomotive engine having ~4000 hp this equates to roughly 7000 hours of operation between maintenance events. By comparison, our NRT4 rule estimated a maintenance interval of 3,000 hours for engines under 175 hp and 4,500 hours for engines over 750 hp. We believe that the estimate of nearly 7,000 hours for the size engines used in applicable marine vessels and locomotives is appropriate, especially given potential use of “flow-through” DPF technologies as discussed in Chapter 4 of this RIA. We have also estimated the ash maintenance event to take four hours per event at $50 per hour for labor, or $200 per event.

By using only those gallons burned in DPF equipped engines, we are then able to calculate the maintenance costs associated with DPF maintenance. These costs are presented in section 5.4.4. The costs associated with DPF maintenance are attributed solely to PM control.

5.4.3 Increased Operating Costs Associated with Fuel Consumption Impacts

The high efficiency emission-control technologies expected to be used to meet the Tier 4 standards involve wholly new system components integrated into engine designs and calibrations and, as such, would be expected to change the fuel consumption characteristics of the overall engine design. After reviewing the likely technology options available to the engine manufacturers, we believe the integration of the engine and exhaust emission-control systems into a single synergistic emission-control system will lead to locomotive and marine engines that can meet demanding emission-control targets with only a small impact on fuel consumption. Technology improvements have historically eliminated these marginal impacts in the past and it is our expectation that this kind of continuing improvement will eliminate the modest impact estimated here. However, because we cannot project the time frame for

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[J] Note that some marine C2 engines will meet the Tier 4 standards beginning in 2014. The operating costs presented here in section 5.4 reflect that implementation schedule while the engine and equipment costs presented in sections 5.2 and 5.3 do not. In those earlier sections, we chose to present all marine costs as though their standards began in 2016 for ease of presentation. However, the operating costs are linked directly to gallons burned which are, in turn, linked directly to emission inventories and reductions. Because our inventory and emission reduction analysis must correspond directly to the actual implementation of the standards, our operating costs are likewise presented according to the actual implementation of standards. Therefore, the marine C2 operating costs are shown as beginning in 2014.

when this improvement would be realized, we have included this impact in our cost estimates for the full period of the program to avoid underestimating costs.

Diesel particulate filters are anticipated to provide a step-wise decrease in PM emissions by trapping and oxidizing the PM. The trapping of the very fine diesel PM is accomplished by forcing the exhaust through a porous filtering media with extremely small openings and long path lengths. This approach, called a wall flow filter, results in filtering efficiencies for diesel PM greater than 90 percent but requires additional pumping work to force the exhaust through these small openings. The impact of this additional pumping work on fuel consumption is dependent on engine operating conditions. At low exhaust flow conditions (i.e., low engine load, low turbocharger boost levels), the impact is so small that it typically cannot be measured, while at very high load conditions, with high exhaust flow conditions, the fuel economy impact can be as large as one to two percent. In our NRT4 rule, for wall flow filters, we estimated that the average impact of this increased pumping work was equivalent to an increased fuel consumption of approximately one percent. To be conservative in this analysis, we have used this one percent impact regardless of DPF technology even though the flow through technology that may be used is expected to have a lower impact on fuel consumption because it results in less pumping work to force the exhaust through the device.

As for the urea SCR system, we do not expect a fuel consumption increase associated with this device. Urea SCR catalysts are flow through devices and while they do indeed represent a slight increase in backpressure (i.e., increased pumping work to force exhaust through the device), we expect that impact to be easily offset through engine control changes that take advantage of the high NO_x conversion afforded by the SCR system. Therefore, in total, we expect a one percent fuel consumption increase for all freshly manufactured Tier 4 engines.

Using the gallons burned in freshly manufactured DPF equipped engines and, for line-haul and passenger locomotives, the gallons burned in remanufactured Tier 0 engines, along with an estimated diesel fuel price less taxes of $1.57/gallon, the costs associated with a fuel consumption impact can be calculated.[K] These costs are presented in section 5.4.4 of this chapter. The costs associated with the fuel consumption impact are split evenly between NO_x and PM control.

[K] To estimate the diesel fuel price, we started with the annual average nationwide price for 2006 for high sulfur diesel fuel (excluding taxes) sold to commercial consumers from Table 41 of the Energy Information Administration (EIA) Petroleum Marketing Annual 2006. We adjusted this 2006 price of $2.03/gallon to a 2012 price using the ratio of projected consumer purchased diesel fuel price in 2012 to the consumer purchased diesel fuel price in 2006 as reported in Table 12 of the Annual Energy Outlook (AEO) 2007. We chose to use the actual price in 2006 as the basis for estimating the future price, instead of directly relying on the projected prices in AEO 2007, because refinery models, like the one used for the AEO, are better at estimating changes in prices than they are at estimating actual prices. The actual price is a function of all the market forces that shape the price, whereas refinery models can only approximately estimate these effects. Note that, in the draft cost analysis, we used a value of $1.24/gallon of diesel fuel. As a result, if we exclude C2 marine remanufacturing program fuel consumption impact which were not considered in the draft cost analysis, the fuel consumption cost estimates are roughly 27% higher in the final cost analysis.

Note that, as discussed in sections 4.2 and 5.2.2, we expect marine Tier 3 engines to generally be recalibrated and marinized nonroad engines originally developed to meet nonroad Tier 4 standards, except for the application of aftertreatment needed to meet nonroad Tier 4 but not marine Tier 3. These advanced engines represent significant technical advances from the marine Tier 2 engines— having better high pressure fuel systems, better injectors, improved turbochargers, and more sophisticated electronic control units. Likewise, they are expected to have brake specific fuel consumption that is as good as, or better than, that of marine Tier 2 engines, while producing significantly less NOx. We have therefore conservatively assumed no impact of the marine Tier 3 standards on fuel consumption.

5.4.4 Total Increased Operating Costs Associated with Freshly Manufactured Tier 4 Engines

The increased annual operating costs for each applicable market segment—locomotive line haul; switcher/passenger; marine C1>600 kW; marine C2—are presented in Table 5-44, Table 5-45, Table 5-46, and Table 5-47, respectively. These costs are summarized to give the total increased operating costs in Table 5-48. Table 5-49 shows the increased operating costs by cost element—reductant, DPF maintenance, and fuel consumption impact.

Note that operating costs are attributed as follows: costs associated with reductant use are attributed solely to NO_x+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; and, costs associated with the fuel consumption impact are split evenly between NO_x+NMHC and PM control.

Table 5-44 Estimated Increased Operating Costs for Freshly Manufactured Tier 4 Line Haul Locomotives (monetary entries in 2005 dollars)

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Reductant Usage (MM gal)	Annual Reductant Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Costs ($MM)
2006										
2007										
2008										
2009										
2010										
2011										
2012										
2013										
2014										
2015	207	8	$11.1	207	1036	$0.2	207	2	$3.3	$14.6
2016	423	17	$22.7	423	2117	$0.4	423	4	$6.6	$29.8
2017	645	26	$34.6	645	3224	$0.6	645	6	$10.1	$45.3
2018	870	35	$46.6	870	4350	$0.9	870	9	$13.7	$61.1
2019	1100	44	$58.9	1100	5499	$1.1	1100	11	$17.3	$77.3
2020	1337	53	$71.6	1337	6683	$1.3	1337	13	$21.0	$93.9
2021	1581	63	$84.7	1581	7905	$1.6	1581	16	$24.8	$111.1
2022	1833	73	$98.2	1833	9163	$1.8	1833	18	$28.8	$128.8
2023	2091	84	$112.1	2091	10456	$2.1	2091	21	$32.8	$147.0
2024	2349	94	$125.9	2349	11747	$2.3	2349	23	$36.9	$165.1
2025	2611	104	$139.9	2611	13055	$2.6	2611	26	$41.0	$183.5
2026	2873	115	$154.0	2873	14365	$2.9	2873	29	$45.1	$202.0
2027	3136	125	$168.1	3136	15682	$3.1	3136	31	$49.2	$220.5
2028	3400	136	$182.2	3400	17001	$3.4	3400	34	$53.4	$239.0
2029	3663	147	$196.4	3663	18317	$3.7	3663	37	$57.5	$257.5
2030	3925	157	$210.4	3925	19623	$3.9	3925	39	$61.6	$275.9
2031	4185	167	$224.3	4185	20926	$4.2	4185	42	$65.7	$294.2
2032	4445	178	$238.3	4445	22227	$4.4	4445	44	$69.8	$312.5
2033	4706	188	$252.2	4706	23529	$4.7	4706	47	$73.8	$330.8
2034	4965	199	$266.1	4965	24825	$5.0	4965	50	$77.9	$349.0
2035	5221	209	$279.8	5221	26105	$5.2	5221	52	$81.9	$367.0
2036	5466	219	$293.0	5466	27329	$5.5	5466	55	$85.8	$384.2
2037	5702	228	$305.6	5702	28510	$5.7	5702	57	$89.5	$400.8
2038	5929	237	$317.8	5929	29647	$5.9	5929	59	$93.0	$416.8
2039	6147	246	$329.5	6147	30736	$6.1	6147	61	$96.5	$432.1
2040	6355	254	$340.6	6355	31777	$6.4	6355	64	$99.7	$446.7
NPV at 7%			$814.1			$15.2			$238.3	$1,067.6
NPV at 3%			$2,100.0			$39.2			$614.8	$2,754.0

Table 5-45 Estimated Increased Operating Costs for Freshly Manufactured Tier 4 Switcher & Passenger Locomotives (monetary entries in 2005 dollars)

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Reductant Usage (MM gal)	Annual Reductant Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Tier 4 Passenger Fuel Usage (MM gal)	Increased Passenger Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Costs ($MM)
2006										
2007										
2008										
2009										
2010										
2011										
2012										
2013										
2014										
2015	10	0	$0.6	10	51	$0.0	7	0	$0.1	$0.7
2016	21	1	$1.1	21	104	$0.0	14	0	$0.2	$1.4
2017	31	1	$1.7	31	156	$0.0	22	0	$0.3	$2.0
2018	42	2	$2.2	42	209	$0.0	29	0	$0.5	$2.7
2019	53	2	$2.8	53	263	$0.1	36	0	$0.6	$3.4
2020	63	3	$3.4	63	317	$0.1	44	0	$0.7	$4.1
2021	74	3	$4.0	74	371	$0.1	51	1	$0.8	$4.9
2022	85	3	$4.6	85	426	$0.1	58	1	$0.9	$5.6
2023	101	4	$5.4	101	505	$0.1	66	1	$1.0	$6.5
2024	119	5	$6.4	119	594	$0.1	73	1	$1.1	$7.6
2025	138	6	$7.4	138	691	$0.1	80	1	$1.3	$8.8
2026	159	6	$8.5	159	793	$0.2	88	1	$1.4	$10.0
2027	180	7	$9.7	180	902	$0.2	95	1	$1.5	$11.3
2028	203	8	$10.9	203	1016	$0.2	102	1	$1.6	$12.7
2029	227	9	$12.2	227	1137	$0.2	109	1	$1.7	$14.1
2030	253	10	$13.6	253	1265	$0.3	116	1	$1.8	$15.6
2031	281	11	$15.0	281	1404	$0.3	123	1	$1.9	$17.3
2032	310	12	$16.6	310	1549	$0.3	131	1	$2.0	$19.0
2033	340	14	$18.2	340	1699	$0.3	138	1	$2.2	$20.7
2034	371	15	$19.9	371	1856	$0.4	146	1	$2.3	$22.6
2035	403	16	$21.6	403	2014	$0.4	154	2	$2.4	$24.4
2036	434	17	$23.3	434	2170	$0.4	161	2	$2.5	$26.2
2037	464	19	$24.9	464	2322	$0.5	168	2	$2.6	$28.0
2038	494	20	$26.5	494	2472	$0.5	173	2	$2.7	$29.7
2039	524	21	$28.1	524	2619	$0.5	178	2	$2.8	$31.4
2040	553	22	$29.6	553	2764	$0.6	183	2	$2.9	$33.0
NPV at 7%			$52.1			$1.0			$7.2	$60.3
NPV at 3%			$141.3			$2.6			$18.5	$162.4

Table 5-46 Estimated Increased Operating Costs for Freshly Manufactured Tier 4 Marine C1 Engines >600 kW (monetary entries in 2005 dollars)

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Reductant Usage (MM gal)	Annual Reductant Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Cost ($MM)
2006										
2007										
2008										
2009										
2010										
2011										
2012										
2013										
2014										
2015										
2016	54	2	$2.9	54	272	$0.1	54	1	$0.9	$3.8
2017	149	6	$8.0	149	745	$0.1	149	1	$2.3	$10.5
2018	281	11	$15.0	281	1403	$0.3	281	3	$4.4	$19.7
2019	412	16	$22.1	412	2058	$0.4	412	4	$6.5	$28.9
2020	542	22	$29.0	542	2709	$0.5	542	5	$8.5	$38.1
2021	671	27	$36.0	671	3356	$0.7	671	7	$10.5	$47.2
2022	800	32	$42.9	800	3999	$0.8	800	8	$12.5	$56.2
2023	927	37	$49.7	927	4635	$0.9	927	9	$14.5	$65.2
2024	1052	42	$56.4	1052	5262	$1.1	1052	11	$16.5	$74.0
2025	1176	47	$63.0	1176	5880	$1.2	1176	12	$18.5	$82.7
2026	1297	52	$69.5	1297	6486	$1.3	1297	13	$20.4	$91.2
2027	1415	57	$75.9	1415	7077	$1.4	1415	14	$22.2	$99.5
2028	1529	61	$82.0	1529	7645	$1.5	1529	15	$24.0	$107.5
2029	1629	65	$87.3	1629	8144	$1.6	1629	16	$25.6	$114.5
2030	1708	68	$91.6	1708	8542	$1.7	1708	17	$26.8	$120.1
2031	1771	71	$94.9	1771	8853	$1.8	1771	18	$27.8	$124.5
2032	1822	73	$97.7	1822	9112	$1.8	1822	18	$28.6	$128.1
2033	1869	75	$100.2	1869	9345	$1.9	1869	19	$29.3	$131.4
2034	1911	76	$102.5	1911	9557	$1.9	1911	19	$30.0	$134.4
2035	1949	78	$104.5	1949	9746	$1.9	1949	19	$30.6	$137.0
2036	1983	79	$106.3	1983	9917	$2.0	1983	20	$31.1	$139.4
2037	2015	81	$108.0	2015	10074	$2.0	2015	20	$31.6	$141.6
2038	2044	82	$109.6	2044	10219	$2.0	2044	20	$32.1	$143.7
2039	2071	83	$111.0	2071	10355	$2.1	2071	21	$32.5	$145.6
2040	2096	84	$112.4	2096	10482	$2.1	2096	21	$32.9	$147.4
NPV at 7%			$322.0			$6.0			$94.3	$422.2
NPV at 3%			$825.6			$15.4			$241.7	$1,082.7

Table 5-47 Estimated Increased Operating Costs for Freshly Manufactured Tier 4 Marine C2 Engines (monetary entries in 2005 dollars)

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Reductant Usage (MM gal)	Annual Reductant Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Cost ($MM)
2006										
2007										
2008										
2009										
2010										
2011										
2012										
2013										
2014	110	4	$5.9	110	551	$0.1	110	1	$1.7	$7.7
2015	212	8	$11.3	212	1058	$0.2	212	2	$3.3	$14.9
2016	313	13	$16.8	313	1566	$0.3	313	3	$4.9	$22.0
2017	417	17	$22.3	417	2083	$0.4	417	4	$6.5	$29.3
2018	520	21	$27.9	520	2602	$0.5	520	5	$8.2	$36.6
2019	624	25	$33.5	624	3121	$0.6	624	6	$9.8	$43.9
2020	728	29	$39.0	728	3639	$0.7	728	7	$11.4	$51.2
2021	831	33	$44.6	831	4156	$0.8	831	8	$13.0	$58.4
2022	934	37	$50.1	934	4672	$0.9	934	9	$14.7	$65.7
2023	1037	41	$55.6	1037	5187	$1.0	1037	10	$16.3	$72.9
2024	1140	46	$61.1	1140	5700	$1.1	1140	11	$17.9	$80.1
2025	1243	50	$66.6	1243	6213	$1.2	1243	12	$19.5	$87.3
2026	1345	54	$72.1	1345	6725	$1.3	1345	13	$21.1	$94.5
2027	1447	58	$77.6	1447	7235	$1.4	1447	14	$22.7	$101.7
2028	1549	62	$83.0	1549	7745	$1.5	1549	15	$24.3	$108.9
2029	1650	66	$88.5	1650	8251	$1.7	1650	17	$25.9	$116.0
2030	1751	70	$93.8	1751	8753	$1.8	1751	18	$27.5	$123.1
2031	1850	74	$99.2	1850	9250	$1.9	1850	19	$29.0	$130.0
2032	1949	78	$104.4	1949	9743	$1.9	1949	19	$30.6	$137.0
2033	2045	82	$109.6	2045	10227	$2.0	2045	20	$32.1	$143.8
2034	2140	86	$114.7	2140	10702	$2.1	2140	21	$33.6	$150.5
2035	2233	89	$119.7	2233	11165	$2.2	2233	22	$35.0	$157.0
2036	2321	93	$124.4	2321	11604	$2.3	2321	23	$36.4	$163.1
2037	2391	96	$128.2	2391	11957	$2.4	2391	24	$37.5	$168.1
2038	2446	98	$131.1	2446	12232	$2.4	2446	24	$38.4	$172.0
2039	2497	100	$133.9	2497	12487	$2.5	2497	25	$39.2	$175.5
2040	2546	102	$136.4	2546	12728	$2.5	2546	25	$39.9	$178.9
NPV at 7%			$386.7			$7.2			$113.2	$507.1
NPV at 3%			$964.4			$18.0			$282.3	$1,264.7

Table 5-48 Estimated Increased Operating Costs by Market Segment; Freshly Manufactured Tier 4 Engines ($Millions, 2005 dollars)

Calendar Year	Locomotive Line-haul	Locomotive Switcher & Passenger	Marine C1 >600kW	Marine C2	Total	PM	NO_X+ NMHC
2006							
2007							
2008							
2009							
2010							
2011							
2012							
2013							
2014				$7.7	$7.7	$1.0	$6.8
2015	$14.6	$0.7		$14.9	$30.1	$3.8	$26.3
2016	$29.8	$1.4	$3.8	$22.0	$57.0	$7.1	$49.8
2017	$45.3	$2.0	$10.5	$29.3	$87.1	$10.9	$76.2
2018	$61.1	$2.7	$19.7	$36.6	$120.2	$15.0	$105.1
2019	$77.3	$3.4	$28.9	$43.9	$153.5	$19.2	$134.3
2020	$93.9	$4.1	$38.1	$51.2	$187.3	$23.5	$163.9
2021	$111.1	$4.9	$47.2	$58.4	$221.6	$27.8	$193.9
2022	$128.8	$5.6	$56.2	$65.7	$256.3	$32.1	$224.2
2023	$147.0	$6.5	$65.2	$72.9	$291.6	$36.5	$255.1
2024	$165.1	$7.6	$74.0	$80.1	$326.9	$40.9	$286.0
2025	$183.5	$8.8	$82.7	$87.3	$362.3	$45.3	$317.1
2026	$202.0	$10.0	$91.2	$94.5	$397.7	$49.6	$348.1
2027	$220.5	$11.3	$99.5	$101.7	$433.0	$54.0	$379.0
2028	$239.0	$12.7	$107.5	$108.9	$468.1	$58.3	$409.8
2029	$257.5	$14.1	$114.5	$116.0	$502.1	$62.5	$439.6
2030	$275.9	$15.6	$120.1	$123.1	$534.6	$66.5	$468.2
2031	$294.2	$17.3	$124.5	$130.0	$565.9	$70.3	$495.7
2032	$312.5	$19.0	$128.1	$137.0	$596.5	$74.0	$522.5
2033	$330.8	$20.7	$131.4	$143.8	$626.7	$77.7	$549.0
2034	$349.0	$22.6	$134.4	$150.5	$656.4	$81.3	$575.1
2035	$367.0	$24.4	$137.0	$157.0	$685.4	$84.8	$600.6
2036	$384.2	$26.2	$139.4	$163.1	$713.0	$88.1	$624.8
2037	$400.8	$28.0	$141.6	$168.1	$738.5	$91.2	$647.3
2038	$416.8	$29.7	$143.7	$172.0	$762.1	$94.0	$668.1
2039	$432.1	$31.4	$145.6	$175.5	$784.6	$96.7	$687.9
2040	$446.7	$33.0	$147.4	$178.9	$806.1	$99.3	$706.8
NPV at 7%	$1,067.6	$60.3	$422.2	$507.1	$2,057.2	$255.9	$1,801.3
NPV at 3%	$2,754.0	$162.4	$1,082.7	$1,264.7	$5,263.7	$653.9	$4,609.9

Table 5-49 Estimated Increased Operating Costs by Cost Element Associated with the Final Program ($Millions, 2005 dollars)

Calendar Year	Reductant Use	DPF Maintenance	Fuel Impact	Total	PM	NO_X+ NMHC
2006						
2007						
2008						
2009						
2010						
2011						
2012						
2013						
2014	$5.9	$0.1	$1.7	$7.7	$1.0	$6.8
2015	$23.0	$0.4	$6.7	$30.1	$3.8	$26.3
2016	$43.5	$0.8	$12.6	$57.0	$7.1	$49.8
2017	$66.6	$1.2	$19.3	$87.1	$10.9	$76.2
2018	$91.8	$1.7	$26.7	$120.2	$15.0	$105.1
2019	$117.3	$2.2	$34.1	$153.5	$19.2	$134.3
2020	$143.1	$2.7	$41.6	$187.3	$23.5	$163.9
2021	$169.3	$3.2	$49.2	$221.6	$27.8	$193.9
2022	$195.8	$3.7	$56.9	$256.3	$32.1	$224.2
2023	$222.8	$4.2	$64.7	$291.6	$36.5	$255.1
2024	$249.8	$4.7	$72.4	$326.9	$40.9	$286.0
2025	$277.0	$5.2	$80.2	$362.3	$45.3	$317.1
2026	$304.1	$5.7	$87.9	$397.7	$49.6	$348.1
2027	$331.2	$6.2	$95.6	$433.0	$54.0	$379.0
2028	$358.1	$6.7	$103.2	$468.1	$58.3	$409.8
2029	$384.3	$7.2	$110.6	$502.1	$62.5	$439.6
2030	$409.3	$7.6	$117.7	$534.6	$66.5	$468.2
2031	$433.4	$8.1	$124.4	$565.9	$70.3	$495.7
2032	$457.0	$8.5	$131.0	$596.5	$74.0	$522.5
2033	$480.3	$9.0	$137.4	$626.7	$77.7	$549.0
2034	$503.2	$9.4	$143.8	$656.4	$81.3	$575.1
2035	$525.6	$9.8	$150.0	$685.4	$84.8	$600.6
2036	$546.9	$10.2	$155.8	$713.0	$88.1	$624.8
2037	$566.7	$10.6	$161.2	$738.5	$91.2	$647.3
2038	$585.0	$10.9	$166.2	$762.1	$94.0	$668.1
2039	$602.4	$11.2	$170.9	$784.6	$96.7	$687.9
2040	$619.1	$11.6	$175.4	$806.1	$99.3	$706.8
NPV at 7%	$1,574.8	$29.4	$453.0	$2,057.2	$255.9	$1,801.3
NPV at 3%	$4,031.2	$75.2	$1,157.3	$5,263.7	$653.9	$4,609.9

As shown in Table 5-49, the net present value of the annual operating costs is estimated at $5.3 billion at a three percent discount rate or $2.1 billion at a seven percent discount rate. The primary increased operating cost is associated with reductant use which accounts for nearly three quarters of the estimated costs. Since reductant use is meant for NO_x+NMHC control, most of the increased operating costs are attributed to NO_x+NMHC control.

5.5 Engineering Hardware Costs and Operating Costs Associated with the Locomotive and Marine Remanufacturing Programs

Our program also contains requirements that remanufactured locomotives meet more stringent standards than those to which they were designed originally. For the final rule, we have included an analogous requirement for remanufactured marine engines. Because the standards for those engines are more stringent, they cannot necessarily be remanufactured to their original configuration but must, instead, include some new technology and/or engine controls to ensure compliance with the more stringent standards. The incremental costs associated with those new technologies must be considered as part of this rule. The remanufacturing process is not a low cost endeavor. However, it is much less costly than purchasing a freshly manufactured engine. The costs we have estimated for the remanufacturing program are meant to capture the incremental costs associated with remanufacturing.

To summarize the requirements, the existing fleet of locomotives that are currently subject to Tier 0 standards would need to comply with a new Tier 0 PM standard and a new Tier 0 NO_x line-haul standard, except that Tier 0 locomotives that were freshly manufactured before 1994 would remain subject to the existing Tier 0 NO_x standards. In general, these new Tier 0 standards would apply when the locomotive is remanufactured as early as January 1, 2008. For locomotives currently subject to Tier 1 and Tier 2 standards, more stringent PM standards would apply at the point of next remanufacture as early as January 1, 2008, but not later than 2010. For marine engines, where an appropriate locomotive remanufacture kit exists, one must be used when the marine engine is remanufactured.

To meet the locomotive remanufactured engine standards, we project that engine manufacturers will utilize incremental improvements to existing engine components. In many cases, similar improvements have already been implemented on freshly manufactured locomotives to meet our current locomotive standards. To meet the lower NO_x standard required for Tier 0 locomotives, we expect possible improvements in the fuel system, the turbo charger, and the engine calibration. Such changes are expected to increase fuel consumption by one percent as discussed below. We have estimated the incremental hardware costs associated with the remanufacture of a Tier 0 locomotive to be $33,800 for the first remanufacture and $22,300 for the second one. The lower cost for the second remanufacture is because not all of the new technology would have to be remanufactured during the second effort. We have estimated that first remanufacture would occur through 2016 with the second one occurring after 2016.

To meet the PM standards for the Tier 1 remanufacturing program, we expect that lubricating oil consumption controls will be implemented, along with the ultra low sulfur diesel fuel requirement for locomotive engines (which was previously finalized in our nonroad clean diesel rulemaking). Because of the significant fraction of lubricating oil present in PM from today’s locomotives, we believe that existing low-oil-consumption piston ring-pack designs, when used in conjunction with improvements to closed crankcase ventilation systems, will provide significant, near-term PM reductions. We have estimated these hardware costs to be roughly equivalent to the hardware costs associated with the Tier 0 remanufacturing. We have also estimated the first remanufacture would occur through 2016 with the second one occurring after 2016. We do not expect a fuel consumption impact for these remanufactured engines.

To meet the more stringent PM standards for the Tier 2 remanufacturing program, we expect use of improved fuel systems. Based on work previously done for our NRT4 rule, we have estimated the incremental hardware cost of a new fuel system on a line haul locomotive at $11,750 and on a switcher at $8,700. This cost differential exists because the line haul locomotives have larger engines and, hence, larger fuel rails and pumps, etc. We have not estimated an incremental hardware cost associated with a second remanufacture for Tier 2 locomotives because we would not expect the fuel system would need a second remanufacture. We have estimated that the first remanufacture would occur prior to 2020. We do not expect a fuel consumption impact for these remanufactured engines.

We have not estimated any incremental costs for Tier 3 remanufacturing because these locomotives would not meet a remanufactured standard more stringent than their original design. Therefore, while costs would be incurred to remanufacture these engines, those costs would not be different from current remanufacturing kits.

In the case of our locomotive standards, it is worthwhile to note the difference in how we have handled variable costs for the remanufactured Tier 2 engines versus the new Tier 3 standards. In some cases, we believe manufacturers may choose to introduce more modern common rail fuel systems for both their freshly manufactured Tier 3 products and for application to their existing Tier 2 products at the time of remanufacturing. In the case of the freshly manufactured Tier 3 engine, we are projecting no increase in engine variable cost because, for example, we expect the common rail fuel system to be no more expensive (and perhaps cheaper) than the fuel system that would have been used absent our new standards. However, we have accounted for these higher costs for the remanufactured Tier 2 engines reflecting the fact that the new fuel system is an incremental cost for the rebuild that would not have occurred absent our new standard (because the existing fuel system could be reused at remanufacture absent the new standard).

For Tier 4 remanufacturing, we have estimated that locomotive engines would need a new set of aftertreatment devices and a remanufactured fuel system. We have estimated the aftertreatment device costs at slightly lower than the original equipment costs because we would expect that precious metals would be recycled from the device being removed and replaced. This results in remanufactured DPF and SCR system costs of 60 percent and 97 percent, respectively, relative to the original cost. The 60/97 differential occurs because of the larger amount of precious metals contained in the DPF versus the SCR catalyst which contains only a small amount of precious metal for the DOC function. For the remanufactured fuel system, we have included the hardware costs already mentioned above associated with costs for Tier 2 remanufacturing (i.e., $11,750 or $8,700). We do not expect a fuel consumption impact for these remanufactured engines since they will not be meeting a more stringent standard than their original design.

For marine engines, we expect the same kits to be used as are used for locomotives. For C2 engines, we have used identical hardware costs as used for Tier 0 locomotives. For C1 engines, we have used half that value simply because the engines are smaller. We do not expect a second remanufacturing event on these engines as is expected for locomotives. However, by the time that some of the C1 engines have been remanufactured, we expect the available locomotive kits to be less costly. We do not expect a fuel consumption impact for the C1 engines, but do expect one for the C2 engines, as discussed below.[L]

These estimated incremental remanufacturing hardware costs are summarized in Table 5-50.

[L] Note that the costs associated with the marine remanufacturing program are consistent with the inventory reductions discussed in section 3.1.3 of this RIA. Our estimate of the number of remanufactured engines is presented in a memorandum from Amy Kopin to the docket for this rule (see Docket Item No. EPA-HQ-OAR-2003-0190-0847).

Table 5-50 Estimated Incremental Hardware Costs Associated with the Locomotive Remanufacturing Program ($/remanufacture, 2005 dollars)

Segment	Tier	1st Remanufacture	2nd Remanufacture
Locomotive Line-haul	Tier 0	$33,800	$22,300
	Tier 1	$33,800	$22,300
	Tier 2	$11,750	$0
	Tier 3	$0	$0
	Tier 4	$66,000	$66,000
Locomotive Switcher/Passenger	Tier 0	$33,800	$22,300
	Tier 1	$33,800	$22,300
	Tier 2	$8,700	$0
	Tier 3	$0	$0
	Tier 4	$21,700	$21,700
C1 Marine	Tier 0	$16,900/$11,150	N/A
C2 Marine	Tier 0	$33,200	N/A

We have also estimated an incremental operating cost associated with the locomotive and marine remanufacturing programs. We expect a fuel consumption impact would occur for those engines remanufactured to a more stringent NO_x standard than the NO_x standard to which they were designed originally. We would expect this because those engines are expected to employ engine control changes—retarded injection timing—to help control NO_x emissions. The result of such a change is slightly higher fuel consumption on the order of one percent. For locomotives, only Tier 0 locomotives would be remanufactured to a more stringent NO_x standard than that for which they were originally designed. Therefore, we have estimated a one percent fuel consumption increase for remanufactured Tier 0 locomotives. On the marine side, only C2 marine remanufactured engines are expected to experience a fuel consumption impact. As noted, the locomotives are expected to see a one percent fuel consumption impact. However, the impacted marine C2 engines will be going from an uncontrolled state to a controlled state resulting in a larger impact relative to the locomotives for which the kits are actually made. Therefore, we have estimated a two percent fuel consumption increase for remanufactured C2 marine engines.

Of note in the following tables is the annual reduction of gallons consumed by remanufactured Tier 0 locomotives and pre-Tier 3 C2 marine engines. This is a result of older Tier 0 locomotives and C2 vessels slowly being retired from duty and being replaced by freshly manufactured Tier 4 locomotives and vessels. There are no fuel consumption impacts shown for remanufactured Tier 1, 2 and 3 locomotives or C1 marine engines because we expect no fuel consumption impacts for them as a result of this program (no new aftertreatment devices so no urea nor DPF maintenance costs and no fuel consumption impact).

Using these remanufacturing kit hardware costs and estimated fuel consumption impacts, we can calculate the total costs associated with the final remanufacturing program. These costs are presented in Table 5-51 for line haul locomotives, Table 5-52 for switchers and passenger locomotives, and Table 5-53 for marine engines. See Chapter 3 of this final RIA for how we determined the rate at which locomotives are remanufactured. The number remanufactured and the calendar years in which they occur are also shown in the tables. As shown, the net present value of the annual remanufacturing costs is estimated at $1.5 billion and $0.8 billion for line haul locomotives at a three percent and seven percent discount rate, respectively. For switchers and passenger locomotives, we have estimated the net present value of the annual costs at $157 million and $90 million at a three and seven percent discount rate, respectively. For marine engines, these costs are $450 million and $289 million, respectively. Note that, while not shown in Table 5-51 through Table 5-53, the costs associated with the locomotive remanufacturing program are split evenly between NO_x+NMHC and PM control. This split is shown in Table 5-59.

Table 5-51 Estimated Annual Costs Associated with the Remanufacturing Program for Line Haul Locomotives (monetary entries in 2005 dollars)

Calendar Year	Tier 0							Tier 1			Tier 2			Tier 4			
	Remans	$/reman	Hardware Costs ($MM)	Reman Tier 0 Fuel Usage (MMgal)	Increased Fuel Consumption (MM gal)	Fuel Costs ($MM)	Subtotal ($MM)	Remans	$/reman	Hardware Costs ($MM)	Remans	$/reman	Hardware Costs ($MM)	Remans	$/reman	Hardware Costs ($MM)	Annual Costs ($MM)
2006																	
2007																	
2008	1651	$33,800	$55.8	146.7	1.5	$2.3	$58.1										$58.1
2009				145.5	1.5	$2.3	$2.3	803	$33,800	$27.1							$29.4
2010	1220	$33,800	$41.2	375.4	3.8	$5.9	$47.1										$47.1
2011	2096	$33,800	$70.8	779.8	7.8	$12.2	$83.1	489	$33,800	$16.5							$99.6
2012	984	$33,800	$33.3	947.0	9.5	$14.9	$48.1	931	$33,800	$31.5							$79.6
2013	1310	$33,800	$44.3	1,174.3	11.7	$18.4	$62.7				719	$11,749	$8.4				$71.1
2014	624	$33,800	$21.1	1,227.5	12.3	$19.3	$40.4				791	$11,749	$9.3				$49.7
2015	393	$33,800	$13.3	1,232.2	12.3	$19.3	$32.6				693	$11,749	$8.1				$40.8
2016	1186	$33,800	$40.1	1,401.1	14.0	$22.0	$62.1				712	$11,749	$8.4				$70.4
2017	1179	$22,300	$26.3	1,554.2	15.5	$24.4	$50.7				737	$11,749	$8.7				$59.3
2018	1284	$22,300	$28.6	1,511.8	15.1	$23.7	$52.4				770	$11,749	$9.0				$61.4
2019	231	$22,300	$5.2	1,443.7	14.4	$22.7	$27.8	803	$22,300	$17.9	791	$11,749	$9.3				$55.0
2020	370	$22,300	$8.2	1,334.6	13.3	$20.9	$29.2										$29.2
2021				1,219.3	12.2	$19.1	$19.1	489	$22,300	$10.9							$30.0
2022	579	$22,300	$12.9	1,108.5	11.1	$17.4	$30.3	931	$22,300	$20.8							$51.1
2023	1103	$22,300	$24.6	1,002.3	10.0	$15.7	$40.3				719			838	$67,108	$56.2	$96.6
2024	501	$22,300	$11.2	900.6	9.0	$14.1	$25.3				791			874	$67,108	$58.7	$84.0
2025	646	$22,300	$14.4	804.3	8.0	$12.6	$27.0				693			896	$67,108	$60.1	$87.1
2026				710.3	7.1	$11.1	$11.1				712			910	$67,108	$61.1	$72.2
2027				622.0	6.2	$9.8	$9.8				737			930	$67,108	$62.4	$72.1
2028	622	$22,300	$13.9	539.1	5.4	$8.5	$22.3				770			957	$67,108	$64.2	$86.6
2029	610	$22,300	$13.6	462.4	4.6	$7.3	$20.9				791			989	$67,108	$66.3	$87.2
2030	505	$22,300	$11.3	393.2	3.9	$6.2	$17.4							1018	$67,108	$68.3	$85.7
2031				330.1	3.3	$5.2	$5.2	442	$22,300	$9.8				1045	$67,108	$70.2	$85.2
2032				272.8	2.7	$4.3	$4.3							1059	$67,108	$71.1	$75.4
2033				220.6	2.2	$3.5	$3.5							1928	$67,108	$129.4	$132.8
2034				168.3	1.7	$2.6	$2.6	220	$22,300	$4.9				1983	$67,108	$133.1	$140.6
2035				123.9	1.2	$1.9	$1.9	419	$22,300	$9.3				2026	$67,108	$136.0	$147.3
2036				88.0	0.9	$1.4	$1.4				324			2060	$67,108	$138.2	$139.6
2037				57.7	0.6	$0.9	$0.9				356			2095	$67,108	$140.6	$141.5
2038				33.4	0.3	$0.5	$0.5				312			2133	$67,108	$143.2	$143.7
2039				15.7	0.2	$0.2	$0.2				320			2181	$67,108	$146.4	$146.6
2040				4.8	0.0	$0.1	$0.1				332			2229	$67,108	$149.6	$149.6
NPV at 7%			$260.3			$139.9	$400.2			$72.1			$29.3			$273.1	$774.8
NPV at 3%			$365.3			$230.4	$595.7			$105.2			$44.3			$767.1	$1,512.4

Table 5-52 Estimated Annual Costs Associated with the Remanufacturing Program for Switcher and Passenger Locomotives (monetary entries in 2005 dollars)

Calendar Year	Tier 0 & Tier 1							Tier 2			Tier 4			
	Remans	$/reman	Hardware Costs ($MM)	Reman Tier 0 Passenger Fuel Usage (MMgal)	Increased Fuel Consumption (MM gal)	Fuel Costs ($MM)	Subtotal ($MM)	Remans	$/reman	Hardware Costs ($MM)	Remans	$/reman	Hardware Costs ($MM)	Annual Costs ($MM)
2006														
2007														
2008	31	$33,800	$1.1	4.8	0.0	$0.1	$1.1							$1.1
2009	78	$33,800	$2.6	16.9	0.2	$0.3	$2.9							$2.9
2010	314	$33,800	$10.6	28.9	0.3	$0.5	$11.1							$11.1
2011	312	$33,800	$10.5	40.0	0.4	$0.6	$11.2							$11.2
2012	309	$33,800	$10.5	44.4	0.4	$0.7	$11.2							$11.2
2013	307	$33,800	$10.4	48.0	0.5	$0.8	$11.1							$11.1
2014	307	$33,800	$10.4	50.9	0.5	$0.8	$11.2							$11.2
2015	269	$33,800	$9.1	47.2	0.5	$0.7	$9.8	112	$8,728	$1.0				$10.8
2016	271	$33,800	$9.2	48.5	0.5	$0.8	$9.9	154	$8,728	$1.3				$11.3
2017	273	$22,300	$6.1	49.3	0.5	$0.8	$6.9	88	$8,728	$0.8				$7.6
2018	274	$22,300	$6.1	43.7	0.4	$0.7	$6.8	89	$8,728	$0.8				$7.6
2019	276	$22,300	$6.2	38.4	0.4	$0.6	$6.8	90	$8,728	$0.8				$7.5
2020	278	$22,300	$6.2	33.0	0.3	$0.5	$6.7	91	$8,728	$0.8				$7.5
2021	279	$22,300	$6.2	27.6	0.3	$0.4	$6.7							$6.7
2022	281	$22,300	$6.3	22.2	0.2	$0.3	$6.6							$6.6
2023	318	$22,300	$7.1	17.5	0.2	$0.3	$7.4							$7.4
2024	315	$22,300	$7.0	13.5	0.1	$0.2	$7.2							$7.2
2025	311	$22,300	$6.9	9.8	0.1	$0.2	$7.1	57			47	$21,937	$1.0	$8.1
2026	266	$22,300	$5.9	6.8	0.1	$0.1	$6.0	169			93	$21,937	$2.0	$8.1
2027	260	$22,300	$5.8	4.3	0.0	$0.1	$5.9	86			94	$21,937	$2.1	$7.9
2028	253	$22,300	$5.6	2.5	0.0	$0.0	$5.7	88			94	$21,937	$2.1	$7.7
2029	245	$22,300	$5.5	1.2	0.0	$0.0	$5.5	89			94	$21,937	$2.1	$7.6
2030	236	$22,300	$5.3	0.4	0.0	$0.0	$5.3	90			94	$21,937	$2.1	$7.3
2031	226	$22,300	$5.0				$5.0	45			94	$21,937	$2.1	$7.1
2032	190	$22,300	$4.2				$4.2				94	$21,937	$2.1	$6.3
2033	179	$22,300	$4.0				$4.0				160	$21,937	$3.5	$7.5
2034	166	$22,300	$3.7				$3.7				183	$21,937	$4.0	$7.7
2035	154	$22,300	$3.4				$3.4	57			201	$21,937	$4.4	$7.8
2036	142	$22,300	$3.2				$3.2	114			212	$21,937	$4.6	$7.8
2037	132	$22,300	$2.9				$2.9	46			230	$21,937	$5.1	$8.0
2038	123	$22,300	$2.7				$2.7	46			238	$21,937	$5.2	$8.0
2039	114	$22,300	$2.5				$2.5	46			246	$21,937	$5.4	$7.9
2040	105	$22,300	$2.3				$2.3	46			263	$21,937	$5.8	$8.1
NPV at 7%			$75.0			$4.6	$79.6			$2.4			$7.6	$89.6
NPV at 3%			$123.9			$6.8	$130.7			$3.8			$22.5	$157.1

Table 5-53 Estimated Annual Costs Associated with the Remanufacturing Program for Marine Engines (monetary entries in 2005 dollars)

	C1 Marine			C2 Marine								
Calendar Year	Remans	$/reman	Reman Hardware Costs ($MM)	Remans	$/reman	C2 Reman Hardware Costs ($MM)	%C2 controlled	Pre-T3 C2 fuel (MMgal)	Controlled C2 fuel (MMgal)	Increased fuel due to FE penalty (MMgal)	C2 Subtotal ($MM)	Annual Costs ($MM)
2006												
2007												
2008				325	$33,800	$11.0	9%	2,044	158	3.2	$5.0	$16.0
2009				331	$33,800	$11.2	18%	2,063	319	6.4	$10.0	$21.2
2010				337	$33,800	$11.4	26%	2,081	483	9.7	$15.2	$26.6
2011				343	$33,800	$11.6	35%	2,100	650	13.0	$20.4	$32.0
2012	403	$16,900	$6.8	349	$33,800	$11.8	44%	2,119	820	16.4	$25.7	$44.3
2013	369	$16,900	$6.2	324	$33,800	$11.0	53%	2,105	978	19.6	$30.7	$47.9
2014	298	$16,900	$5.0	241	$33,800	$8.1	62%	2,021	1,095	21.9	$34.4	$47.6
2015	241	$16,900	$4.1				62%	1,937	1,050	21.0	$32.9	$37.0
2016	184	$16,900	$3.1				62%	1,853	1,004	20.1	$31.5	$34.6
2017	128	$11,150	$1.4				62%	1,769	959	19.2	$30.1	$31.5
2018	73	$11,150	$0.8				62%	1,685	913	18.3	$28.7	$29.5
2019							62%	1,602	868	17.4	$27.2	$27.2
2020							62%	1,519	823	16.5	$25.8	$25.8
2021							62%	1,436	778	15.6	$24.4	$24.4
2022							62%	1,354	734	14.7	$23.0	$23.0
2023							62%	1,272	690	13.8	$21.6	$21.6
2024							62%	1,191	646	12.9	$20.3	$20.3
2025							62%	1,110	602	12.0	$18.9	$18.9
2026							62%	1,030	558	11.2	$17.5	$17.5
2027							62%	949	515	10.3	$16.1	$16.1
2028							62%	870	471	9.4	$14.8	$14.8
2029							62%	791	429	8.6	$13.5	$13.5
2030							62%	713	387	7.7	$12.1	$12.1
2031							62%	637	345	6.9	$10.8	$10.8
2032							62%	562	304	6.1	$9.6	$9.6
2033							62%	488	265	5.3	$8.3	$8.3
2034							62%	417	226	4.5	$7.1	$7.1
2035							62%	349	189	3.8	$5.9	$5.9
2036							62%	289	157	3.1	$4.9	$4.9
2037							62%	247	134	2.7	$4.2	$4.2
2038							62%	218	118	2.4	$3.7	$3.7
2039							62%	193	104	2.1	$3.3	$3.3
2040							62%	170	92	1.8	$2.9	$2.9
NPV at 7%			$15.1			$51.5		21,279	7,089	141.8	$222.5	$289.1
NPV at 3%			$21.1			$64.0		30,735	11,628	232.6	$364.9	$450.1

5.6 Summary of Final Program Engineering Costs

Details of our engine and equipment cost estimates were presented in Sections 5.2 and 5.3. Here we summarize the cost estimates. Section 5.6.1 summarizes the engine-related costs associated with the new Tier 4 standards for freshly manufactured engines. Section 5.6.2 summarizes the equipment-related costs associated with the new Tier 4 standards for freshly manufactured equipment. Section 5.6.3 summarizes the operating costs associated with the freshly manufactured Tier 4 engines and equipment. Section 5.6.4 summarizes the hardware costs and operating costs associated with the locomotive and marine remanufacturing programs. Section 5.6.5 summarizes all these costs and presents the total estimated costs for the final program. Note that all present value costs presented here are 2006 through 2040 numbers (the net present values in 2006 of the stream of costs occurring from 2006 through 2040, expressed in $2005).

5.6.1 Engineering Costs for Freshly Manufactured Engines

5.6.1.1 Fixed Engineering Costs

Engine fixed costs include costs for engine R&D, tooling, and certification. These costs are discussed in detail in Section 5.2.1. The total estimated engine fixed costs are summarized in Table 5-54. The table also includes net present values using both a three percent and a seven percent discount rate.

Table 5-54 Summary of Engine-Related Fixed Costs for Freshly Manufactured Tier 4 Engines ($Millions, 2005 dollars)

	Costs Incurred	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Engine and Emission Control Research	$ 569	$ 471	$ 371
Engine Tooling	$ 41	$ 33	$ 24
Engine Certification	$ 7	$ 6	$ 5
Total Engine Fixed Costs	$ 618	$ 509	$ 399
Total Allocated to PM	$ 212	$ 175	$ 137
Total Allocated to NO_X+NMHC	$ 406	$ 335	$ 263

Note: As explained in the text, we have attributed engine fixed costs to NO_X+NMHC and PM control as follows: engine research costs are split two-thirds to NO_X+NMHC control and one-third to PM control; engine tooling costs are split equally; engine certification costs are split equally except where new standards are implemented in different years (e.g., for Tier 4 locomotive standards).

5.6.1.2 Variable Engineering Costs

Engine variable, or hardware, costs are discussed in detail in Section 5.2.2. For engine variable costs, we have generated cost estimation equations as a function of engine displacement (see Table 5-27). Using these equations, we have calculated the hardware costs for freshly manufactured engines meeting the Tier 4 standards for each year through 2040. We present those annual engine variable costs in Section 5.2.2. Table 5-55 shows the net present value of those annual costs using a three percent discount rate and a seven percent discount rate.

Table 5-55 Summary of Engine-Related Variable Costs for Freshly Manufactured Tier 4 Engines ($Millions, 2005 dollars)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 840	$ 386
C1 Marine	$ 188	$ 86
C2 Marine	$ 227	$ 103
Small Commercial Marine & Recreational Marine	$ 0	$ 0
Total Engine Variable Costs	$ 1,255	$ 575
Total Allocated to PM	$ 662	$ 303
Total Allocated to NO_X+NMHC	$ 593	$ 271

Note: The PM/NO_X+NMHC cost allocations for engine variable costs are as follows: SCR systems including marinization costs on marine applications are attributed 100% to NO_X+NMHC control; and, DPF systems including marinization costs on marine applications are attributed 100% to PM control.

5.6.2 Engineering Costs for Freshly Manufactured Equipment

5.6.2.1 Fixed Engineering Costs

Equipment fixed costs are discussed in detail in Section 5.3.1. Table 5-56 shows the estimated equipment fixed costs—for redesign efforts—associated with the Tier 4 program. The table also includes net present values of the annual costs using both a three percent and a seven percent discount rate.

Table 5-56 Summary of Equipment-Related Fixed Costs for Freshly Manufactured Tier 4 Equipment ($Millions, 2005 dollars)

	Costs Incurred	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 0.7	$ 0.5	$ 0.4
C1 Marine	$ 40	$ 25	$ 14
C2 Marine	$ 23	$ 14	$ 8
Small Commercial Marine & Recreational Marine	$ 0	$ 0	$ 0
Total Equipment Fixed Costs	$ 64	$ 39	$ 22
Total Allocated to PM	$ 32	$ 20	$ 11
Total Allocated to NO_X+NMHC	$ 32	$ 20	$ 11

Note: Equipment fixed costs are split evenly between NO_X+NMHC and PM control.

5.6.2.2 Variable Engineering Costs

Equipment variable costs are discussed in detail in Section 5.3.2. Using the costs presented there we have calculated the hardware costs for new pieces of equipment—locomotives and vessels—meeting the new Tier 4 standards for each year through 2040. We present those annual equipment variable costs in Section 5.3.2. Table 5-57 shows the net present value of those annual costs using a three percent and a seven percent discount rate.

Table 5-57 Summary of Equipment-Related Variable Costs for Freshly Manufactured Tier 4 Equipment ($Millions, 2005 dollars)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 171	$ 78
C1 Marine	$ 38	$ 17
C2 Marine	$ 11	$ 5
Small Commercial Marine & RecMarine	$ 0	$ 0
Total Equipment Variable Costs	$ 220	$ 100
Total Allocated to PM	$ 110	$ 50
Total Allocated to NO_X+NMHC	$ 110	$ 50

Note: Equipment variable costs are split evenly between NO_X+NMHC and PM control.

5.6.3 Operating Costs for Freshly Manufactured Tier 4 Engines

Operating costs are discussed in detail in Section 5.4 where we present the operating costs for each year through 2040. Operating costs consist of costs associated with urea use, DPF maintenance, and a fuel consumption impact on some engines. Table 5-58 shows the net present value of those annual operating costs using a three percent and a seven percent discount rate.

Table 5-58 Summary of Operating Costs for Freshly Manufactured Tier 4 Engines ($Millions, 2005 dollars)

	2006-2040 NPV at 3%				2006-2040 NPV at 7%			
	Reductant	DPF Maint.	Fuel	Total	Reductant	DPF Maint.	Fuel	Total
Locomotive	$2,241	$42	$633	$2,916	$866	$16	$246	$1,128
C1 Marine	$826	$15	$242	$1,083	$322	$6	$94	$422
C2 Marine	$964	$18	$282	$1,265	$387	$7	$113	$507
Small Commercial Marine & RecMarine	$ 0	$0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Total Operating Costs	$4,031	$75	$1,157	$5,264	$1,575	$29	$453	$2,057
Total Allocated to PM	$ 0	$75	$579	$654	$ 0	$29	$227	$256
Total	$4,031	$ 0	$579	$4,610	$1,575	$ 0	$227	$1,801

Allocated to NO_X+NMHC								

Note: Operating costs are attributed as follows: costs associated with reductant use are attributed solely to NO_X+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; and, costs associated with the fuel consumption impact are split evenly between NO_X+NMHC and PM control.

5.6.4 Engineering Hardware and Operating Costs for Remanufactured Engines

Costs associated with the locomotive and marine remanufacturing programs are discussed in detail in Section 5.5 where we present the costs for each year through 2040. These costs include the hardware costs that are incremental to current remanufacturing practices and any increased operating costs. Table 5-59 shows the net present value of those annual remanufacturing costs using a three percent and a seven percent discount rate.

Table 5-59 Summary of Remanufacturing Program Costs ($Millions, 2005 dollars)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Line Haul	$ 1,512	$ 775
Switcher & Passenger	$ 157	$ 90
C1 Marine	$ 21	$ 15
C2 Marine	$ 429	$ 274
Total Remanufacturing Costs	$ 2,120	$ 1,153
Total Allocated to PM	$ 1,060	$ 577
Total Allocated to NO_X+NMHC	$ 1,060	$ 577

Note: Costs associated with the locomotive and marine remanufacturing programs are split evenly between NO_X+NMHC and PM control.

5.6.5 Total Engineering and Operating Costs Associated with the Final Program

Table 5-60 shows the total annual costs for each market segment—locomotive line haul, C2 marine, etc—for the final program. Table 5-61 shows the total annual costs for each cost element—engine, equipment, operating, etc.—on an annual basis for the final program. As shown, the net present value of the annual costs is estimated at $9.4 billion at a three percent discount rate and $4.3 billion at a seven percent discount rate. In the year 2030, the annual costs are estimated at $759 million.

Note that costs throughout this cost analysis have been allocated as follows: engine research costs are split two-thirds to NO_X+NMHC control and one-third to PM control; engine tooling costs are split equally; engine certification costs are split equally except where new standards are implemented in different years (e.g., for Tier 4 locomotive standards); SCR systems including marinization costs on marine applications are attributed 100% to NO_X+NMHC control; DPF systems including marinization costs on marine applications are attributed 100% to PM control; equipment fixed and variable costs are split evenly between NO_x+NMHC and PM control; costs associated with reductant use are attributed solely to NO_x+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; costs associated with the fuel consumption impact are split evenly between NO_x+NMHC and PM control; and, costs associated with the locomotive remanufacturing program are split evenly between NO_x+NMHC and PM control.

Table 5-60 Estimated Annual Engineering Costs by Market Segment for the Final Program ($Millions, 2005 dollars)

Calendar Year	Locomotive		Marine					Total
	Line Haul	Switcher & Passenger	C2 Marine	C1 Marine >600kW	C1 Marine <600kW	Recreational	Small Commercial	
2006								
2007	$6.0	$2.6	$4.2	$2.3	$10.9	$5.8	$1.7	$33.5
2008	$64.1	$3.7	$20.1	$2.3	$10.9	$5.8	$1.7	$108.7
2009	$35.4	$5.5	$25.4	$2.3	$10.9	$5.8	$1.7	$87.1
2010	$80.6	$20.8	$30.7	$2.3	$10.9	$5.8	$1.7	$152.9
2011	$134.6	$22.9	$61.3	$31.0	$16.2	$10.9	$3.7	$280.7
2012	$107.0	$18.4	$59.9	$30.2	$0.0	$0.0	$0.0	$215.4
2013	$98.6	$18.4	$64.0	$29.6	$0.0	$0.0	$0.0	$210.5
2014	$80.5	$22.9	$72.6	$28.4	$0.0	$0.0	$0.0	$204.5
2015	$123.7	$13.9	$83.0	$44.8	$0.2	$0.0	$0.0	$265.7
2016	$171.8	$15.1	$76.6	$31.3	$0.0	$0.0	$0.0	$294.8
2017	$161.7	$11.7	$81.7	$34.4	$0.0	$0.0	$0.0	$289.4
2018	$180.7	$12.3	$82.7	$37.7	$0.0	$0.0	$0.0	$313.4
2019	$192.0	$13.0	$88.8	$46.3	$0.0	$0.0	$0.0	$340.0
2020	$184.8	$13.6	$94.8	$55.5	$0.0	$0.0	$0.0	$348.8
2021	$204.8	$13.5	$100.8	$64.8	$0.0	$0.0	$0.0	$383.9
2022	$245.4	$14.2	$106.8	$74.0	$0.0	$0.0	$0.0	$440.3
2023	$310.8	$17.3	$112.8	$83.1	$0.0	$0.0	$0.0	$524.0
2024	$317.2	$18.7	$118.8	$92.0	$0.0	$0.0	$0.0	$546.8
2025	$340.7	$21.2	$124.8	$100.9	$0.0	$0.0	$0.0	$587.5
2026	$345.4	$22.6	$130.8	$109.5	$0.0	$0.0	$0.0	$608.4
2027	$365.4	$24.1	$136.7	$118.0	$0.0	$0.0	$0.0	$644.2
2028	$399.4	$25.5	$142.7	$126.1	$0.0	$0.0	$0.0	$693.8
2029	$419.5	$26.9	$148.6	$133.3	$0.0	$0.0	$0.0	$728.3
2030	$436.9	$28.5	$154.6	$139.0	$0.0	$0.0	$0.0	$759.1
2031	$455.7	$30.3	$160.4	$143.6	$0.0	$0.0	$0.0	$790.0
2032	$465.2	$31.5	$166.2	$147.4	$0.0	$0.0	$0.0	$810.3
2033	$542.2	$34.5	$171.9	$150.8	$0.0	$0.0	$0.0	$899.4
2034	$569.2	$36.7	$176.6	$152.5	$0.0	$0.0	$0.0	$934.9
2035	$594.3	$38.6	$182.1	$155.3	$0.0	$0.0	$0.0	$970.3
2036	$601.6	$40.2	$187.4	$157.8	$0.0	$0.0	$0.0	$987.1
2037	$618.5	$42.0	$191.8	$160.2	$0.0	$0.0	$0.0	$1,012.6
2038	$634.8	$43.6	$195.4	$162.4	$0.0	$0.0	$0.0	$1,036.2
2039	$651.1	$45.0	$198.7	$164.5	$0.0	$0.0	$0.0	$1,059.3
2040	$666.5	$46.7	$201.9	$166.5	$0.0	$0.0	$0.0	$1,081.5
NPV at 7%	$2,393.9	$209.3	$984.7	$639.5	$45.4	$25.7	$8.0	$4,306.5
NPV at 3%	$5,364.1	$420.7	$2,061.2	$1,468.2	$53.0	$30.2	$9.4	$9,406.8

Table 5-61 Estimated Annual Engineering Costs by Cost Element for the Final Program ($Millions, 2005 dollars)

Calendar Year	Tier 4 Engine Costs	Tier 4 Equipment Costs	Reman Program Costs	Tier 4 Operating Costs	Total	PM	NO_X+NMHC
2006							
2007	$33.5				$33.5	$11.1	$22.5
2008	$33.5		$75.2		$108.7	$48.7	$60.1
2009	$33.5		$53.5		$87.1	$37.8	$49.2
2010	$68.2		$84.7		$152.9	$64.9	$88.0
2011	$137.9		$142.8		$280.7	$121.0	$159.7
2012	$80.4		$135.1		$215.4	$94.1	$121.4
2013	$80.4		$130.2		$210.5	$91.6	$118.9
2014	$87.6	$0.7	$108.4	$7.7	$204.5	$85.7	$118.8
2015	$123.1	$23.9	$88.6	$30.1	$265.7	$115.7	$150.0
2016	$99.6	$21.9	$116.3	$57.0	$294.8	$128.7	$166.1
2017	$86.4	$17.4	$98.5	$87.1	$289.4	$114.3	$175.1
2018	$78.9	$15.9	$98.5	$120.2	$313.4	$113.8	$199.7
2019	$80.4	$16.2	$89.8	$153.5	$340.0	$114.6	$225.4
2020	$82.3	$16.6	$62.5	$187.3	$348.8	$106.4	$242.4
2021	$84.3	$16.9	$61.1	$221.6	$383.9	$111.2	$272.7
2022	$86.1	$17.2	$80.7	$256.3	$440.3	$126.4	$313.9
2023	$88.7	$18.0	$125.6	$291.6	$524.0	$155.1	$368.9
2024	$90.1	$18.4	$111.4	$326.9	$546.8	$153.3	$393.5
2025	$92.2	$18.9	$114.1	$362.3	$587.5	$160.4	$427.1
2026	$93.7	$19.2	$97.8	$397.7	$608.4	$157.6	$450.8
2027	$95.4	$19.6	$96.2	$433.0	$644.2	$162.2	$481.9
2028	$96.7	$19.9	$109.1	$468.1	$693.8	$173.8	$519.9
2029	$97.9	$20.1	$108.2	$502.1	$728.3	$178.3	$550.0
2030	$98.9	$20.3	$105.2	$534.6	$759.1	$181.4	$577.6
2031	$100.2	$20.7	$103.1	$565.9	$790.0	$185.1	$604.8
2032	$101.6	$21.0	$91.2	$596.5	$810.3	$183.8	$626.5
2033	$102.9	$21.2	$148.6	$626.7	$899.4	$217.0	$682.5
2034	$104.2	$19.0	$155.4	$656.4	$934.9	$223.5	$711.4
2035	$104.8	$19.1	$161.1	$685.4	$970.3	$230.2	$740.1
2036	$103.1	$18.7	$152.3	$713.0	$987.1	$228.1	$759.0
2037	$102.0	$18.4	$153.7	$738.5	$1,012.6	$231.1	$781.5
2038	$100.7	$18.1	$155.4	$762.1	$1,036.2	$233.9	$802.4
2039	$99.1	$17.7	$157.9	$784.6	$1,059.3	$236.8	$822.5
2040	$97.5	$17.4	$160.6	$806.1	$1,081.5	$239.7	$841.9
NPV at 7%	$973.8	$122.0	$1,153.4	$2,057.2	$4,306.5	$1,333.4	$2,973.1
NPV at 3%	$1,764.1	$259.5	$2,119.5	$5,263.7	$9,406.8	$2,680.0	$6,726.8

5.7 Engineering Costs and Savings Associated with Idle Reduction Technology

Locomotives idle for many reasons, not all of which can be avoided. The primary reason they idle is to protect their engines. Locomotives use water, rather than antifreeze for engine cooling because water is more efficient at removing heat despite its higher freezing point. Therefore, by keeping the locomotive engine idling, the cooling water is kept from freezing and damaging the engine block. Engineers may also idle a locomotive to maintain critical system parameters: the batteries must maintain a certain charge in order to be able to restart the engine, the air brake system must be kept pressurized, and in some cases the locomotive is left to idle in order to properly cool down after heavy use. It may also be necessary to idle a locomotive to provide and maintain cab comfort for the crew or to otherwise comply with applicable government regulations.. Idling locomotives can be found both inside and outside of the switchyard, for example, line-hauls may idle while waiting on sidings for other trains to pass, during crew changes, or while moving (when some locomotives in a consist pulling a train are not needed to provide power).

There are several technologies currently available to reduce unnecessary locomotive idling or idling emissions. First, shore power systems allow for the locomotive engine to be plugged into a stationary power source to keep the batteries charged, and to heat and circulate the water and oil. They range in price from $4,000 - $14,000 depending on the options installed.[M] These systems are most widely used on passenger trains that return to the same location at night, but are not always practical for switchers that idle in different locations throughout a switchyard, or for line-hauls that generally stop in many locations outside a switchyard. Second, Low Emission Idle Systems (LEI) made by Energy Conversions Inc. work by alternating the banks of cylinders that fire during idle. LEI runs the engine on half of its cylinders at idle which increases the load on the firing cylinders and causes them to burn fuel more efficiently, however, while this system may reduce some idling emissions it does not eliminate idling. The cost of the system is approximately $4000, and it can be installed in just two hours.[N] Third, an Auxiliary Power Unit (APU) is an idle reduction technology that reduces the amount of time when locomotive engine idling is necessary. APUs are small (less than 50 hp) diesel engines that stop and start themselves as needed to provide heat to both engine coolant and engine oil, and power to charge the batteries and run cab accessories, instead of this work being done by the much larger (2,000-4,000 hp) locomotive engine. There are two main manufacturers of APUs, EcoTrans which makes the K9 APU and Kim Hotstart which makes the Diesel Driven Heating System (DDHS). APUs can provide substantial fuel savings depending on a number of variables, such as: what the function of a locomotive is (e.g. a switcher or a line-haul), where it operates (i.e. geographical area), and what its operating characteristics are (e.g. number of hours per day that it operates). The cost of an APU ranges from $25,000 - $32,000, depending on the options installed, although Kim Hotstart has just developed a “Junior” model with a smaller engine that is priced around

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[M] Docket ID # OAR-2003-0190-0588.1

[N] www.energyconversions.com/lei1.htm

\$16,000.[l,O] Fourth, a more complex solution has been demonstrated by the Advanced Locomotive Emissions Control Systems (ALECS). It uses emission reduction technology developed for stationary sources to capture the emissions from both stationary and slow moving trains in a railyard. Its cost can be upwards of one million dollars, but it can be used on any locomotive that enters the railyard.[P] Fifth, locomotive engines can be replaced with two or three smaller non-road engines, referred to as gensets.[Q] This configuration allows the locomotive to idle using only one small engine, while the other engines only operate when more power is needed. Sixth, a hybrid-electric system has been designed for switch yard purposes only (known as the GreenGoat.)[R] The hybrid-electric switcher engine only operates when the batteries need to be charged. The locomotive is powered by the batteries and can sit in a state of readiness without idling, similar to an electric car.

Finally, one of the most cost effective onboard solutions that can provide idle reduction benefits to both line-haul and switcher locomotives nearly anywhere they operate is an automatic engine stop/start system (AESS). AESS is an electronic control system that reduces idling by shutting down a locomotive engine when it is idling unnecessarily e.g. it is not needed to maintain critical system parameters such as brake system pressure. AESS is a microprocessor technology that operates by continually monitoring certain operating parameters such as: reverser and throttle position, engine coolant and ambient air temperature, battery charge, brake system pressure, and time spent idling. The AESS will shutdown the locomotive engine after a prescribed period of time spent idling, usually fifteen to thirty minutes, if conditions meet a preprogrammed set of values (for example the ambient temperature must be greater than 32ºF, and the water temperature must be greater than 100ºF), and will restart the engine if one of the aforementioned parameters goes out of its specified range in order to both protect the locomotive engine and keep it in a ready-to-use state.

AESS is limited in its ability to provide idle reduction in cold weather as it can only monitor the conditions under which the locomotive engine is operating and the condition of the engine itself. An APU can provide further reductions for those locomotives operating in colder climates by actually maintaining the necessary engine parameters, and is included as part of some Tier 0 certified kits. In fact, EPA demonstrated an APU/AESS combined systems approach in one of its grant projects using a Kim Hotstart DDHS.[S] An AESS alone can provide some fuel savings during the cold winter, but when combined with an APU will achieve considerable fuel savings. AESS systems will be required on all freshly manufactured Tier 3 and Tier 4 locomotives, and on all existing locomotives when they are

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[O] http://www.epa.gov/otaq/smartway/idlingtechnologies.htm#loco-mobile-apu

[P] Tom Christofk, "Statewide Railyard Agreement" Presentation given at Second Public Meeting 7/13/06 for Placer County Air Pollution Control District htttp://www.placer.ca.gov/upload/apc/documents/up/up_arb_public_meeting_7_13_06.pdf

[Q] www.northeastdiesel.org, "Multi-Engine GenSet Ultra Low Emissions Road-Switcher Locomotive" presentation by National Railway Equipment Co., Jan, 2006.

[R] www.railpower.com

[S] See “Case Study: Chicago Locomotive Idle Reduction Project” (EPA420-R-04-003) (March, 2004), available at http://www.epa.gov/smartway/documents/420r04003.pdf first remanufactured under the revised remanufacturing program (see section III.B.(1)(c) of the Preamble for more details on the idle reduction program).

If installed at the time of remanufacture, the AESS installation costs vary depending on the age and characteristics of the locomotive. On average, the cost of a basic system is approximately $10,000, and in some cases volume discounts may be available.[M,T] This cost estimate includes $2,500 in labor costs for installation, and $7,500 for the hardware costs for a basic AESS microprocessor system and monitoring equipment (systems including GPS or satellite uplink optional features are more expensive).[O,T] The cost may also vary depending on whether the locomotive is already equipped with the necessary sensors, and whether the AESS would require a stand alone electronic control unit as may be the case for older locomotives that are completely mechanical and do not have electronic controls. If installed on a new locomotive, costs should be much lower since the equipment could be installed at the factory and integrated with the original design of the locomotive.

Idle reduction technology (e.g., AESS systems) can provide substantial emission reductions as well as cost savings by reducing fuel consumption. We estimated these cost savings for both a line-haul and switcher locomotive using 4,350 annual hours of operation for a line-haul or 36,500 hours over one useful life, and 4,450 annual hours for a switcher or 101,000 hours over one useful life (see section 3.3.2 of this RIA for more details on the useful life of locomotives). The regulatory duty cycle (see 40CFR 92.132) indicates that a line-haul locomotive idles 38% of its operating time, and that a switcher locomotive idles 59.8% of its operating time. Using these values, we can estimate that a line-haul locomotive idles approximately 1,650 hours annually or nearly 14,000 hours over one useful life, and a switcher locomotive idles approximately 2,660 hours annually or slightly over 60,000 hours over one useful life (cost and emission savings estimates used the net present value of these idle hour values).

These duty cycles include two types of idling: normal idle and low idle. Low idle indicates that there is no accessory load on the engine where normal idle indicates a load on the engine (for example, an accessory load occurs when the locomotive engine is charging a battery). As a conservative estimate, we are calculating that AESS provides a 50% reduction in low idling, although additional reductions in both low and normal idling may be possible[U,V,W]. Using this reduction value, we have estimated that AESS will reduce unnecessary idling by over 410 hours a year on a line-haul locomotive, and approximately 660 hours a year on a switcher locomotive. This means that over the useful life of a line-haul locomotive, we expect at least 2,900 hours of idling at a 3% net present value (2,500 at 7%

[T] Jessica Montañez and Matthew Mahler, "Reducing Idling Locomotives Emissions", North Carolina Department of Environment and Natural Resources, DAQ http://daq.state.nc.us/planning/locoindex.shtml

[U] David E. Brann, "Locomotive Idling Reduction", http://www1.eere.energy.gov/vehiclesandfuels/pdfs/idling_2004/brann.pdf

[V] http://www.arb.ca.gov/railyard/ryagreement/aess_electromotive.pdf

[W] Draft Maryland Locomotive Idle Reduction Program Demonstration Project – DE-FG36-02GO12022 http://www.osti.gov/bridge/servlets/purl/838872-D6MxUD/838872.PDF net present value) to have been eliminated, and at least 11,000 hours of idling at a 3% net present value (7,400 hours at 7% net present value) over the course of one useful life for a switcher locomotive.

Using a fuel consumption value of three gallons per hour idled from Tier 2 Certification data, a cost value of $1.57 per gallon of diesel fuel (see section 5.4.3 for information on how this cost was derived) and the yearly amount of idle hours avoided, we can estimate that this technology will pay for itself in just over three years on a switcher locomotive, and slightly over five years on a line-haul locomotive. It is important to note that locomotives typically operate for more than one useful life, and this technology does not have to be replaced upon remanufacture of the locomotive and therefore, it should continue to provide savings throughout the additional useful lives of that locomotive. It is also important to note that our estimates are conservative when compared to estimates by other groups, and when compared to data from locomotives equipped with AESS in the field. For comparative purposes, Table 5-62 shows the different payback times associated with the different savings estimates. Data from locomotives in the field indicate that this technology will pay for itself in eight months. That figure is derived from data that has been collected from a large number of locomotives, over many years of operation, in several different geographical regions of the country, and averaged separately for both line-haul and switcher locomotives.

Table 5-62 Estimates of Typical AESS Payback Time by other Sources[X] (monetary entries in 2005 dollars)

Source of Estimate	Hours of Idle per switcher locomotive per year	AESS reduced hours of idle	Fuel Usage during idle (gal/hour)	Gallons Saved per Year	Cost of Fuel[b]	Fuel Savings ($)	Payback time of AESS[c]
RIA for this rule	2,650	665	3[d]	2,000	$1.57	$3,120	3.2 years
DOE	5,300	2,650	4.5	12,000	$1.57	$18,800	6 months
SmartStart Reports	3,840[a]	2,050	4.5	9,200	$1.57	$14,400	8 months

Notes:

[a] This average value comes from data accumulated over at least three years on both line-haul and switcher locomotives

[b] The $1.57 cost of a gallon of diesel is calculated in Chapter 5 of this RIA

[c] Payback time of AESS is based on average price of $10,000 which includes installation costs

[d] 3 gal/hr is based on Tier 2 Certification Data

For simplicity we are presenting savings and emission reductions for a single useful life, even though locomotives are typically remanufactured at least three times before being scrapped. The AESS hardware would generally be expected to last for the remainder of a

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[X] These values have changed since the NPRM due to the increase estimate in the price of diesel fuel, see section 5.4.3 of this chapter for more information.

locomotive's service life, which could be as little as one useful life for a very old locomotive being remanufactured for the last time, to more than four useful lives for a freshly manufactured locomotive. Thus actual cost savings will be significantly higher than the single useful life values presented here, even when discounted.

It is also important to note that while we present annual and per-useful life emission reductions in this analysis, in Table 5-63, and in Table -5-64, these reductions are not aggregated into our final program as part of the emission reductions from the finalized program. In the past and in this recently finalized program, locomotives are tested and emissions are calculated to reflect the emission reductions associated with idle reduction technologies. AESS systems are currently being used by some manufacturers and remanufacturers as part of their certified locomotive emission controls. From both a regulatory and inventory perspective, the use of AESS is considered the same as installing aftertreatment or recalibrating the engine. The emission reductions are presented here merely to show the environmental significance of AESS.

Reduced idling time means reduced fuel consumption. Tier 2 certification data indicates that modern locomotives typically burn 3 gallons of fuel an hour during low-idle. We estimated the cost savings of using an AESS based on an estimated diesel fuel cost (less taxes) of $1.57/gallon. For a line-haul locomotive, use of an AESS is estimated to provide fuel cost savings of almost $1,900 annually. Over the useful life, this would mean a net present value savings of nearly $13,700 at a three percent discount rate ($11,600 at a seven percent discount rate). For a switcher locomotive, an AESS could provide fuel savings of nearly $3,100 annually or, over its useful life, a net present value savings of approximately $50,000 at a three percent discount rate ($35,000 at a seven percent discount rate).

Reduced idling time also means reducing idle emissions. Tier 2 certification data suggests that locomotives emit an average of 10g/hr of PM and 600g/hr of NO_x during low idle. This means that a line-haul locomotive's emissions could be reduced by over 0.005 tons of PM and 0.27 tons of NO_x annually. Over the useful life, the net present value of PM reductions could be 0.032 tons at a three percent discount rate (0.027 tons at a seven percent discount rate). Likewise, the net present value of NO_x reductions could be 1.9 tons at a three percent discount rate (1.5 tons at a seven percent discount rate). A switcher locomotive's emissions can be reduced by over 0.007 tons of PM and 0.44 tons NO_x annually. Over the useful life of the switcher, the net present value of PM reductions could be 0.12 tons at a three percent discount rate (0.08 tons at a seven percent discount rate) and, for NO_x reductions, 7.0 tons at a three percent discount rate (4.9 tons at a seven percent discount rate), older switchers would be expected to emit more pollutants than the Tier 2 estimates given here.

Table 5-63 shows the annual fuel savings, the associated cost savings, and the emissions reductions we estimate would result from the AESS requirements. These values would be expected to be consistent for newer locomotives, although older locomotives may provide greater savings as they may consume more fuel at idle. Table -5-64 shows this information on a useful life basis along with net present value information and a net cost. The idle emission reductions are particularly important considering that we do not expect aftertreatment technologies to reduce NO_x emissions for extended periods of idle, and further, we expect PM control to be reduced due to poor oxidation efficiency at idle. The ability of aftertreatment technologies to control emissions during idle operation is discussed in more detail in Chapter 4 of this RIA. Because of the limitations of the aftertreatment technology at idle, idle reduction via an AESS system is one of the best methods to ensure control of emissions at idle.

Table 5-63 Annual Effects of Using AESS on Line-Haul and Switcher Locomotives[Y] (monetary entries in 2005 dollars)

Annual Estimates for a Typical Tier 2 Locomotive						
Type of Locomotive	Time Spent Idling[a] (hrs)	Idling Reduced Using AESS[b] (hrs)	Fuel Savings[c] (gals)	Fuel Savings[d] ($)	PM Emission Reductions[e] (tons)	NO_x Emission Reductions[f] (tons)
Line-Haul	1,650	413	1,238	1,943	0.005	0.27
Switcher	2,650	663	1,988	3,120	0.007	0.44

Notes:

[a] Using 38% idling time for line-hauls and 59.8% for switchers from Duty-Cycle (see 40CFR 92.132)

[b] Assuming 50% of low-idle is reduced by AESS

[c] Using 3 gallons of fuel burned per hour at low-idle (estimated from Tier 2 Certification Data)

[d] Using diesel fuel price less taxes of $1.57/gallon (see section 5.4.3)

[e] Using PM estimate of 10g/hr emitted during low idle (estimated from Tier 2 Certification Data)

[f] Using NO_x estimate of 600g/hr emitted during low idle (estimated from Tier 2 Certification Data)

[Y] These values have changed since the NPRM due to the increase estimate in the cost of diesel fuel, see section 5.4.3 of this chapter for more information.

Table -5-64 NPV 3% & 7% Effects of Using AESS Over the First Useful Life on Line-Haul and Switcher Locomotives[Z] (monetary entries in 2005 dollars)

Estimates Over the First[a] Useful Life of a Typical Tier 2 Locomotive									
Type of Locomotive	NPV Factor	Time Spent Idling[b] (hrs)	Idling Reduced Using AESS[c] (hrs)	Fuel Savings[d] (gals)	Fuel Savings[e] ($)	Average Installation Cost of AESS($)f	Net Savings ($)	PM Emission Reductions[g] (tons)	NO$_x$ Emission Reductions[h] (tons)
Line-Haul	NPV 3%	12,000	2,900	8,700	13,700	10,000	3,700	0.032	1.9
	NPV 7%	9,900	2,500	7,400	11,600	10,000	1,600	0.027	1.6
Switcher	NPV 3%	42,000	11,000	32,000	50,000	10,000	40,000	0.12	7.0
	NPV 7%	29,000	7,400	22,000	35,000	10,000	25,000	0.08	4.9

Notes:

[a] Additional savings not accounted for in this analysis include: reduced wear on engine components, reduced oil consumption, and fuel savings over subsequent useful lives of a locomotive's full lifetime.

[b] Using 38% idling time for line-hauls and 59.8% for switchers from Duty-Cycle (see 40CFR 92.132)

[c] Assuming 50% of low-idle is reduced by AESS

[d] Using 3 gallons of fuel burned per hour at low-idle (estimated from Tier 2 Certification Data)

[e] Using diesel fuel price less taxes of $1.57 gallon (see section 5.4.3)

[f] Average cost assumes AESS was bought and paid for the first year of installation

[g] Using PM estimate of 10g/hr emitted during low idle (estimated from Tier 2 Certification Data)

[h] Using NO$_x$ estimate of 600g/hr emitted during low idle (estimated from Tier 2 Certification Data)

Note that we have not included the costs and savings associated with AESS systems in the overall cost analysis of the program summarized in Section 5.6. The primary reason for this is the expectation that these systems would be in widespread use absent a requirement from EPA, even in retrofit applications on existing locomotives. We did not believe it would be appropriate to assume no one would employ these systems absent a requirement, nor did we want to assume that everyone would absent a requirement. Further, as shown in Table -5-64, a net savings is likely, which would in effect, reduce the overall cost of our final program were we to include the costs and savings associated with AESS systems. Because of the difficulty and uncertainty involved in estimating their use absent a requirement, and their net effect of providing savings to users, we decided to present the costs and savings separately from the overall program.

5.8 Analysis of Energy Effects

Under E.O. 13211, a "significant energy action" is any regulatory action that might have a significant adverse effect on the supply, distribution, or use of energy. A significant adverse effect is, along with several other factors, any outcome that could reduce crude oil supply in excess of 10,000 barrels per day, reduce fuel production in excess of 4,000 barrels

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[Z] These values have changed since the NPRM due to the increase estimate in the price of diesel fuel, see section 5.4.3 of this chapter for more information.

per day, or increase energy usage in excess of either of those thresholds. The final locomotive and marine program is projected to have an impact on fuel usage in excess of one of these thresholds.

Sections 5.4.3 and 5.5 of this RIA present our analysis of the increased costs associated with fuel consumption impacts that would result from both the addition of diesel particulate filters to some locomotive and marine engines, and the remanufacture of Tier 0 locomotive and C2 marine engines. Table 5-44 through Table 5-47 show the increased number of gallons we have estimated would be consumed as a result of the final program. Table 5-51 through Table 5-53 show the increased number of gallons we have estimated would be consumed as a result of the remanufacturing programs. Using the metrics of 42 gallons of fuel per barrel of crude oil and 365 days in a year, the projected number of barrels of oil per day can be calculated as shown in Table 5-65. As shown, in the year 2022, our program is projected to result in excess of 4,000 barrels of oil per day in increased energy usage. Note that the fuel consumption estimates shown in Table 5-65 do not reflect the potential fuel savings associated with automatic engine stop/start (AESS) systems or other idle reduction technologies. As discussed in section 5.7, such technologies can provide significant fuel savings which could offset the increased fuel consumption estimates shown in Table 5-65.

Table 5-65 Estimated Increase in Fuel Consumed in Million Gallons per Year and Average Barrels per Day

Calendar Year	Increase in Fuel Consumed (Million gallons per year)					Barrels/day
	Tier 4 Locomotive	Tier 4 Marine	Locomotive Reman	Marine Reman	Total	
2006	0	0	0	0	0	0
2007	0	0	0	0	0	0
2008	0	0	2	3	5	305
2009	0	0	2	6	8	523
2010	0	0	4	10	14	894
2011	0	0	8	13	21	1383
2012	0	0	10	16	26	1717
2013	0	0	12	20	32	2073
2014	0	1	13	22	36	2335
2015	2	2	13	21	38	2482
2016	4	4	14	20	43	2781
2017	7	6	16	19	48	3101
2018	9	8	16	18	51	3315
2019	11	10	15	17	54	3516
2020	14	13	14	16	57	3695
2021	16	15	12	16	59	3874
2022	19	17	11	15	62	4060
2023	22	20	10	14	65	4253
2024	24	22	9	13	68	4449
2025	27	24	8	12	71	4649
2026	30	26	7	11	74	4851
2027	32	29	6	10	77	5055
2028	35	31	5	9	81	5260
2029	38	33	5	9	84	5461
2030	40	35	4	8	87	5653
2031	43	36	3	7	89	5838
2032	46	38	3	6	92	6020
2033	48	39	2	5	95	6203
2034	51	41	2	5	98	6382
2035	54	42	1	4	101	6562
2036	56	43	1	3	103	6740
2037	59	44	1	3	106	6915
2038	61	45	0	2	109	7086
2039	63	46	0	2	111	7253
2040	65	46	0	2	114	7416

5.9 Cost Effectiveness

As discussed in Chapter 6, this rule is very cost beneficial, with social benefits far outweighing social costs. However, this does not shed light on how cost effective this control program is compared to other control programs at providing the expected emission reductions. One tool that can be used to assess the value of the final program is the ratio of engineering costs incurred per ton of emissions reduced and comparing that ratio to other control programs. As we show in this section, the PM and NOx emissions reductions from the new locomotive and marine diesel program compare favorably—in terms of cost effectiveness—to other mobile source control programs that have been or will soon be implemented. We note that the locomotive and marine final rule builds upon the efforts undertaken by the engine manufacturing industry to comply with our recent 2007/2010 heavy-duty highway and nonroad Tier 4 (NRT4) rulemakings. As such, and as discussed at length in section 5.2.1 of this final RIA, much of the research and development associated with diesel emission controls builds upon the work done to comply with those earlier rules. This does not change the conclusion that the cost effectiveness of the locomotive and marine standards compares favorably with other actions deemed appropriate for society.

Table 5-66 shows the emissions reductions associated with the final locomotive and marine program. These reductions are discussed in more detail in Chapter 3 of this final RIA.

Table 5-66 Estimated Emissions Reductions Associated with the Final Locomotive and Marine Program (Short tons)

Year	$PM_{2.5}$	PM_{10}[a]	NO_x	NMHC
2015	7,000	8,000	161,000	14,000
2020	14,000	15,000	371,000	26,000
2030	27,000	27,000	795,000	40,000
2040	37,000	38,000	1,144,000	52,000
NPV at 3%	308,000	318,000	8,757,000	492,000
NPV at 7%	134,000	139,000	3,708,000	221,000

[a] Note that, $PM_{2.5}$ is estimated to be 97 percent of the more inclusive PM_{10} emission inventory. In Chapter 3 we generate and present $PM_{2.5}$ inventories since recent research has determined that these are of greater health concern. Similarly, NMHC is estimated to be 93 percent of the more inclusive VOC emission inventory. Traditionally, we have used PM_{10} and NMHC in our cost effectiveness calculations. Since cost effectiveness is a means of comparing control measures to one another, we use PM_{10} and NMHC in our cost effectiveness calculations for comparisons to past control measures.

Using the costs associated with PM and NO_x control shown in Table 5-61 and the emission reductions shown in Table 5-66, we can calculate the $/ton associated with the final program. These are shown in Table 5-67. The resultant cost per ton numbers depend on how the costs are allocated to each pollutant. We have allocated costs as closely as possible to the pollutants for which they are incurred. These allocations are also discussed in detail in Section 5.6 of this final RIA.

Table 5-67 Final Program Aggregate Cost per Ton and Long-Term Annual Cost per Ton (2005 dollars)

Pollutant	2006 Thru 2040 Discounted Lifetime Cost Per Ton At 3%	2006 Thru 2040 Discounted Lifetime Cost Per Ton At 7%	Cost Per Ton In 2030	Cost Per Ton In 2040
NO_x+NMHC	$730	$760	$690	$700
PM	$8,440	$9,620	$6,620	$6,360

The costs per ton shown in Table 5-67 for 2006 through 2040 use the net present value of the annualized costs and emissions reductions associated with the program for the years 2006 through 2040. We have also calculated the costs per ton of emissions reduced in the years 2030 and 2040 using the annual costs and emissions reductions in those specific years. These numbers are also shown in Table 5-67. All of the costs per ton include costs and emission reductions that will occur from the locomotive and marine remanufacturing programs.

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CHAPTER 6: Cost-Benefit Analysis

6.1 Overview

This chapter presents our analysis of the health and environmental benefits that are estimated to occur as a result of the final locomotive and marine engine standards throughout the period from initial implementation through 2030. Nationwide, the engines subject to the final emission standards in this rule are a significant source of mobile source air pollution. The final standards will reduce exposure to direct $PM_{2.5}$, NOx and air toxics emissions and help avoid a range of adverse health effects associated with ambient ozone and $PM_{2.5}$ levels.

EPA is required by Executive Order (E.O.) 12866 to estimate the benefits and costs of major new pollution control regulations. Accordingly, the analysis presented here attempts to answer three questions: (1) what are the physical health and welfare effects of changes in ambient air quality resulting from particulate matter (PM) and ozone precursor emission reductions (direct PM and NOx)? (2) what is the monetary value of the changes in these effects attributable to the final rule? and (3) how do the monetized benefits compare to the costs? It constitutes one part of EPA's thorough examination of the relative merits of this regulation.

The benefits analysis relies on three major components to answer these questions:

- Calculation of the impact of the final rule on the national nonroad emissions inventory of precursors to ozone and $PM_{2.5}$, specifically NOx, and direct PM, for two future years (2020 and 2030).

- Air quality modeling for 2020 and 2030 to determine changes in ambient concentrations of ozone and $PM_{2.5}$, reflecting baseline and post-control emissions inventories.

- A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the projected changes in ambient concentrations of ozone and $PM_{2.5}$ for the modeled standards.

A wide range of human health and welfare effects are linked to the emissions of direct PM and NOx and the resulting impact on ambient concentrations of ozone and $PM_{2.5}$. Recent studies have linked short-term ozone exposures with premature mortality. Exposure to ozone has also been linked to a variety of respiratory effects including hospital admissions and illnesses resulting in school absences. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis). Welfare effects potentially linked to PM include materials damage and visibility impacts, while ozone can adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests.

The benefits modeling is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality and peer-reviewed studies of the dollar values of those public health and welfare effects. All of the benefit estimates for the control options in this analysis are based on an analytical structure and sequence consistent with benefits analyses performed for the recent analysis of the proposed Ozone NAAQS and the final PM NAAQS analysis.[1,2] For a more detailed discussion of the principles of benefits analysis used here, we refer the reader to those documents, as well as to the EPA Guidelines for Economic Analysis.

Table 6.1-1 summarizes the annual monetized health and welfare benefits associated with the final standards for two years, 2020 and 2030. The estimates in Table 6.1-1, and all monetized benefits presented in this chapter, are in year 2006 dollars. There are a few items to note about these benefits:

- Using the most conservative benefits estimate, the 2020 benefits outweigh the costs by a factor of 10. Using the upper end of the benefits range, the benefits could outweigh the costs by a factor of 25. Likewise, in 2030 benefits outweigh the costs by at least a factor of 10 and could be as much as a factor of 28. Thus, even taking the most conservative benefits assumptions, benefits of the final standards clearly outweigh the costs.

- Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission control program. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario.

- The RIA for the proposal for this rulemaking only quantified benefits from PM; in the current RIA we quantify and monetize the ozone-related health and environmental impacts associated with the final rule. The science underlying the analysis is based on the current ozone criteria document.[3] The analytic approach to characterizing uncertainty is consistent with the analysis used in the RIA for the proposed O3 NAAQS.

- The range of ozone benefits associated with the final standards is based on risk reductions using several sources of ozone-related mortality effect estimates. There is considerable uncertainty in the magnitude of the association between ozone and premature mortality. This analysis presents four alternative estimates for the association based upon different functions reported in the scientific literature. Recognizing that additional research is necessary to clarify the underlying mechanisms causing these effects, we also consider the possibility that the observed associations between ozone and mortality may not be causal in nature.

- For this analysis, we observed two urban areas that, to some degree, experience ozone disbenefits related to NOx control: Southern California and the metropolitan Chicago area.[A] Ozone disbenefits associated with NOx control typically occur during nighttime and early morning hours, when NOx titrates ozone. Because human exposure to ozone is a function of the temporal and spatial patterns of ambient concentrations of ozone in the atmosphere, the ozone-related health impacts analysis is sensitive to which ozone exposure metric we use in the health impact functions. For example, the 24-hour average incorporates both nighttime and daytime hours, which means the decrease in ozone titration caused by reduced NOx emissions can cause relatively large increases in 24-hour average ozone. This is not the most relevant ozone exposure metric to characterize population-level exposure given that the majority of the people tend to be outdoors during the daylight hours. Furthermore, concentrations are highest during the daylight hours. Together, this means that the most biologically relevant metric, and the one used in the ozone NAAQS since 1997, is the 8-hour maximum standard. Thus, although epidemiological studies often present their results in terms of 24-hour average ozone levels, for the final rule analysis, we have converted health impact functions that use a 24-hour average ozone metric to 8-hour maximum ozone concentration using standard conversion functions.

[A] In areas prone to ozone disbenefits, our ability to draw conclusions based on air quality modeling conducted for the final rule is limited. Marginal ozone changes in these areas are much more dependent upon baseline air quality conditions than PM due to nonlinearities present in the chemistry of ozone formation. A marginal decrease in NOx emissions modeled on its own in these areas, as was done for this analysis, may yield a very different ambient ozone concentration than if it were modeled in combination with other planned or future controls. This is because “yet-to-occur” emission reductions in these areas, associated with local controls and other unknown measures, are not accounted for in our analytical approach. Within these regions, we expect that the additional NOx reductions from SIP-based controls will lead to fewer ozone disbenefits from the marginal changes modeled here.

Table 6.1-1. Estimated Monetized PM- and Ozone-Related Health Benefits of the Final Locomotive and Marine Engine Standards

2030 Total Ozone and PM Benefits – PM Mortality Derived from American Cancer Society Analysis[a]			
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2006$, 3% Discount Rate)[c,d]	Mean Total Benefits (Billions, 2006$, 7% Discount Rate)[c,d]
NMMAPS	Bell et al., 2004	$9.7	$8.9
Meta-analysis	Bell et al., 2005	$11	$9.8
	Ito et al., 2005	$11	$10
	Levy et al., 2005	$11	$10
Assumption that association is not causal		$9.2	$8.4
2030 Total Ozone and PM Benefits – PM Mortality Derived from Expert Elicitation[b]			
Premature Ozone Mortality Function or Assumption	Reference	Mean Total Benefits (Billions, 2006$, 3% Discount Rate)[c,d]	Mean Total Benefits (Billions, 2006$, 7% Discount Rate)[c,d]
NMMAPS	Bell et al., 2004	$5.2 to $37	$4.8 to $34
Meta-analysis	Bell et al., 2005	$6.2 to $38	$5.8 to $35
	Ito et al., 2005	$6.7 to $39	$6.3 to $35
	Levy et al., 2005	$6.7 to $39	$6.4 to $35
Assumption that association is not causal		$4.7 to $37	$4.4 to $33

[a] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from the American Cancer Society analysis (Pope et al., 2002).

[b] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the $PM_{2.5}$ premature mortality functions characterized in the expert elicitation. The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 6.4-1.

[d] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

Table 6.1-1 reflects those human health and welfare effects we are able to quantify and monetize. However, the full complement of human health and welfare effects associated with PM, ozone and air toxics remain unquantified because of current limitations in methods or available data. 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). Additionally, we are 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 acidification in lakes and streams and eutrophication in coastal areas. As a result, we may underestimate the total benefits attributable to the implementation of the final standards.

This chapter is organized as follows. In Section 6.2, we provide an overview of the air quality impacts modeled for the final standards that are used as inputs to the benefits analysis. In Section 6.3, we discuss how uncertainty is characterized in this analysis. Section 6.4 discusses the literature on ozone- and PM-related health effects and describes the specific set of health impact functions we used in the benefits analysis. Section 6.5 describes the economic values selected to estimate the dollar value of ozone- and PM-related health impacts. In Section 6.6, we report the results of the analysis for human health and welfare effects. Finally, Section 6.7 presents a comparison of the costs and benefits associated with the final standards.

6.2 Air Quality Impacts for Benefits Analysis

In Chapter 2, we summarize the methods for and results of estimating air quality for the 2020 and 2030 base case and final control scenario. These air quality results are in turn associated with human populations and ecosystems to estimate changes in health and welfare effects. For the purposes of the benefits analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emission reductions estimated to occur due to the final standards. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). The air quality modeling Technical Support Document (TSD), which can be found in the docket for this rule, contains detailed information about the modeling conducted for this rule. In this section, we describe how the modeled air quality results were used for the benefits analysis.

We remind the reader that the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission control program. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Emissions and air quality modeling decisions are made early in the analytical process. Chapter 3 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario.

6.2.1 Converting CMAQ Outputs to Full-Season Profiles for Benefits Analysis

This analysis extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[B,C]

[B] The ozone season for this analysis is defined as the 5-month period from May to September.

[C] Based on AIRS, there were 961 ozone monitors with sufficient data (i.e., 50 percent or more days reporting at

The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (i.e., the Environmental Benefits Mapping and Analysis Program [BenMAP]).

To estimate ozone-related health and welfare effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily 8-hour maximum.[D,E]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2002 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 1999). The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the final emissions controls. Full documentation of the revised SMAT methodology is contained in the Air Quality Modeling TSD.

6.2.2 Ozone and $PM_{2.5}$ Air Quality Results

This section provides a summary of the predicted ambient $PM_{2.5}$ and ozone concentrations from the CMAQ model for the 2020 and 2030 base cases and changes

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least nine hourly observations per day [8 am to 8 pm] during the ozone season).

[D] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.

[E] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www.epa.gov/air/benmap.

associated with the final rule. Table 6.2-1 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

Table 6.2-1. Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Due to the Final Locomotive and Marine Engine Standards

	2020		2030	
Statistic[a]	Baseline	Change[b]	Baseline	Change[b]
Ozone Metrics: National Population-Weighted Average (ppb)[c]				
Daily 1-Hour Maximum Concentration	49.13	0.060	48.78	0.202
Daily 8-Hour Maximum Concentration	42.89	0.033	42.65	0.137
Daily 8-Hour Average Concentration	41.71	0.031	41.49	0.130
Daily 24-Hour Average Concentration	28.16	-0.033	28.11	-0.039
$PM_{2.5}$ Metrics: National Population-Weighted Average (ug/m^3)				
Annual Average Concentration	11.85	0.061	11.87	0.122

[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates based on the results of spatial and temporal Voronoi Neighbor Averaging. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (i.e., May through September). For the 8-hour average, for example, the relevant time period is 9 am to 5 pm.

[b] The change is defined as the base-case value minus the control-case value.

[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

6.2.2.1 Modeled Ozone-Related Disbenefits and Treatment in Benefits Analysis

While this rule will reduce ozone levels generally and provide national ozone-related health benefits, as demonstrated in Table 6.2-1, this is not always the case at the local level. Due to the complex photochemistry of ozone production, reductions in NO_x emissions lead to both the formation and destruction of ozone, depending on the relative quantities of NO_x, VOC, and ozone catalysts such as the OH and HO_2 radicals. In areas dominated by fresh emissions of NO_x, ozone catalysts are removed via the production of nitric acid which slows the ozone formation rate. Because NO_x is generally depleted more rapidly than VOC, this effect is usually short-lived and the emitted NOx can lead to ozone formation later and further downwind. The terms "NO_x disbenefits" or "ozone disbenefits" refer to the ozone increases that can result from NOx emissions reductions in these localized areas. According to the North American Research Strategy for Tropospheric Ozone (NARSTO) Ozone Assessment, these disbenefits are generally limited to small regions within specific urban cores and are surrounded by larger regions in which NO_x control is beneficial.[F] For this analysis, we observed two urban areas that experience ozone disbenefits: Southern California and, to a lesser degree, the metropolitan Chicago area. Full documentation of these disbenefits is contained in the Air Quality Modeling TSD, located in the docket for this rule.

Marginal changes in ozone in these areas are much more dependent upon baseline air quality conditions than PM due to nonlinearities present in the chemistry of ozone formation. A marginal decrease in NOx emissions modeled on its own in these areas, as was done for this analysis, may yield a very different ambient ozone concentration than if it were modeled in combination with other planned or future controls. For example, recent California SIP modeling indicates that with a combined program of national and local controls, including the final locomotive and marine controls, Southern California can reach ozone attainment by 2024 through a mixture of substantial NOx (and VOC) reductions.[G]

In areas prone to ozone disbenefits, such as Southern California, our ability to draw conclusions based on air quality modeling conducted for the final rule is limited because the yet-to-occur emission reductions in these areas are not accounted for in our analytical approach. Within these regions, it is expected that the additional NOx reductions from SIP-based controls would lead to fewer ozone disbenefits from the marginal changes modeled here. The ozone benefits in these regions may therefore be underestimated.

EPA has been aware of the issue of ozone disbenefits for a number of years. We have recognized the implications of this issue for cost-benefit analyses of mobile source strategies in our recent rulemakings for heavy duty onroad and nonroad diesel engines. For example, in the Nonroad Diesel rule RIA, we noted that "our ozone air quality modeling showed that the NOx emissions reductions from the preliminary modeled standards are projected to result in increases in ozone concentrations for certain hours during the year, especially in urban, NOx-limited areas. Most of these increases are expected to occur during hours where ozone levels are low (and often below the one-hour ozone standard)."

EPA has always incorporated ozone-related disbenefits into our estimates of total benefits. In the Nonroad Diesel rule RIA, we provided this statement regarding disbenefits: "Ozone benefits arising from this rule are in aggregate positive for the nation. However, due to ozone increases occurring during certain hours of the day in some urban areas, in 2020 the

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[F] The NARSTO Assessment Document synthesizes the scientific understanding of ozone pollution, giving special consideration to behavior on expanded scales over the North American continent, encompassing Canada, the United States, and Mexico. Successive drafts of this Assessment Document experienced progressive stages of review by its authors and by outside peers, and transcripts were recorded containing the review comments and the corresponding actions. This included an external review by the NRC, the comments of which were addressed and incorporated in the final draft. NARSTO, 2000. An Assessment of Tropospheric Ozone Pollution – A North American Perspective. NARSTO Management Office (Envair), Pasco, Washington. http://narsto.org/

[G] SCAQMD (2007). Final 2007 Air Quality Management Plan. Available at: http://www.aqmd.gov/aqmp/07aqmp/index.html. Accessed November 8, 2007.

net effect is an increase in ozone-related minor restricted activity days (MRAD), which are related to changes in daily average ozone (which includes hours during which ozone levels are low, but are increased relative to the baseline based on the preliminary modeling). However, by 2030, there is a net decrease in ozone-related MRAD consistent with widespread reductions in ozone concentrations from the increased NOx emissions reductions. Note that in both years, the overall impact of changes in both PM and ozone is a large decrease in the number of MRAD. Overall, ozone benefits are low relative to PM benefits for similar endpoint categories because of the increases in ozone concentrations during some hours of some days in certain urban areas."

The addition of ozone mortality to our health impacts analysis has led to an increased focus on the issue of ozone disbenefits for two related reasons: (1) The monetized value of ozone-related benefits, in terms of ozone’s contribution to total rule-related benefits, has increased due to the inclusion of ozone mortality; and (2) The overall ozone impacts of NOx reductions in certain geographic regions of the U.S., when modeled on the margin, may be negative.

Figure 1 shows the diurnal pattern of ozone concentrations in the 2030 baseline and post-control scenarios for a grid cell in Orange County, CA during July. From this figure it is clear that the disbenefits (points when the control case ozone levels are higher than the baseline) are occurring primarily during nighttime hours when ozone is generally low.

This diurnal pattern means that the extent of the disbenefits is not as large as one might have thought. Our conversion from using a 24-hour metric to using the maximum 8-hour average metric in the ozone mortality studies (see page 6-4 and the health impacts section) excludes the nighttime hours when NOx-related disbenefits are most likely to occur.

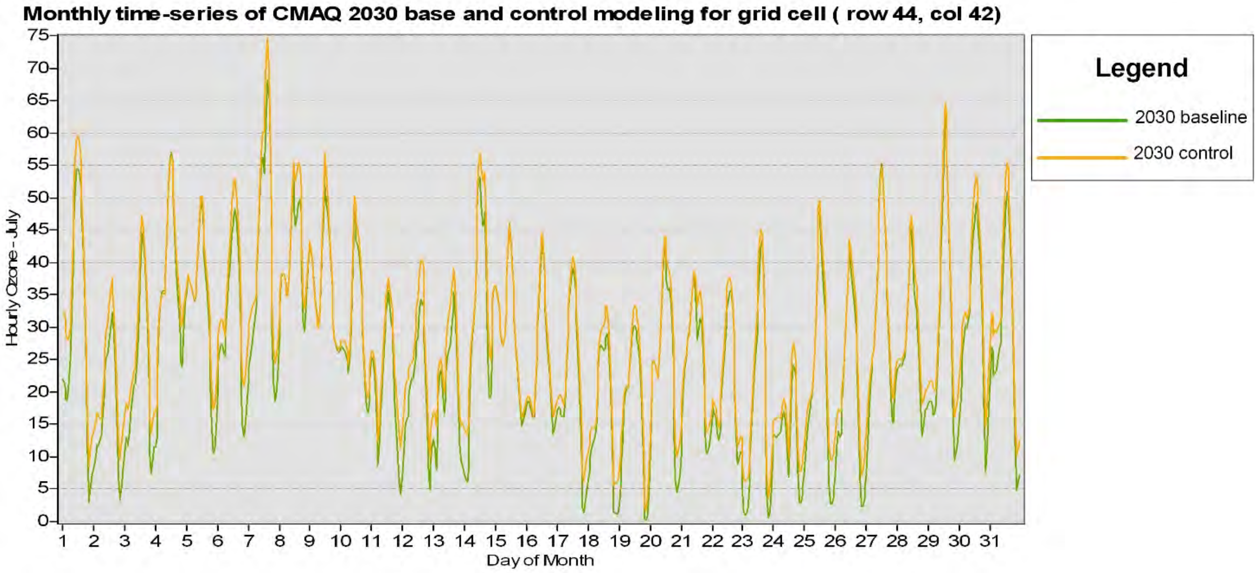

Figure 1. July 2030 time-series of CMAQ base and control modeling for Orange County, CA

6.3 Characterizing Uncertainty: Moving Toward a Probabilistic Framework for Benefits Assessment

The National Research Council (NRC)[4] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that process include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, it is particularly important to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies.[H] In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs. In

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[H] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration.

addition, we characterize the uncertainty introduced by the inability of existing empirical studies to discern whether the relationship between ozone and pre-mature mortality is causal by providing an effect estimate preconditioned on an assumption that the effect estimate for pre-mature mortality from ozone is zero.

For premature mortality associated with exposure to PM, we follow the same approach that has been used in several recent RIAs.[I,J,K] First, we use Monte Carlo methods for estimating random sampling error associated with the concentration response functions from epidemiological studies and economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. Distributions for individual effect estimates are based on the reported standard errors in the epidemiological studies. Distributions for unit values are described in Table 6.5-1.

Second, we use the results of our expert elicitation of the concentration response function describing the relationship between premature mortality and ambient $PM_{2.5}$ concentration.[L, M] Incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model; whether or not a threshold may exist). This second approach attempts to incorporate these other sources of uncertainty.

Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA.

[I] U.S. Environmental Protection Agency, 2004a. Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. EPA420-R-04-007. Prepared by Office of Air and Radiation. Available at http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf

[J] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the Clean Air Interstate Rule. EPA 452/-03-001. Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/interstateairquality/tsd0175.pdf

[K] U.S. Environmental Protection Agency, 2006. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

[L] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

[M] Industrial Economics, Inc. 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Prepared for EPA Office of Air Quality Planning and Standards, September. Available at: http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf

These multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

6.4 Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: 1) an effect estimate from a particular study; 2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); 3) the size of the potentially affected population; and 4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), ∃ is the effect estimate, and)x is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. Section 6.2 described the ozone and PM air quality inputs to the health impact functions. The following subsections describe the sources for each of the other elements: size of potentially affected populations; effect estimates; and baseline incidence rates.

6.4.1 Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[5] Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2020 using growth factors based on economic projections.[6]

6.4.2 Effect Estimate Sources

The most significant monetized benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents[7,8] and the World Health Organization's 2003 and 2004[9,10] reports outline numerous health effects known or suspected to be linked to exposure to ambient ozone and PM. EPA recently evaluated the PM literature for use in the benefits analysis for the 2006 PM NAAQS RIA. Because we used the same literature for the PM benefits analysis in this RIA, and also in the RIA for the proposed rule, we do not provide a detailed discussion of individual effect estimates for PM in this section. Instead, we refer the reader to the 2006 PM NAAQS RIA and the proposed Locomotive and Marine RIA for details.[N]

The RIA for the proposal for this rulemaking only quantified benefits from PM; in the current RIA we quantify and monetize the ozone-related health and environmental impacts associated with the final rule using an approach consistent with the proposed ozone NAAQS RIA. More than one thousand new ozone health and welfare studies have been published since EPA issued the 8-hour ozone standard in 1997. Many of these studies investigated the impact of ozone exposure on health effects such as: changes in lung structure and biochemistry; lung inflammation; asthma exacerbation and causation; respiratory illness-related school absence; hospital and emergency room visits for asthma and other respiratory causes; and premature death. We provide a discussion of those ozone-related impacts in this section. For a more detailed discussion of the health effects of ozone exposure, we point the reader to EPA's ozone Criteria Document.[11]

It is important to note that we were not able to separately quantify all of the PM and ozone health effects that have been reported in the ozone and PM criteria documents in this analysis for four reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; (3) the lack of an established concentration-response relationship; or 4) the inability to appropriately value the effect (for example, changes in forced expiratory volume) in economic terms. Table 6.4-1 lists the human health and welfare effects of pollutants affected by the alternate standards. Table 6.4-2 lists the health endpoints included in this analysis.

[N] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf pp. 5-29.

Table 6.4-1 Human Health and Welfare Effects of Pollutants Affected by the Final Standards

Pollutant/Effect	*Quantified and Monetized in Base Estimates*[a]	*Unquantified Effects - Changes in:*
PM/Health[b]	Premature mortality based on both cohort study estimates and on expert elicitation[c,d] Bronchitis: chronic and acute 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) Respiratory symptoms (asthmatic population) Infant mortality	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
PM/Welfare		Visibility in Southeastern Class I areas Visibility in northeastern and Midwestern Class I areas Household soiling Visibility in western U.S. Class I areas Visibility in residential and non-Class I areas UVb exposure (+/-)[e]
Ozone/Health[f]	Premature mortality: short-term exposures Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Acute respiratory symptoms	Cardiovascular emergency room visits Chronic respiratory damage[g] Premature aging of the lungs[g] Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare	Decreased outdoor worker productivity	Yields for commercial crops Yields for commercial forests and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]
CO Health		Behavioral effects

Pollutant/Effect	*Quantified and Monetized in Base Estimates*[a]	*Unquantified Effects - Changes in:*
Nitrogen Deposition/ Welfare		Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
NOx/Health		Lung irritation Lowered resistance to respiratory infection Hospital admissions for respiratory and cardiac diseases
HC/Toxics Health[h]		Cancer, including lung (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene) Anemia (benzene) Disruption of production of blood components (benzene) 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) Neurotoxicity (n-hexane, toluene, xylenes)
HC/Toxics Welfare[h]		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the final standards.

[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[c] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli, 2001 for a discussion of this issue).

[d] While some of the effects of short-term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short-term PM exposure not captured in the cohort estimates included in the primary analysis.

[e] May result in benefits or disbenefits.

[f] The public health impact of biological responses such as increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection are likely partially represented by our quantified endpoints.

[g] The public health impact of effects such as chronic respiratory damage and premature aging of the lungs may be partially represented by quantified endpoints such as hospital admissions or premature mortality, but a number of other related health impacts, such as doctor visits and decreased athletic performance, remain unquantified.

[h] The categorization of unquantified toxic health and welfare effects is not exhaustive.

Table 6.4-2. Ozone- and PM-Related Health Endpoints

Endpoint	*Pollutant*	*Study*	*Study Population*
Premature Mortality			
Premature mortality – daily time series, non-accidental	O3	Bell et al (2004) (NMMAPS study)[12] Meta-analyses: Bell et al (2005)[13] Ito et al (2005)[14] Levy et al (2005)[15]	All ages
Premature mortality —cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[16] Laden et al. (2006)[17]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[18]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[19]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[20]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[21]	Adults (>18 years)
Hospital Admissions			
Respiratory	O3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[22] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[23,24] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[25] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[26]	<2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[27] Ito (2003)—ICD 490-496 (COPD)[28]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[29]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[30]	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years

Endpoint	*Pollutant*	*Study*	*Study Population*
Asthma-related ER visits	O3	Pooled estimate: Jaffe et al (2003)[31] Peel et al (2005)[32] Wilson et al (2005)[33]	5–34 years All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[34]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[35]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[36]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[37]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[38] (cough, wheeze and shortness of breath) Vedal et al. (1998)[39] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[40]	18–65 years
School absence days	O3	Pooled estimate: Gilliland et al. (2001)[41] Chen et al. (2000)[42]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O3	Ostro and Rothschild (1989)[43]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the Science Advisory Board Health Effects Subcommittee (SAB-HES), we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations.* Washington, DC: The National Academies Press.

[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the 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.

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.[44,45]

A number of endpoints that are not health-related also may significantly contribute to monetized benefits. Potential welfare benefits associated with ozone exposure include: increased outdoor worker productivity; increased yields for commercial and non-commercial crops; increased commercial forest productivity; reduced damage to urban ornamental plants;

increased recreational demand for undamaged forest aesthetics; and reduced damage to ecosystem functions.[46,47] While we include estimates of the value of increased outdoor worker productivity, estimation of other welfare impacts is beyond the scope of this analysis.

6.4.2.1 Ozone Exposure Metric

Because several of the ozone mortality epidemiology studies report their base results relating mortality to 24-hour average ozone, the importance of understanding the biological relevance of the 24-hour metric relative to other possible metrics is critical.

As mentioned above, ozone-related disbenefits are projected to occur in small regions within specific urban cores (though yet-to-occur emissions reductions related to ozone attainment efforts are not accounted for in our current air quality modeling approach). When NOx reductions increase ozone in these regions, however, it is typically during nighttime and early morning hours, when NOx titrates ozone. Because human exposure to ozone is a function of the temporal and spatial patterns of ambient concentrations of ozone in the atmosphere, the ozone-related health impacts analysis is especially sensitive to which ozone exposure metric we use in the health impact functions.[O]

Prior to the addition of ozone-related premature mortality functions to the health impacts analysis, most of our ozone health impact functions have used metrics which are less sensitive to ozone disbenefits (e.g., 8-hour daily average). For example, emergency department visits for asthma are related to 1- or 8-hour maxima. School absences are based on 8-hour mean and 1-hour maximum ozone levels. It should be noted that ozone disbenefits that occur during daylight hours, when ozone is higher, are accounted for in these averages.

Epidemiology studies are retrospective in nature and focus on identifying a statistical relationship between some measure of ozone and a health outcome. The specific epidemiological studies that form the basis for the ozone mortality impact estimates use time-series statistical methods that estimate the relationship between daily ozone levels and mortality based on day to day variations in ozone and mortality. The focus of these studies is not as much on a specific ozone averaging time as on the day to day variation in the ozone metrics. In fact, epidemiologists often analyze and report results for multiple ozone metrics, but may report results for only one metric in the abstract of an article.

In most cases, the day to day variation in different metrics (24-hour average vs 8-hour maximum, for example) is highly correlated. As such, the relationships between mortality

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[O] An exposure metric is a measure of air quality calculated as the average or maximum of modeled ambient concentrations over a relevant time period, such as during the daylight hours of the “ozone season” (which is May through September for this analysis). The 24-hour average is therefore calculated as the average of all hourly ozone concentrations throughout the day (from 12am to 11:59pm). The 8-hour maximum is the maximum hourly value observed between 9am and 5pm each day. The 1-hour maximum is the maximum hourly value observed throughout an entire day.

and different ozone metrics will be highly correlated as well. However, when we apply the mortality impact functions derived from these time-series results to evaluate the impacts of a specific control measure, we do not focus on the day to day variation in ozone levels so much as the shift in the overall distribution of ozone concentrations over an entire season. Because specific emission control strategies might result in a different diurnal profile than was observed in the monitored ozone data used in the studies, it is important to choose an ozone metric that is best suited to capturing changes in ozone that are likely to occur during hours where populations are likely to be exposed to the ozone.

To address this issue in the final rule analysis, we have used standard conversion functions to convert ozone-related premature mortality health impact functions that use a 24-hour average or 1-hour maximum ozone metric to functions that use an 8-hour maximum ozone concentration instead. This is consistent both with the available exposure modeling and with the form of the current ozone standard. This conversion also does not affect the relative magnitude of the health impact function. An equivalent change in the 24-hour average and 8-hour maximum will provide the same overall change in incidence of a health effect. The conversion ratios are based on observed relationships between the 24-hour average and 8-hour maximum ozone values. For example, in the Bell et al., 2004 analysis of ozone-related premature mortality, the authors found that the relationship between the 24-hour average, the 8-hour maximum, and the 1-hour maximum was 2:1.5:1, so that the derived health impact effect estimate based on the 1-hour maximum should be half that of the effect estimate based on the 24-hour values (and the 8-hour maximum three-quarters of the 24-hour effect estimate).

The conversion of ozone metrics does not require adjustment to the air quality modeling. It preserves the observed patterns of ozone-related disbenefits, and allows for disbenefits to occur in the health impact estimates if those disbenefits occur during hours when populations are likely to be exposed. In future analyses, we will also convert the ozone exposure metrics in morbidity studies that do not use an 8-hour exposure metric.

6.4.2.2 Premature Mortality Effect Estimates

While particulate matter is the criteria pollutant most clearly associated with premature mortality, recent research suggests that short-term repeated ozone exposure likely contributes to premature death. The 2006 Ozone Criteria Document states: “Consistent with observed ozone-related increases in respiratory- and cardiovascular-related morbidity, several newer multi-city studies, single-city studies, and several meta-analyses of these studies have provided relatively strong epidemiologic evidence for associations between short-term ozone exposure and all-cause mortality, even after adjustment for the influence of season and PM” (EPA, 2006: E-17).[48] The epidemiologic data are also supported by newly available experimental data from both animal and human studies which provide evidence suggestive of plausible pathways by which risk of respiratory or cardiovascular morbidity and mortality could be increased by ambient ozone. With respect to short-term exposure, the ozone Criteria Document concludes: “This overall body of evidence is highly suggestive that ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to more fully establish underlying mechanisms by which such effects occur" (pg. E-18).

With respect to the time-series studies, the conclusion regarding the relationship between short-term exposure and premature mortality is based, in part, upon recent city-specific time-series studies such as the Schwartz (2004) analysis in Houston and the Huang et al. (2004) analysis in Los Angeles.[P] This conclusion is also based on recent meta-analyses by Bell et al. (2005), Ito et al. (2005), and Levy et al. (2005), and a new analysis of the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) data set by Bell et al. (2004), which specifically sought to disentangle the roles of ozone, PM, weather-related variables, and seasonality. The 2006 Criteria Document states that "the results from these meta-analyses, as well as several single- and multiple-city studies, indicate that co-pollutants generally do not appear to substantially confound the association between ozone and mortality" (p. 7-103). However, CASAC raised questions about the implications of these time-series results in a policy context. Specifically, CASAC emphasized that "…while the time-series study design is a powerful tool to detect very small effects that could not be detected using other designs, it is also a blunt tool" (Henderson, 2006: 3). They point to findings (e.g., Stieb et al., 2002, 2003) that indicated associations between premature mortality and all of the criteria pollutants, indicating that "findings of time-series studies do not seem to allow us to confidently attribute observed effects to individual pollutants" (id.). They note that "not only is the interpretation of these associations complicated by the fact that the day-to-day variation in concentrations of these pollutants is, to a varying degree, determined by meteorology, the pollutants are often part of a large and highly correlated mix of pollutants, only a very few of which are measured" (id.). Even with these uncertainties, the CASAC Ozone Panel, in its review of EPA's Staff Paper, found "…premature total non-accidental and cardiorespiratory mortality for inclusion in the quantitative risk assessment to be appropriate."

Consistent with the methodology used in the ozone risk assessment found in the Characterization of Health Risks found in the Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, we included ozone mortality in the primary health effects analysis, with the recognition that the exact magnitude of the effects estimate is subject to continuing uncertainty. We used effect estimates from the Bell et al. (2004) NMMAPS analysis, as well as effect estimates from the three meta-analyses. In addition, we include the possibility that there is not a causal association between ozone and mortality, i.e., that the effect estimate for premature mortality could be zero.

[P] For an exhaustive review of the city-specific time-series studies considered in the ozone staff paper, see: U.S. Environmental Protection Agency, 2007. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. Prepared by the Office of Air and Radiation. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2007_01_ozone_staff_paper.pdf. pp. 5-36.

We estimate the change in mortality incidence and estimated credible interval[Q] resulting from application of the effect estimate from each study and present them separately to reflect differences in the study designs and assumptions about causality. However, it is important to note that this procedure only captures the uncertainty in the underlying epidemiological work, and does not capture other sources of uncertainty, such as uncertainty in the estimation of changes in air pollution exposure (Levy et al., 2000).

6.4.2.3 Respiratory Hospital Admissions Effect Estimates

Detailed hospital admission and discharge records provide data for an extensive body of literature examining the relationship between hospital admissions and air pollution. This is especially true for the portion of the population aged 65 and older, because of the availability of detailed Medicare records. In addition, there is one study (Burnett et al., 2001) providing an effect estimate for respiratory hospital admissions in children under two.

Because the number of hospital admission studies we considered is so large, we used results from a number of studies to pool some hospital admission endpoints. Pooling is the process by which multiple study results may be combined in order to produce better estimates of the effect estimate, or β. For a complete discussion of the pooling process, see Abt (2005).[R] To estimate total respiratory hospital admissions associated with changes in ambient ozone concentrations for adults over 65, we first estimated the change in hospital admissions for each of the different effects categories that each study provided for each city. These cities included Minneapolis, Detroit, Tacoma and New Haven. To estimate total respiratory hospital admissions for Detroit, we added the pneumonia and COPD estimates, based on the effect estimates in the Schwartz study (1994). Similarly, we summed the estimated hospital admissions based on the effect estimates the Moolgavkar study reported for Minneapolis (Moolgavkar et al., 1997). To estimate total respiratory hospital admissions for Minneapolis using the Schwartz study (1994), we simply estimated pneumonia hospital admissions based on the effect estimate. Making this assumption that pneumonia admissions represent the total impact of ozone on hospital admissions in this city will give some weight to the possibility that there is no relationship between ozone and COPD, reflecting the equivocal evidence represented by the different studies. We then used a fixed-effects pooling procedure to combine the two total respiratory hospital admission estimates for Minneapolis. Finally, we used random effects pooling to combine the results for Minneapolis and Detroit with results from studies in Tacoma and New Haven from Schwartz (1995). As noted above, this pooling approach incorporates both the precision of the individual effect estimates and between-study variability characterizing differences across study locations.

[Q] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[R] Abt Associates, Incorporated. Environmental Benefits Mapping and Analysis Program, Technical Appendices. May 2005. pp. I-3

6.4.2.4 Asthma-Related Emergency Room Visits Effect Estimates

We used three studies as the source of the concentration-response functions we used to estimate the effects of ozone exposure on asthma-related emergency room (ER) visits: Peel et al. (2005); Wilson et al. (2005); and Jaffe et al. (2003). We estimated the change in ER visits using the effect estimate(s) from each study and then pooled the results using the random effects pooling technique (see Abt, 2005). The study by Jaffe et al. (2003) examined the relationship between ER visits and air pollution for populations aged five to 34 in the Ohio cities of Cleveland, Columbus and Cincinnati from 1991 through 1996. In single-pollutant Poisson regression models, ozone was linked to asthma visits. We use the pooled estimate across all three cities as reported in the study. The Peel et al. study (2005) estimated asthma-related ER visits for all ages in Atlanta, using air quality data from 1993 to 2000. Using Poisson generalized estimating equations, the authors found a marginal association between the maximum daily 8-hour average ozone level and ER visits for asthma over a 3-day moving average (lags of 0, 1, and 2 days) in a single pollutant model. Wilson et al. (2005) examined the relationship between ER visits for respiratory illnesses and asthma and air pollution for all people residing in Portland, Maine from 1998-2000 and Manchester, New Hampshire from 1996-2000. For all models used in the analysis, the authors restricted the ozone data incorporated into the model to the months ozone levels are usually measured, the spring-summer months (April through September). Using the generalized additive model, Wilson et al. (2005) found a significant association between the maximum daily 8-hour average ozone level and ER visits for asthma in Portland, but found no significant association for Manchester. Similar to the approach used to generate effect estimates for hospital admissions, we used random effects pooling to combine the results across the individual study estimates for ER visits for asthma. The Peel et al. (2005) and Wilson et al. (2005) Manchester estimates were not significant at the 95 percent level, and thus, the confidence interval for the pooled incidence estimate based on these studies includes negative values. This is an artifact of the statistical power of the studies, and the negative values in the tails of the estimated effect distributions do not represent improvements in health as ozone concentrations are increased. Instead these should be viewed as a measure of uncertainty due to limitations in the statistical power of the study. Note that we included both hospital admissions and ER visits as separate endpoints associated with ozone exposure, because our estimates of hospital admission costs do not include the costs of ER visits, and because most asthma ER visits do not result in a hospital admission.

6.4.2.5 Minor Restricted Activity Days Effects Estimate

Minor restricted activity days (MRADs) occur when individuals reduce most usual daily activities and replace them with less-strenuous activities or rest, but do not miss work or school. We estimated the effect of ozone exposure on MRADs using a concentration-response function derived from Ostro and Rothschild (1989). These researchers estimated the impact of ozone and $PM_{2.5}$ on MRAD incidence in a national sample of the adult working population (ages 18 to 65) living in metropolitan areas. We developed separate coefficients for each year of the Ostro and Rothschild analysis (1976-1981), which we then combined for use in EPA's analysis. The effect estimate used in the impact function is a weighted average of the coefficients in Ostro and Rothschild (1989, Table 4), using the inverse of the variance as the weight.

6.4.2.6 School Absences Effect Estimate

Children may be absent from school due to respiratory or other acute diseases caused, or aggravated by, exposure to air pollution. Several studies have found a significant association between ozone levels and school absence rates. We use two studies (Gilliland et al., 2001; Chen et al., 2000) to estimate changes in school absences resulting from changes in ozone levels. The Gilliland et al. study estimated the incidence of new periods of absence, while the Chen et al. study examined daily absence rates. We converted the Gilliland et al. estimate to days of absence by multiplying the absence periods by the average duration of an absence. We estimated 1.6 days as the average duration of a school absence, the result of dividing the average daily school absence rate from Chen et al. (2000) and Ransom and Pope (1992) by the episodic absence duration from Gilliland et al. (2001). Thus, each Gilliland et al. period of absence is converted into 1.6 absence days.

Following recent advice from the National Research Council (2002), we calculated reductions in school absences for the full population of school age children, ages five to 17. This is consistent with recent peer-reviewed literature on estimating the impact of ozone exposure on school absences (Hall et al. 2003). We estimated the change in school absences using both Chen et al. (2000) and Gilliland et al. (2001) and then, similar to hospital admissions and ER visits, pooled the results using the random effects pooling procedure.

6.4.2.7 Worker Productivity

To monetize benefits associated with increased worker productivity resulting from improved ozone air quality, we used information reported in Crocker and Horst (1981). Crocker and Horst examined the impacts of ozone exposure on the productivity of outdoor citrus workers. The study measured productivity impacts. Worker productivity is measuring the value of the loss in productivity for a worker who is at work on a particular day, but due to ozone, cannot work as hard. It only applies to outdoor workers, like fruit and vegetable pickers, or construction workers. Here, productivity impacts are measured as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration. The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income. Given the national median daily income for outdoor workers engaged in strenuous activity reported by the U.S. Census Bureau (2002), \$68 per day (2000\$), a ten percent reduction in ozone yields about \$0.97 in increased daily wages. We adjust the national median daily income estimate to reflect regional variations in income using a factor based on the ratio of county median household income to national median household income. No information was available for quantifying the uncertainty associated with the central valuation estimate. Therefore, no uncertainty analysis was conducted for this endpoint.

6.4.2.8 Unquantified Effects

6.4.2.8.1 Direct Ozone Effects on Vegetation

The Ozone Criteria Document notes that "current ambient concentrations in many areas of the country are sufficient to impair growth of numerous common and economically valuable plant and tree species." (U.S. EPA, 2006, page 9-1). Changes in ground-level ozone resulting from the implementation of alternative ozone standards are expected to affect crop and forest yields throughout the affected area. Recent scientific studies have also found the ozone negatively impacts the quality or nutritive value of crops (U.S. EPA, 2006, page 9-16).

Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of planting decisions, yield response functions, and the supply of and demand for agricultural products. The resulting welfare measures are based on predicted changes in market prices and production costs. Models also exist to measure benefits to silvicultural producers and consumers. However, these models have not been adapted for use in analyzing ozone-related forest impacts. Because of resource limitations, we are unable to provide agricultural or benefits estimates for the final rule.

An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 2006, page 9-19). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals (floriculture and nursery crops) represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to affect large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. The farm production value of ornamental crops was estimated at over $14 billion in 2003 (USDA, 2004). This is therefore a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

6.4.2.8.2 Nitrogen Deposition

Deposition to Estuarine and Coastal Waters

Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999). A recent study found that for the period 1990-2002, atmospheric deposition accounted for 17 percent of nitrate loadings in the Gulf of Mexico, where severe hypoxic zones have been existed over the last two decades (Booth and Campbell, 2007)[S].

Reductions in atmospheric deposition of NOx are expected to reduce the adverse impacts associated with nitrogen deposition to estuarine and coastal waters. However, direct functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP-based measure of benefits depends on the availability of these functions and on estimates of the value of environmental responses. Because neither appropriate functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

Deposition to Agricultural and Forested Land

Implementation strategies for alternative standards which reduce NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and

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[S] Booth, M.S., and C. Campbell. 2007. Spring Nitrate Flux in the Mississippi River Basin: A Landscape Model with Conservation Applications. Environ. Sci. Technol.; 2007; ASAP Web Release Date: 20-Jun-2007; (Article) DOI: 10.1021/es070179e other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (US EPA, 1993). Moreover, any positive effect that nitrogen deposition has on forest productivity would enhance the level of carbon dioxide sequestration as well.[T,U,V]

On the other hand, there is evidence that forest ecosystems in some areas of the United States (such as the western U.S.) are nitrogen saturated (US EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

6.4.2.8.3 Ultraviolet Radiation

Atmospheric ozone absorbs a harmful band of ultraviolet radiation from the sun called UV-B, providing a protective shield to the Earth's surface. The majority of this protection occurs in the stratosphere where 90% of atmospheric ozone is located. The remaining 10% of the Earth's ozone is present at ground level (referred to as tropospheric ozone) (NAS, 1991; NASA). Only a portion of the tropospheric fraction of UV-B shielding is from anthropogenic sources (e.g., power plants, byproducts of combustion). The portion of ground level ozone associated with anthropogenic sources varies by locality and over time. Even so, it is reasonable to assume that reductions in ground level ozone would lead to increases in the same health effects linked to in UV-B exposures. These effects include fatal and nonfatal melanoma and non-melanoma skin cancers and cataracts. The values of $15,000 per case for non-fatal melanoma skin cancer, $5,000 per case for non-fatal non-melanoma skin cancer, and $15,000 per case of cataracts have been used in analyses of stratospheric ozone depletion (U.S. EPA, 1999). Fatal cancers are valued using the standard VSL estimate, which for 2020 is $6.6 million (1999$). UV-B has also been linked to ecological effects including damage to crops and forest. For a more complete listing of quantified and unquantified UV-B radiation effects, see Table G-4 and G-7 in the Benefits and Costs of the Clean Air Act, 1990-2010 (U.S. EPA, 1999. UV-B related health effects are also discussed in the context of stratospheric ozone in a 2006 report by ICF Consulting, prepared for the U.S. EPA.

There are many factors that influence UV-B radiation penetration to the earth’s surface, including latitude, altitude, cloud cover, surface albedo, PM concentration and

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[T] Peter M. Vitousek et. al., “Human Alteration of the Global Nitrogen Cycle: Causes and Consequences” *Issues in Ecology* No. 1 (Spring) 1997.

[U] Knute J. Nadelhoffer et. al., “Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests” *Nature* 398, 145-148 (11 March 1999)

[V] Martin Köchy and Scott D. Wilson, “Nitrogen deposition and forest expansion in the northern Great Plains Journal of Ecology *Journal of Ecology* 89 (5), 807–817 composition, and gas phase pollution. Of these, only latitude and altitude can be defined with small uncertainty in any effort to assess the changes in UV-B flux that may be attributable to any changes in tropospheric O3 as a result of any revision to the O3 NAAQS. Such an assessment of UV-B related health effects would also need to take into account human habits, such as outdoor activities (including age- and occupation-related exposure patterns), dress and skin care to adequately estimate UV-B exposure levels. However, little is known about the impact of these factors on individual exposure to UV-B.

Moreover, detailed information does not exist regarding other factors that are relevant to assessing changes in disease incidence, including: type (e.g., peak or cumulative) and time period (e.g., childhood, lifetime, current) of exposures related to various adverse health outcomes (e.g., damage to the skin, including skin cancer; damage to the eye, such as cataracts; and immune system suppression); wavelength dependency of biological responses; and interindividual variability in UV-B resistance to such health outcomes. Beyond these well recognized adverse health effects associated with various wavelengths of UV radiation, the Criteria Document (section 10.2.3.6) also discusses protective effects of UV-B radiation. Recent reports indicate the necessity of UV-B in producing vitamin D, and that vitamin D deficiency can cause metabolic bone disease among children and adults, and may also increase the risk of many common chronic diseases (e.g., type I diabetes and rheumatoid arthritis) as well as the risk of various types of cancers. Thus, the Criteria Document concludes that any assessment that attempts to quantify the consequences of increased UV-B exposure on humans due to reduced ground-level O3 must include consideration of both negative and positive effects. However, as with other impacts of UVB on human health, this beneficial effect of UVB radiation has not previously been studied in sufficient detail. The Agency is currently exploring the feasibility of estimating the effects of increased UVB exposures resulting from reductions in tropospheric ozone.

6.4.2.8.4 Climate Implications of Tropospheric Ozone

Although climate and air quality are generally treated as separate issues, they are closely coupled through atmospheric processes. Ozone, itself, is a major greenhouse gas and climate directly influences ambient concentrations of ozone.

The concentration of tropospheric ozone has increased substantially since the pre-industrial era and has contributed to warming. Tropospheric ozone is (after CO2 and CH4) the third most important contributor to greenhouse gas warming. The National Academy of Sciences recently stated[W] that regulations targeting ozone precursors would have combined benefits for public health and climate. As noted in the OAQPS Staff Paper, the overall body of scientific evidence suggests that high concentrations of ozone on a regional scale could have a discernible influence on climate. However, the Staff Paper concludes that insufficient information is available at this time to quantitatively inform the secondary NAAQS process

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[W] National Academy of Sciences, “Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties,” October 2005.

with regard to this aspect of the ozone-climate interaction.

Climate change can affect tropospheric ozone by modifying emissions of precursors, chemistry, transport and removal.[X] Climate change affects the sources of ozone precursors through physical response (lightning), biological response (soils, vegetation, and biomass burning) and human response (energy generation, land use, and agriculture). Increases in regional ozone pollution are expected due to higher temperatures and weaker circulation. Simulations with global climate models for the 21st century indicate a decrease in the lifetime of tropospheric ozone due to increasing water vapor which could decrease global background ozone concentrations.

The Intergovernmental Panel on Climate Change (IPCC) recently released a report[Y] which projects, with "virtual certainty," declining air quality in cities due to warmer and fewer cold days and nights and/or warmer/more frequent hot days and nights over most land areas. The report states that projected climate change-related exposures are likely to affect the health status of millions of people, in part, due to higher concentrations of ground level ozone related to climate change.

The IPCC also reports[Z] that the current generation of tropospheric ozone models is generally successful in describing the principal features of the present-day global ozone distribution. However, there is much less confidence in the ability to reproduce the changes in ozone associated with perturbations of emissions or climate. There are major discrepancies with observed long-term trends in ozone concentrations over the 20th century, including after 1970 when the reliability of observed ozone trends is high. Resolving these discrepancies is needed to establish confidence in the models.

The EPA is currently leading a research effort with the goal of identifying changes in regional US air quality that may occur in a future (2050) climate, focusing on fine particles and ozone. The research builds first on an assessment of changes in US air quality due to climate change, which includes direct meteorological impacts on atmospheric chemistry and

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[X] Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment*

Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[Y] IPCC, Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability,

Summary for Policymakers

[Z] Denman, et al, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis.*

transport and the effect of temperature changes on air pollution emissions. Further research will result in an assessment that adds the emission impacts from technology, land use, demographic changes, and air quality regulations to construct plausible scenarios of US air quality 50 years into the future. As noted in the Staff Paper, results from these efforts are expected to be available for consideration in the next review of the ozone NAAQS.

6.4.3 Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 100 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per 100,000 people, that number must be multiplied by the number of 100,000s in the population.

Table 6.4-3 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth (Abt Associates, 2005).

Table 6.4-3. National Average Baseline Incidence Rates[a]

Endpoint	Source	Notes	Rate per 100 people per year[d] by Age Group						
			<18	*18-24*	*25-34*	*35-44*	*45-54*	*55-64*	*65+*
Mortality	CDC Compressed Mortality File, accessed through CDC Wonder (1996-1998)	non-accidental	0.025	0.022	0.057	0.150	0.383	1.006	4.937
Respiratory Hospital Admissions.	1999 NHDS public use data files[b]	incidence	0.043	0.084	0.206	0.678	1.926	4.389	11.629
Asthma ER visits	2000 NHAMCS public use data files[c]; 1999 NHDS public use data files[b]	incidence	1.011	1.087	0.751	0.438	0.352	0.425	0.232
Minor Restricted Activity Days (MRADs)	Ostro and Rothschild (1989, p. 243)	incidence	–	780	780	780	780	780	–
School Loss Days	National Center for Education Statistics (1996) and 1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year	all-cause	990.0	–	–	–	–	–	–

[a] The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS - National Hospital Discharge Survey; NHAMCS - National Hospital Ambulatory Medical Care Survey.

[b] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/

[c] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/

[d] All of the rates reported here are population-weighted incidence rates per 100 people per year. Additional details on the incidence and prevalence rates, as well as the sources for these rates are available upon request.

Table 6.4-3 National Average Baseline Incidence Rates (continued)

Endpoint	Source	Notes		Rate per 100 people per year
Asthma Exacerbations	Ostro et al. (2001)	Incidence (and prevalence) among asthmatic African-American children	Daily wheeze	0.076 (0.173)
			Daily cough	0.067 (0.145)
			Daily dyspnea	0.037 (0.074)
	Vedal et al. (1998)	Incidence (and prevalence) among asthmatic children	Daily wheeze	0.038
			Daily cough	0.086
			Daily dyspnea	0.045

6.5 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993). Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987). We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 6.5-1. All values are in constant year 2000 dollars, adjusted for growth in real income out to 2020 using projections provided by Standard and Poor’s. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. Table 6.5-1 presents the values for individual endpoints adjusted to year 2020 income levels. The discussion below provides additional details on ozone related endpoints not previously included in the proposal for this rule. For details on valuation estimates for PM related endpoints, see the 2006 PM NAAQS RIA and the proposed Locomotive and Marine RIA.

6.5.1 Mortality Valuation

To estimate the monetary benefit of reducing the risk of premature death, we used the "value of statistical lives" saved (VSL) approach, which is a summary measure for the value of small changes in mortality risk for a large number of people. The VSL approach applies information from several published value-of-life studies to determine a reasonable monetary value of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be roughly $5.5 million at 1990 income levels (2000 $), and $6.6 million at 2020 income levels. This represents an intermediate value from a variety of estimates in the economics literature (see the 2006 PM NAAQS RIA for more details on the calculation of VSL).

6.5.2 Hospital Admissions Valuation

In the absence of estimates of societal WTP to avoid hospital visits/admissions for specific illnesses, estimates of total cost of illness (total medical costs plus the value of lost productivity) typically are used as conservative, or lower bound, estimates. These estimates are biased downward, because they do not include the willingness-to-pay value of avoiding pain and suffering.

The International Classification of Diseases (ICD-9, 1979) code-specific COI estimates used in this analysis consist of estimated hospital charges and the estimated opportunity cost of time spent in the hospital (based on the average length of a hospital stay for the illness). We based all estimates of hospital charges and length of stays on statistics provided by the Agency for Healthcare Research and Quality (AHRQ 2000). We estimated the opportunity cost of a day spent in the hospital as the value of the lost daily wage, regardless of whether the hospitalized individual is in the workforce. To estimate the lost daily wage, we divided the 1990 median weekly wage by five and inflated the result to year 2000$ using the CPI-U "all items." The resulting estimate is $109.35. The total cost-of-illness estimate for an ICD code-specific hospital stay lasting *n* days, then, was the mean hospital charge plus $109 X *n*.

6.5.3 Asthma-Related Emergency Room Visits Valuation

To value asthma emergency room visits, we used a simple average of two estimates from the health economics literature. The first estimate comes from Smith et al. (1997), who reported approximately 1.2 million asthma-related emergency room visits in 1987, at a total cost of $186.5 million (1987$). The average cost per visit that year was $155; in 2000$, that cost was $311.55 (using the CPI-U for medical care to adjust to 2000$). The second estimate comes from Stanford et al. (1999), who reported the cost of an average asthma-related emergency room visit at $260.67, based on 1996-1997 data. A simple average of the two estimates yields a (rounded) unit value of $286.

6.5.4 Minor Restricted Activity Days Valuation

No studies are reported to have estimated WTP to avoid a minor restricted activity day. However, one of EPA's contractors, IEc (1993) has derived an estimate of willingness to pay to avoid a minor *respiratory* restricted activity day, using estimates from Tolley et al. (1986) of WTP for avoiding a combination of coughing, throat congestion and sinusitis. The IEc estimate of WTP to avoid a minor respiratory restricted activity day is $38.37 (1990$), or about $52 ($2000).

Although Ostro and Rothschild (1989) statistically linked ozone and minor restricted activity days, it is likely that most MRADs associated with ozone exposure are, in fact, minor *respiratory* restricted activity days. For the purpose of valuing this health endpoint, we used the estimate of mean WTP to avoid a minor respiratory restricted activity day.

6.5.5 School Absences

To value a school absence, we: (1) estimated the probability that if a school child stays home from school, a parent will have to stay home from work to care for the child; and (2) valued the lost productivity at the parent's wage. To do this, we estimated the number of families with school-age children in which both parents work, and we valued a school-loss day as the probability that such a day also would result in a work-loss day. We calculated this value by multiplying the proportion of households with school-age children by a measure of lost wages.

We used this method in the absence of a preferable WTP method. However, this approach suffers from several uncertainties. First, it omits willingness to pay to avoid the symptoms/illness that resulted in the school absence; second, it effectively gives zero value to school absences that do not result in work-loss days; and third, it uses conservative assumptions about the wages of the parent staying home with the child. Finally, this method assumes that parents are unable to work from home. If this is not a valid assumption, then there would be no lost wages.

For this valuation approach, we assumed that in a household with two working parents, the female parent will stay home with a sick child. From the Statistical Abstract of the United States (U.S. Census Bureau, 2001), we obtained: (1) the numbers of single, married and "other" (widowed, divorced or separated) working women with children; and (2) the rates of participation in the workforce of single, married and "other" women with children. From these two sets of statistics, we calculated a weighted average participation rate of 72.85 percent.

Our estimate of daily lost wage (wages lost if a mother must stay at home with a sick child) is based on the year 2000 median weekly wage among women ages 25 and older (U.S.

Census Bureau, 2001). This median weekly wage is $551. Dividing by five gives an estimated median daily wage of $103. To estimate the expected lost wages on a day when a mother has to stay home with a school-age child, we first estimated the probability that the mother is in the workforce then multiplied that estimate by the daily wage she would lose by missing a work day: 72.85 percent times $103, for a total loss of $75.   This valuation approach is similar to that used by Hall et al. (2003).

Table 6.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Premature Mortality (Value of a Statistical Life): $PM_{2.5}$- and Ozone-related	$5,500,000	$6,600,000	$6,800,000	Point estimate is the mean of a normal distribution with a 95 percent confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002)[49] meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003)[50] meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000	Point estimate is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., [1991][51]) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Nonfatal Myocardial Infarction (heart attack) 3% discount rate				Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[52] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[53] and Wittels et al. (1990).[54] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25-44 $8,774 $7,855 45-54 $12,932 $11,578 55-65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($102,658—no discounting) 2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
Age 0–24	$66,902	$66,902	$66,902	
Age 25–44	$74,676	$74,676	$74,676	
Age 45–54	$78,834	$78,834	$78,834	
Age 55–65	$140,649	$140,649	$140,649	
Age 66 and over	$66,902	$66,902	$66,902	
7% discount rate				
Age 0–24	$65,293	$65,293	$65,293	
Age 25–44	$73,149	$73,149	$73,149	
Age 45–54	$76,871	$76,871	$76,871	
Age 55–65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	

(continued)

Table 6.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000)[55] (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Emergency Room Visits for Asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997)[56] and (2) $260.67, from Stanford et al. (1999).[57]

(continued)

Table 6.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994)[58] to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the seven different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Asthma Exacerbations	$42	$45	$45	Asthma exacerbations are valued at $42 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[59] This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma attack is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study.
Acute Bronchitis	$360	$380	$390	Assumes a 6-day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann et al. (1994).[60]

(continued)

Table 6.5-1. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median =)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.
School Absence Days	$75	$75	$75	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	Based on $68 – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States ("Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[61]

[a] Although the unit values presented in this table are in year 2000 dollars, all monetized annual benefit estimates associated with the final standards have been inflated to reflect values in year 2006 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2006 dollars from 2000 dollars.[62] For WTP-based estimates, we use an inflation factor of 1.17 based on the CPI-U for "all items." For COI-based estimates, we use an inflation factor of 1.29 based on the CPI-U for medical care.

[b] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis. Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

6.6 Benefits Analysis Results for the Final Standards

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ and ozone associated with the final standards results in estimates of the changes in health damages (e.g., premature mortalities, cases, admissions) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 6.6-1. Monetized values for those health endpoints are presented in Table 6.6-2. Total aggregate monetized benefits are presented in Table 6.6-3 and Table 6.6-4 using either a 3 percent or 7 percent discount rate, respectively. All of the monetary benefits are in constant-year 2006 dollars. For each endpoint presented in Tables 6.6-1 and 6.6-2, we provide both the mean estimate and the 90% confidence interval.

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health benefits of the final standards is thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health benefits we are able to quantify plus the sum of the nonmonetized health and welfare benefits. We believe the total benefits are therefore likely underestimated.

Total monetized benefits are dominated by benefits of mortality risk reductions. We provide results based on concentration response functions from the American Cancer Society Study (ACS), Six Cities, and Expert Elicitation to give an indication of the sensitivity of the benefits estimates to alternative assumptions. Following the recommendations of the NRC report (NRC, 2002), we identify those estimates which are based on empirical data, and those which are based on expert judgments. EPA intends to ask its Science Advisory Board to evaluate how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies, and if so, the appropriateness of using Laden et al 2006, the most recently published update, as the estimate for the Six Cities based model.

Using the ACS and Six-Cities results, we estimate that the final standards would result in between 490 and 1,100 cases of avoided $PM_{2.5}$-related premature deaths annually in 2020 and between 1,100 and 2,600 avoided premature deaths annually in 2030. When the range of expert opinion is used, we estimate between 220 and 2,200 fewer premature mortalities in 2020 and between 500 and 4,900 fewer premature mortalities in 2030. Note that in the case of the premature mortality estimates derived from the expert elicitation, we report the 90% credible interval, which encompasses a broader representation of uncertainty relative to the statistical confidence intervals provided for the effect estimates derived from the epidemiology literature.

The range of ozone benefits associated with the final standards is estimated based on risk reductions estimated using several sources of ozone-related mortality effect estimates. There is considerable uncertainty in the magnitude of the association between ozone and premature mortality. This analysis presents four alternative estimates for the association based upon different functions reported in the scientific literature. We also consider the possibility that the observed associations between ozone and mortality may not be causal in nature. EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits associated with ozone control strategies.

For ozone-related premature mortality, we estimate a range of between 13 to 62 fewer premature mortalities as a result of the final rule in 2020 and between 54 to 250 in 2030, assuming that there is a causal relationship between ozone exposure and mortality. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from the final standards, as well as increases in total population and the average age (and thus baseline mortality risk) of the population.

Our estimate of total monetized benefits in 2020 for the final standards, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between \$3.7 billion and \$8.8 billion, assuming a 3 percent discount rate, or between \$3.6 billion and \$8.0 billion, assuming a 7 percent discount rate. In 2030, we estimate the monetized benefits to be between \$9.2 billion and \$22 billion, assuming a 3 percent discount rate, or between \$8.4 billion and \$20 billion, assuming a 7 percent discount rate. The monetized benefit associated with reductions in the risk of both ozone- and $PM_{2.5}$-related premature mortality ranges between 90 to 98 percent of total monetized health benefits, in part because we are unable to quantify a number benefits categories (see Table 6.4-1). These unquantified benefits may be substantial, although their magnitude is highly uncertain.

The next largest benefit is for reductions in chronic illness (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are over 100 times more work loss days than PM-related premature mortalities (based on the ACS study), yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (e.g., cost-of-illness). As such, the true value of these effects may be higher than that reported in Table 6.6-2.

Following these tables, we also provide a more comprehensive presentation of the distributions of incidence generated using the available information from empirical studies and expert elicitation. Tables 6.6-5 and 6.6-6 present the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-cities study (Laden et al., 2006). The 90% confidence interval for each separate estimate of PM-related mortality is also provided.

The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in these tables, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

Table 6.6-1. Estimated Reduction in Incidence of Adverse Health Effects Related to the Final Standards[a]

		2020	2030
Health Effect		Mean Incidence Reduction (5th – 95th %ile)	
PM-Related Endpoints			
Premature Mortality – Derived from Epidemiology Literature	Adult, age 30+ - ACS cohort study (Pope et al., 2002)	490 (190 - 790)	1,100 (440 – 1,800)
	Adult, age 25+ - Six-Cities study (Laden et al., 2006)	1,100 (610 - 1,600)	2,600 (1,400 – 3,700)
	Infant, age <1 year – Woodruff et al. 1997	1 (1 - 2)	2 (1 – 3)
Premature Mortality – Derived from Expert Elicitation[b]	Adult, age 25+ - Lower Bound (Expert K)	220 (0 - 1,100)	500 (0 – 2,400)
	Adult, age 25+ - Upper Bound (Expert E)	2,200 (1,100 - 3,300)	4,900 (2,500 – 7,500)
Chronic bronchitis (adult, age 26 and over)		310 (56 - 560)	680 (130 – 1,200)
Acute myocardial infarction (adults, age 18 and older)		1,000 (550 - 1,500)	2,500 (1,300 – 3,600)
Hospital admissions—respiratory (all ages)[c]		120 (58 - 170)	270 (130 – 400)
Hospital admissions—cardiovascular (adults, age >18)[d]		240 (150 - 330)	600 (380 – 820)
Emergency room visits for asthma (age 18 years and younger)		410 (240 - 580)	890 (520 – 1,300)
Acute bronchitis (children, age 8–12)		1,000 (-35 – 2,100)	2,300 (-77 – 4,600)
Lower respiratory symptoms (children, age 7–14)		9,200 (4,400 – 14,000)	20,000 (9,700 – 31,000)
Upper respiratory symptoms (asthmatic children, age 9–18)		6,700 (2,100 – 11,000)	15,000 (4,600 – 25,000)
Asthma exacerbation (asthmatic children, age 6–18)		8,400 (920 – 24,000)	19,000 (2,000 – 53,000)
Work loss days (adults, age 18–65)		59,000 (51,000 – 67,000)	120,000 (110,000 – 140,000)
Minor restricted-activity days (adults, age 18–65)		350,000 (290,000 – 400,000)	720,000 (610,000 – 830,000)
Ozone-Related Endpoints			
Premature Mortality, All ages – Derived from NMMAPS	Bell et al., 2004	13 (-22 - 49)	54 (-43 – 150)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	44 (-47 - 140)	180 (-69 – 420)
	Ito et al., 2005	60 (-34 - 150)	240 (-14 – 500)
	Levy et al., 2005	62 (-14 – 138)	250 (44 - 450)
Premature Mortality – Assumption that association between		0	0

ozone and mortality is not causal		
Hospital admissions- respiratory causes (children, under 2; adult, 65 and older)[e]	14 (-146 - 170)	260 (-350 – 890)
Emergency room visit for asthma (all ages)	69 (-89 - 270)	250 (-190 – 830)
Minor restricted activity days (adults, age 18-65)	84,000 (43,000 – 120,000)	290,000 (150,000 – 430,000)
School absence days	33,000 (-17,000 – 77,000)	110,000 (-15,000 – 240,000)

[a] Incidence is rounded to two significant digits. PM and ozone estimates represent impacts from the final standards nationwide.

[b] Based on effect estimates derived from the full-scale expert elicitation assessing the uncertainty in the concentration-response function for PM-related premature mortality (IEc, 2006).[AA] The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[c] Respiratory hospital admissions for PM include admissions for COPD, pneumonia, and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[e] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

[AA] Industrial Economics, Incorporated (IEc). 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Peer Review Draft. Prepared for: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. August.

Table 6.6-2. Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2005$)[a,b]

		2020	2030
$PM_{2.5}$-Related Health Effect		Estimated Mean Value of Reductions (5th and 95th %ile)	
Premature Mortality – Derived from Epidemiology Studies[c,d,]	Adult, age 30+ - ACS study (Pope et al., 2002)		
	3% discount rate	$3,400 ($810 - $7,00)	$8,100 ($1,900 - $16,000)
	7% discount rate	$3,100 ($730 - $6,300)	$7,300 ($1,700 - $15,000)
	Adult, age 25+ - Six-cities study (Laden et al., 2006)		
	3% discount rate	$7,800 ($2,200 - $15,000)	$18,000 ($5,100 - $35,000)
	7% discount rate	$7,000 ($1,900 - $13,000)	$17,000 ($4,600 - $32,000)
	Infant Mortality, <1 year – (Woodruff et al. 1997)		
	3% discount rate	$7 ($2 - $14)	$13 ($3.5 - $26)
	7% discount rate	$7 ($2 - $13)	$12 ($3.1 - $23)
Premature mortality – Derived from Expert Elicitation[c,d,e]	Adult, age 25+ - Lower bound (Expert K)		
	3% discount rate	$1,500 ($0 - $7,700)	$3,600 ($0 - $18,000)
	7% discount rate	$1,400 ($0 - $7,000)	$3,200 ($0 - $16,000)
	Adult, age 25+ - Upper bound (Expert E)		
	3% discount rate	$15,000 ($4,100 - $30,000)	$36,000 ($9,500 - $70,000)
	7% discount rate	$14,000 ($3,700 - $27,000)	$32,000 ($8,600 - $63,000)
Chronic bronchitis (adults, 26 and over)		$150 ($12 - $500)	$340 ($28 - $1,100)
Non-fatal acute myocardial infarctions			
3% discount rate		$110 ($34 - $230)	$260 ($74 - $550)
7% discount rate		$110 ($31 - $230)	$250 ($69 - $540)
Hospital admissions for respiratory causes		$2.1 ($1.0 - $3.2)	$4.9 ($2.4 - $7.3)
Hospital admissions for cardiovascular causes		$6.7 ($4.2 - $9.2)	$17 ($11 - $23)
Emergency room visits for asthma		$0.15 ($0.08 - $0.23)	$0.33 ($0.18 - $0.49)
Acute bronchitis (children, age 8–12)		$0.08 ($0 - $0.2)	$0.17 ($0 - $0.42)
Lower respiratory symptoms (children, 7–14)		$0.18	$0.40

		($0.07 - $0.33)	($0.15 - $0.73)
Upper respiratory symptoms (asthma, 9–11)		$0.21 ($0.06 - $0.46)	$0.46 ($0.13 - $1.0)
Asthma exacerbations		$0.45 ($0.05 - $1.3)	$1.0 ($0.11 - $2.9)
Work loss days		$8.9 ($7.7 - $10)	$18 ($16 - $21)
Minor restricted-activity days (MRADs)		$22 ($13 – $32)	$46 ($27 - $66)
Recreational Visibility, 86 Class I areas		$ (na)[f]	$ (na)
Ozone-related Health Effect			
Premature Mortality, All ages – Derived from NMMAPS	Bell et al., 2004	$100 (-$170 - $420)	$440 (-$340 - $1,400)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	$340 (-$360 - $1,200)	$1,400 (-$550 - $3,900)
	Ito et al., 2005	$460 (-$260 - $1,400)	$1,900 (-$120 - $4,700)
	Levy et al., 2005	$480 (-$110 - $1,300)	$2,000 ($280 - $4,400)
Premature Mortality – Assumption that association between ozone and mortality is not causal		$0	$0
Hospital admissions- respiratory causes (children, under 2; adult, 65 and older)		-$0.54 (-$4.6 - $3.3)	$2.7 (-$11 - $17)
Emergency room visit for asthma (all ages)		$0.03 (-$0.03 - $0.1)	$0.09 (-$0.07 - $0.30)
Minor restricted activity days (adults, age 18-65)		$2.5 (-$4.0 - $9.9)	$8.8 (-$7.8 - $28)
School absence days		$2.9 (-$1.5 - $6.8)	$11 (-$1.3 - $21)
Worker Productivity		$0.53 (na)[f]	$2.9 (na)[f]

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.

[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030)

[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).

[d] The valuation of adult premature mortality, derived either from the epidemiology literature or the expert elicitation, is not additive. Rather, the valuations represent a range of possible mortality benefits.

[e] Based on effect estimates derived from the full-scale expert elicitation assessing the uncertainty in the concentration-response function for PM-related premature mortality (IEc, 2006).[BB] The effect estimates of five of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and six of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[f] We are unable at this time to characterize the uncertainty in the estimate of benefits of worker productivity and improvements in visibility at Class I areas. As such, we treat these benefits as fixed and add them to all percentiles of the health benefits distribution.

Table 6.6-3 Total Monetized Benefits of the Final Locomotive and Marine Engine Rule – 3% Discount Rate

Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from Epidemiology Studies (ACS and Six Cities)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$4.0 to $8.4	NMMAPS	Bell et al., 2004	$9.7 to $20
Meta-analysis	Bell et al., 2005	$4.2 to $8.6	Meta-analysis	Bell et al., 2005	$11 to $21
	Ito et al., 2005	$4.4 to $8.8		Ito et al., 2005	$11 to $21
	Levy et al., 2005	$4.4 to $8.8		Levy et al., 2005	$11 to $22
Assumption that association is not causal		$3.9 to $8.3	Assumption that association is not causal		$9.2 to $20
Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$2.1 to $16	NMMAPS	Bell et al., 2004	$5.2 to $37
Meta-analysis	Bell et al., 2005	$2.4 to $16	Meta-analysis	Bell et al., 2005	$6.2 to $38
	Ito et al., 2005	$2.5 to $16		Ito et al., 2005	$6.7 to $39
	Levy et al., 2005	$2.5 to $16		Levy et al., 2005	$6.7 to $39

[BB] Industrial Economics, Incorporated (IEc). 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Peer Review Draft. Prepared for: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. August.

Assumption that association is not causal		$2.0 to $16	Assumption that association is not causal		$4.7 to $37

Table 6.6-4 Total Monetized Benefits of the Final Locomotive and Marine Engine Rule – 7% Discount Rate

Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from Epidemiology Studies (ACS and Six Cities)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$3.7 to $7.6	NMMAPS	Bell et al., 2004	$8.9 to $18
Meta-analysis	Bell et al., 2005	$3.9 to $7.9	Meta-analysis	Bell et al., 2005	9.8 to $19
	Ito et al., 2005	$4.0 to $8.0		Ito et al., 2005	$10 to $20
	Levy et al., 2005	$4.0 to $8.0		Levy et al., 2005	$10 to $20
Assumption that association is not causal		$3.6 to $7.5	Assumption that association is not causal		$8.4 to $18
Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
NMMAPS	Bell et al., 2004	$2.0 to $14	NMMAPS	Bell et al., 2004	$4.8 to $34
Meta-analysis	Bell et al., 2005	$2.2 to $15	Meta-analysis	Bell et al., 2005	$5.8 to $35
	Ito et al., 2005	$2.3 to $15		Ito et al., 2005	$6.3 to $35
	Levy et al., 2005	$2.3 to $15		Levy et al., 2005	$6.4 to $35
Assumption that association is not causal		$1.9 to $14	Assumption that association is not causal		$4.4 to $33

Table 6.6-5. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with the Final Standards

Source of Mortality Estimate	2020 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	190	490	790
Laden et al. (2006)	610	1,100	1,600
Expert A	320	1,700	3,200
Expert B	180	1,300	2,800
Expert C	240	1,300	2,800
Expert D	190	920	1,500
Expert E	1,100	2,200	3,300
Expert F	840	1,200	1,700
Expert G	0	770	1,400
Expert H	4	980	2,300
Expert I	210	1,300	2,300
Expert J	310	1,100	2,300
Expert K	0	220	1,100
Expert L	150	930	1,800

Table 6.6-6. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Final Standards

Source of Mortality Estimate	2030 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	440	1,100	1,800
Laden et al. (2006)	1,400	2,600	3,700
Expert A	730	4,000	7,200
Expert B	410	3,000	6,500
Expert C	540	3,000	6,500
Expert D	440	2,100	3,400
Expert E	2,500	4,900	7,500
Expert F	1,900	2,700	3,900
Expert G	0	1,800	3,200
Expert H	8	2,200	5,100
Expert I	470	3,000	5,300
Expert J	720	2,400	5,300
Expert K	0	500	2,400
Expert L	340	2,100	4,000

6.7 Comparison of Costs and Benefits

In estimating the net benefits of the final standards, the appropriate cost measure is ‘social costs.’ Social costs represent the welfare costs of a rule to society. These costs do not consider transfer payments (such as taxes) that are simply redistributions of wealth. Table 6.7-1 contains the estimates of monetized benefits and estimated social welfare costs for the final rule and each of the final control programs. The annual social welfare costs of all provisions of this final rule are described more fully in Chapter 7 of this RIA.

The results in Table 6.7-1 suggest that the 2020 monetized benefits of the final standards are greater than the expected social welfare costs. Specifically, the annual benefits of the total program will range between $3.9 to $8.8 billion annually in 2020 using a three percent discount rate,or between $3.6 to $8.0 billion assuming a 7 percent discount rate, compared to estimated social costs of approximately $330 million in that same year. These benefits are expected to increase to between $9.2 and $22 billion annually in 2030 using a three percent discount rate,or between $8.4 and $20 billion assuming a 7 percent discount rate, while the social costs are estimated to be approximately $740 million. Though there are a number of health and environmental effects associated with the final standards that we are unable to quantify or monetize (see Table 6.4-1), the benefits of the final standards far outweigh the projected costs.

Using the most conservative benefits estimate, the 2020 benefits outweigh the costs by a factor of 10. Using the upper end of the benefits range, the benefits could outweigh the costs by a factor of 25. Likewise, in 2030 benefits outweigh the costs by at least a factor of 10 and could be as much as a factor of 28. Thus, even taking the most conservative benefits assumptions, benefits of the final standards clearly outweigh the costs.

Table 6.7-1. Summary of Annual Benefits and Costs of the Final Standards[a] (Millions of 2006 dollars)

Description	2020 (Millions of 2006 dollars)	2030 (Millions of 2006 dollars)
Estimated Social Costs[b]		
Locomotive	$200	$460
Marine	$140	$280
Total Social Costs	$330	$740
Estimated Health Benefits of the Final Standards[c,d,e,f]		
Locomotive		
3 percent discount rate	$2,000 to $4,400	$4,300 to $11,000
7 percent discount rate	$1,900 to $4,000	$4,000 to $10,000
Marine		
3 percent discount rate	$1,900 to $4,400	$4,900 to $11,000
7 percent discount rate	$1,700 to $4,000	$4,400 to $10,000
Total Benefits		
3 percent discount rate	$3,900 to $8,800	$9,200 to $22,000
7 percent discount rate	$3,600 to $8,000	$8,400 to $20,000
Annual Net Benefits (Total Benefits – Total Costs)		
3 percent discount rate	$3,600 to $8,500	$8,500 to $21,000
7 percent discount rate	$3,300 to $7,700	$7,700 to $19,000

[a] All estimates represent annualized benefits and costs anticipated for the years 2020 and 2030. Totals may not sum due to rounding.

[b] The calculation of annual costs does not require amortization of costs over time. Therefore, the estimates of annual cost do not include a discount rate or rate of return assumption (see Chapter 7 of the RIA). In Chapter 7, however, we do use both a 3 percent and 7 percent social discount rate to calculate the net present value of total social costs consistent with EPA and OMB guidelines for preparing economic analyses.

[c] Total includes ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function, including an assumption that the association is not causal, to both estimates of $PM_{2.5}$-related premature mortality derived from the ACS (Pope et al., 2002) and Six-Cities (Laden et al., 2006) studies, respectively.

[d] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).[CC,DD]

[e] Valuation of premature mortality based on long-term PM exposure assumes discounting over the SAB recommended 20-year segmented lag structure described in the Regulatory Impact Analysis for the Final Clean Air Interstate Rule (March, 2005).

[f] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 6.4-1.

[CC] U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. www.yosemite1.epa.gov/ee/epa/eed/hsf/pages/Guideline.html.

[DD] Office of Management and Budget, The Executive Office of the President, 2003. Circular A-4. http://www.whitehouse.gov/omb/circulars.

Appendix 6A: Health-Based Cost Effectiveness Analysis

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. The Office of Management and Budget (OMB) recently issued Circular A-4 guidance on regulatory analyses, requiring federal agencies to "prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes." Environmental quality improvements may have multiple health and ecological benefits, making application of CEA more difficult and less straightforward. For the recently finalized PM NAAQS analysis, CEA provided a useful framework for evaluation: non-health benefits were substantial, but the majority of quantified benefits came from health effects. EPA included in the PM NAAQS RIA a preliminary and experimental application of one type of CEA—a modified quality-adjusted life-years (QALYs) approach. A detailed description of this QALY approach is provided in Appendix G of the final PM NAAQS RIA. For the analysis presented here, we use the same modified QALY approach to characterize the health-based cost effectiveness of the final standards.

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA of environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for nonhealth benefits, such as improved visibility.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled "Valuing Health for Regulatory Cost-Effectiveness Analysis," which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006).[63] They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses.

The methodology derived from the final PM NAAQS analysis is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations where it may be inappropriate. It is intended solely to demonstrate one particular approach to estimating the cost-effectiveness of reductions in ambient $PM_{2.5}$ in achieving improvements in public health. Reductions in ambient $PM_{2.5}$ likely will have other health and environmental benefits that will not be reflected in this CEA. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar health-based CEAs. A number of additional methodological issues must be considered when conducting CEAs for environmental policies, including treatment of nonhealth effects, aggregation of acute and long-term health impacts, and aggregation of life extensions and quality-of-life improvements in different populations. The appropriateness of health-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models, among other factors.

The final locomotive and marine standards are expected to result in substantial reductions in potential population exposure to ambient concentrations of PM by 2030. The benefit-cost analysis presented in Chapter 6 of the RIA shows that the standards will achieve substantial health benefits whose monetized value far exceeds costs (net benefits are between \$8.5 and \$21 billion in 2030, based on empirically derived estimates of PM mortality and using a 3 percent discount rate). Despite the risk of oversimplifying benefits, cautiously-interpreted cost-effectiveness calculations may provide further evidence of whether the costs associated with the final standards are a reasonable health investment for the nation.

This analysis provides estimates of commonly used health-based effectiveness measures, including lives saved, life years saved (from reductions in mortality risk), and QALYs saved (from reductions in morbidity risk) associated with the reduction of ambient $PM_{2.5}$ due to the final standards. In addition, we use an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILY) to address some of the concerns about aggregation of life extension and quality-of-life impacts. It represents the sum of life years gained due to reductions in premature mortality and the QALY gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy. This analysis focuses on life extensions and improvements in quality of life through reductions in two diseases with chronic impacts: chronic bronchitis (CB) and nonfatal acute myocardial infarctions. Monte Carlo simulations are used to propagate uncertainty in several analytical parameters and characterize the distribution of estimated impacts. While the benefit-cost analysis presented in the RIA characterizes mortality impacts using a number of different sources for the PM mortality effect estimate, for this analysis, we focus on the mortality results generated using the effect estimate derived from the Pope et al. (2002) study.

Presented in three different metrics, the analysis suggests the following:

- In 2020, the locomotive and marine standards will result in:

  - 490 (95% CI: 190 – 790) premature PM-related deaths avoided, or
  - 5,500 (95% CI: 2,100 – 8,800) PM-related life years gained (discounted at 3 percent), or
  - 7,800 (95% CI: 2,600 – 14,000) MILYs gained (discounted at 3 percent).

- In 2030, the final standards will result in:
  - 1,100 (95% CI: 4400 – 1,800) premature PM-related deaths avoided, or
  - 12,000 (95% CI: 4,800 – 20,000) PM-related life years gained (discounted at 3 percent), or
  - 17,000 (95% CI: 5,700 – 31,000) MILYs gained (discounted at 3 percent).
- Using a 7 percent discount rate, mean discounted life years gained are 4,100 for the final standards in 2020 and 9,300 in 2030; mean MILYs gained are 5,800 in 2020 and 13,000 in 2030. (The estimates of premature deaths avoided are not affected by the discount rate.)
- The associated reductions in CB and nonfatal acute myocardial infarctions will reduce medical costs by approximately $150 million in 2020 and $340 million in 2030 based on a 3 percent discount rate, or $130 million in 2020 and $300 million in 2030 based on a 7 percent discount rate.
- Other health and visibility benefits are valued at $210 million in 2020 and $490 million in 2030.

Direct private compliance costs for the final standards are $340 million in 2020 and $750 million in 2030 (see Chapter 7 of this RIA for more discussion of the cost estimates). Therefore, the net costs (private compliance costs minus avoided cost of illness minus other benefits) are negative, indicating that the final standards result in cost savings. As such, traditional cost-effectiveness ratios are not informative. However, it is possible to calculate the maximum costs for the rule that would still result in cost-effective improvements in public health compared with standard benchmarks of $50,000 and $100,000 per MILY:

- Taking into account avoided medical costs and other benefits, annual costs of the final standards would need to exceed $750 million (95% CI: $360 million – $1,200 million) in 2020 and $1.7 billion (95% CI: $0.8 billion – $2.8 billion) in 2030 to have a cost per MILY that exceeds a benchmark of $50,000, based on a 3 percent discount rate.
- Annual costs of the final standards would need to exceed $1.1 billion (95% CI: $0.5 billion – $1.9 billion) in 2020 and $2.6 billion (95% CI: $1.1 billion – $4.3 billion) in

2030 to have a cost per MILY that exceeds a benchmark of $100,000, based on a 3 percent discount rate.

- Using a 7 percent discount rate, annual costs of the final standards would need to exceed $630 million in 2020 and $1.4 billion in 2030 to have a cost per MILY that exceeds a benchmark of $50,000, and would need to exceed $0.9 billion in 2020 and $2.1 billion in 2030 to have a cost per MILY that exceeds a benchmark of $100,000.

Given costs of $340 million and $750 million in 2020 and 2030, respectively, the locomotive and marine standards are clearly a very cost-effective way to achieve improvements in public health.

Tables 6.A-1 through 6.A-9 present the intermediate and summary results of the health-based CEA of the final standards. Note that the methods used to generate these estimates follow the same methods as those explained in Appendix G of the final PM NAAQS RIA. We refer the reader to that document for more details about this modified QALY approach to health-based CEA.

Table 6.A-1: Estimated Reduction in Incidence of All-cause Premature Mortality Associated with the Final Standards in 2020 and 2030

	Reduction in All-Cause Premature Mortality (95% CI)	
Age Interval	2020	2030
30 – 34	4 (2-7)	8 (3-13)
35 – 44	13 (5-21)	26 (10-42)
45 – 54	26 (10-43)	47 (18-75)
55 – 64	65 (25-105)	110 (44-180)
65 – 74	106 (41-170)	250 (98-400)
75 – 84	120 (48-200)	350 (140-550)
85+	150 (59-240)	340 (130-540)
Total	490 (190-790)	1,100 (440-1,800)

Table 6.A-2: Estimated Life Years Gained from All-cause Premature Mortality Risk Reductions Associated with the Final Standards in 2020 and 2030

	Life Years Gained from Mortality Risk Reduction, 3% Discount Rate (95% CI)	
Age Interval	2020	2030
25 – 34	120 (45-190)	210 (83-340)
35 – 44	330 (130-530)	650 (260-1,100)
45 – 54	580 (230-930)	1,000 (400-1,600)
55 – 64	1,200 (470-1,900)	2,000 (800-3,300)
65 – 74	1,500 (600-2,400)	3,500 (1,400-5,700)
75 – 84	1,200 (460-1,900)	3,400 (1,300-5,400)
85+	600 (230-960)	1,300 (520-2,100)
Total	5,500 (2,100-8,800)	12,000 (4,800-20,000)

Table 6.A-3: Estimated Reduction in Incidence of Chronic Bronchitis Associated with the Final Standards in 2020 and 2030

	Reduction in Incidence (95% Confidence Interval)	
Age Interval	2020	2030
25 – 34	57 (10-100)	120 (21-210)
35 – 44	62 (11-110)	140 (26-250)
45 – 54	58 (11-110)	120 (22-210)
55 – 64	59 (11-110)	110 (21-210)
65 – 74	41 (8-74)	110 (19-190)
75 – 84	20 (4-37)	62 (12-110)
85+	9 (2-16)	22 (4-39)
Total	310 (56-560)	680 (130-1,200)

Table 6.A-4: QALYs Gained per Avoided Incidence of CB

Age Interval		QALYs Gained per Incidence	
Start Age	End Age	Undiscounted	Discounted (3%)
25	34	12.15 (4.40-19.95)	6.52 (2.36-10.71)
35	44	9.91 (3.54-16.10)	5.94 (2.12-9.66)
45	54	7.49 (2.71-12.34)	5.03 (1.82-8.29)
55	64	5.36 (1.95-8.80)	4.03 (1.47-6.61)
65	74	3.40 (1.22-5.64)	2.84 (1.02-4.71)
75	84	2.15 (0.77-3.49)	1.92 (0.69-3.13)
85+		0.79 (0.27-1.29)	0.77 (0.26-1.25)

Table 6.A-5: Estimated Reduction in Nonfatal Acute Myocardial Infarctions Associated with the Final Standards in 2020 and 2030

	Reduction in Incidence (95% Confidence Interval)	
Age Interval	2020	2030
18 – 24	1 (0-1)	1 (1-2)
25 – 34	1 (0-1)	1 (1-2)
35 – 44	33 (18-48)	73 (40-110)
45 – 54	100 (56-150)	210 (110-310)
55 – 64	250 (130-360)	470 (260-690)
65 – 74	290 (160-430)	760 (410-1,100)
75 – 84	220 (120-320)	670 (360-970)
85+	120 (64-170)	290 (160-430)
Total	1,000 (550-1,500)	2,500 (1,300-3,600)

Table 6.A-6: QALYs Gained per Avoided Nonfatal Myocardial Infarction

Age Interval		QALYs Gained per Incidence	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	4.18 (1.24-7.09)	2.17 (0.70-3.62)
25	34	3.48 (1.09-5.87)	2.00 (0.68-3.33)
35	44	2.81 (0.88-4.74)	1.79 (0.60-2.99)
45	54	2.14 (0.67-3.61)	1.52 (0.51-2.53)
55	64	1.49 (0.42-2.52)	1.16 (0.34-1.95)
65	74	0.97 (0.30-1.64)	0.83 (0.26-1.39)
75	84	0.59 (0.20-0.97)	0.54 (0.19-0.89)
85+		0.32 (0.13-0.50)	0.31 (0.13-0.49)

Table 6.A-7. Estimated Gains in 3 Percent Discounted MILYs Associated with the Final Standards in 2020[a]

Age	Life Years Gained from Mortality Risk Reductions (95% CI)	QALY Gained from Reductions in Chronic Bronchitis (95% CI)	QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)	Total Gain in MILYs (95% CI)
18–24	-	-	1 (0-3)	1 (0-3)
25–34	120 (45-190)	370 (52-850)	1 (0-2)	490 (97-1,100)
35–44	330 (130-530)	370 (50-870)	58 (15-120)	750 (190-1,500)
45–54	580 (230-930)	290 (41-700)	160 (40-320)	1,000 (310-1,900)
55–64	1,200 (470-1,900)	240 (32-560)	280 (70-570)	1,700 (570-3,000)
65–74	1,500	120	240	1,800

	(580-2.400)	(16-280)	(53-490)	(660-3,200)
75–84	1,200 (460-1,900)	39 (5-92)	120 (31-230)	1,300 (500-2,200)
85+	600 (230-960)	7 (1-18)	35 (10-69)	640 (250-1,000)
Total	5,500 (2,100-8,800)	1,400 (200-3,400)	880 (230-1,800)	7,800 (2,600-14,000)

[a] Note that all estimates have been rounded to two significant digits.

Table 6.A-8: Estimated Gains in 3 Percent Discounted MILYs Associated with the Final Standards in 2030[a]

Age	Life Years Gained from Mortality Risk Reductions (95% CI)	QALY Gained from Reductions in Chronic Bronchitis (95% CI)	QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)	Total Gain in MILYs (95% CI)
18–24	-	-	3 (1-5)	3 (1-5)
25–34	210 (83-340)	760 (110-1,800)	2 (1-5)	970 (190-2,100)
35–44	650 (260-1,100)	820 (110-2,000)	130 (34-260)	1,600 (400-3,300)
45–54	1,000 (400-1,600)	600 (82-1,400)	310 (80-640)	1,900 (560-3,700)
55–64	2,000 (800-3,300)	460 (63-1,100)	530 (130-1,100)	3,000 (1,000-5,400)
65–74	3,500 (1,400-5,700)	300 (42-710)	620 (160-1,300)	4,500 (1,600-7,700)
75–84	3,400 (1,300-5,400)	120 (16-290)	350 (94-710)	3,800 (1,400-6,400)
85+	1,300 (520-2,100)	16 (2-39)	86 (25-170)	1,400 (550-2,400)
Total	12,000 (4,800-20,000)	3,100 (420-7,200)	2,000 (530-4,100)	17,000 (5,700-31,000)

[a] Note that all estimates have been rounded to two significant digits.

Table 6.A-9: Summary of Health-Based Cost Effectiveness Results for the Final Standards in 2020 and 2030[a]

	Result Using 3% Discount Rate (95% Confidence Interval)	
	2020	2030
Life years gained from mortality risk reductions	5,500 (2,100-8,800)	12,000 (4,800-20,000)
QALY gained from reductions in chronic bronchitis	1,400 (200-3,400)	3,100 (420-7,200)
QALY gained from reductions in acute myocardial infarctions	880 (230-1,800)	2,000 (530-4,100)
Total gain in MILYs	7,800 (2,600-14,000)	17,000 (5,700-31,000)
Avoided cost of illness		
Chronic bronchitis	$37 Million ($6.9 - $68 Million)	$78 Million ($14 - $140 Million)
Nonfatal AMI	$110 Million ($29 - $250 Million)	$260 Million ($64 - $580 Million)
Other benefits (based on COI and WTP estimates)	$210 Million ($190 - $220 Million)	$490 Million ($460 – $520 Million)
Implementation strategy costs[b]	$340 Million	$750 Million
Net cost per MILY	Cost Savings	Cost Savings

[a] All summary results are reported at a precision level of two significant digits to reflect limits in the precision of the underlying elements.

[b] Costs are the private firm costs of control, as discussed in Chapter 7, and reflect discounting using firm specific costs of capital.

Appendix 6.B: Sensitivity Analyses of Key Parameters in the Benefits Analysis

The primary analysis presented in Chapter 6 is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies and the assumptions that are most appropriate to adopt in the face of important uncertainties and resource limitations. The majority of the analytical assumptions used to develop the primary estimates of benefits have been used to support similar rulemakings and approved by EPA=s Science Advisory Board (SAB). Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions.

This appendix supplements our primary estimates of benefits with a series of sensitivity calculations that use other sources of health effect estimates and valuation data for key benefits categories. The supplemental estimates examine sensitivity to both valuation issues and for physical effects issues. These supplemental estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. The individual adjustments in the tables should not simply be added together because: 1) there may be overlap among the alternative assumptions; and 2) the joint probability among certain sets of alternative assumptions may be low.

6.B.1 Premature Mortality – Alternative Threshold Analysis

To consider the impact of a threshold in the response function for the chronic mortality endpoint, we have constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, we have adjusted the mortality function slopes accordingly.[EE] Five cutpoints (including the base case assumption) were included in the sensitivity analysis: (a) 14 µg/m3 (assumes no impacts below the alternative annual NAAQS), (b) 12 µg/m3 (c) 10 µg/m3 (reflects comments from CASAC, 2005) [64], (d) 7.5 µg/m3 (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the Pope 2002 study used as the basis for modeling chronic mortality) [65] and (e) background or 3 µg/m3 (reflects NRC recommendation to consider effects all the way to background).[66] We repeat this sensitivity analysis for the RIA of the final standards, the results of which can be found in Table 6B-1.

[EE] Note that this analysis only adjusted the mortality slopes for the 10 µg/m^3, 12 µg/m^3 and 14 µg/m^3 cutpoints since the 7.5 µg/m^3 and background cutpoints were at or below the lowest measured exposure levels reported in the Pope et al. (2002) study for the combined exposure dataset.

Table 6B-1. PM-Related Mortality Benefits of the Final Standards: Cutpoint Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Certainty that Benefits are At Least Specified Value	Level of Assumed Threshold	PM Mortality Incidence	
		2020	2030
More Certain that Benefits Are at Least as Large	14 µg/m3 [b]	140	320
⇩	12 µg/m3	200	490
	10 µg/m3 [c]	490	1,100
	7.5 µg/m3 [d]	600	1,400
Less Certain that Benefits Are at Least as Large	3 µg/m3 [e]	640	1,500

[a] Note that this table only presents the effects of a cutpoint on PM-related mortality incidence.
[b] Alternative annual PM NAAQS.
[c] Primary threshold assumption based on CASAC (2005).[85]
[d] SAB-HES (2004)[86]
[e] NAS (2002)[87]

6.B.2 Premature Mortality - Alternative Lag Structures

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient $PM_{2.5}$ will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question.

The SAB-HES has recognized this lack of direct evidence. However, in early advice, they also note that "although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population," (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9).[67] In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using "a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions," (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that "an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate," (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its follow-up advice provided in December 2004, the SAB suggested that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004).[68] The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). The 0-year lag is representative of EPA=s assumption in previous RIAs. The 8- and 15-year lags are based on the study periods from the Pope et al. (1995)[69] and Dockery et al. (1993)[70] studies, respectively.[FF] However, neither the Pope et al. nor Dockery et al. studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope et al. and Dockery et al. analyses do not support or refute the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8- and 15-year lags implicitly assume that all premature mortalities occur at the end of the study periods (i.e., at 8 and 15 years).

In addition to the simple 8- and 15-year lags, we have added two additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 30 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table 6B-2. These estimates are based on the value of statistical lives saved approach (i.e., $5.5 million per incidence) and are presented using both a 3 percent and 7 percent discount rate over the lag period.

[FF] Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

Table 6B-2. Sensitivity of Benefits of Premature Mortality Reductions to Alternative Lag Assumptions (Relative to Primary Benefits Estimates of the Final Standards)

		Avoided Incidences (ACS; Pope et al., 2002)[a]		Value (million 2006$)[b]	
	Description of Sensitivity Analysis	2020	2030	2020	2030
Alternative Lag Structures for PM-Related Premature Mortality					
Primary	30 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 20 percent in years 6 to 20				
	3% Discount Rate	490	1,100	$3,400	$8,100
	7% Discount Rate	490	1,100	$3,100	$7,300
None	Incidences all occur in the first year	490	1,100	$3,800	$8,900
8-year	Incidences all occur in the 8th year				
	3% Discount Rate	490	1,100	$3,100	$7,300
	7% Discount Rate	490	1,100	$2,400	$5,600
15-year	Incidences all occur in the 15th year				
	3% Discount Rate	490	1,100	$2,500	$5,900
	7% Discount Rate	490	1,100	$1,500	$3,500
Alternative Segmented	20 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20				
	3% Discount Rate	490	1,100	$3,300	$7,800
	7% Discount Rate	490	1,100	$2,900	$6,800
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5				
	3% Discount Rate	490	1,100	$3,600	$8,500
	7% Discount Rate	490	1,100	$3,400	$8,000

[a] Incidences rounded to two significant digits.

[b] Dollar values rounded to two significant digits. The alternative lag structure analysis presents benefits calculated using both a 3 percent and 7 percent discount rate.

The results of the scaled alternative lag sensitivity analysis demonstrate that choice of lag structure can have a large impact on benefits. Because of discounting of delayed benefits, the lag structure may have a large downward impact on monetized benefits if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits.

6.B.3 Visibility Benefits in Additional Class I Areas

The Chestnut and Rowe (1990)[71] study from which the primary visibility valuation estimates are derived only examined WTP for visibility changes in Class I areas (national parks and wilderness areas) in the southeast, southwest, and California. To obtain estimates of WTP for visibility changes at national parks and wilderness areas in the northeast, northwest, and central regions of the U.S., we have to transfer WTP values from the studied regions. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions.

Based on this benefits transfer methodology (implemented within the preference calibration framework discussed in Chapter 5 and Appendix I of the final PM NAAQS RIA), estimated additional visibility benefits in the northwest, central, and northeastern U.S. are provided in Table 6B-3.

Table 6.B-3: Monetary Benefits Associated with Improvements in Visibility in Additional Federal Class I Areas in 2020 and 2030 (in millions of 2006$)[a]

Year	Northwest[b]	Central[c]	Northeast[d]	Total
2020	$13	$27	$9	$49
2030	$34	$41	$32	$110

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns

[b] Northwest Class I areas include Crater Lake, Mount Rainier, North Cascades, and Olympic national parks, and Alpine Lakes, Diamond Peak, Eagle Cap, Gearhart Mountain, Glacier Peak, Goat Rocks, Hells Canyon, Kalmiopsis, Mount Adams, Mount Hood, Mount Jefferson, Mount Washington, Mountain Lakes, Pasayten, Strawberry Mountain, and Three Sisters wilderness areas.

[c] Central Class I areas include Craters of the Moon, Glacier, Grand Teton, Theodore Roosevelt, Badlands, Wind Cave, and Yellowstone national parks, and Anaconda-Pintlar, Bob Marshall, Bridger, Cabinet Mountains, Fitzpatrick, Gates of the Mountain, Lostwood, Medicine Lake, Mission Mountain, North Absaroka, Red Rock Lakes, Sawtooth, Scapegoat, Selway-Bitterroot, Teton, U.L. Bend, and Washakie wilderness areas.

[d] Northeast Class I areas include Acadia, Big Bend, Guadalupe Mountains, Isle Royale, Voyageurs, and Boundary Waters Canoe national parks, and Brigantine, Caney Creek, Great Gulf, Hercules-Glades, Lye Brook, Mingo, Moosehorn, Presidential Range-Dry Roosevelt Campobello, Seney, Upper Buffalo, and Wichita Mountains wilderness areas.

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CHAPTER 7: ECONOMIC IMPACT ANALYSIS

CHAPTER 7: Economic Impact Analysis

We prepared an Economic Impact Analysis (EIA) to estimate the economic impacts of the new emission control program on the locomotive and marine diesel engine and vessel markets. In this chapter we describe the Economic Impact Model (EIM) we developed to estimate the market-level changes in prices and outputs for affected markets, the social costs of the program, and the expected distribution of those costs across stakeholders. We also present the result of our analysis.

We estimate the social costs of the new program to be approximately $738 million in 2030.[A, B] The rail sector is expected to bear about 62.5 percent of the social costs of the program in 2030, and the marine sector is expected to bear about 37.5 percent. In each of these two sectors, these social costs are expected to be born primarily by producers and users of locomotive and marine transportation services (62 and 36 percent, respectively). The remaining 2 percent is expected to be borne by locomotive, marine engine, and marine vessel manufacturers and fishing and recreational vessel users.

The impact of these costs on society are expected to be minimal, with the prices of rail and marine transportation services in 2030 estimated to increase by less about 0.6 percent for locomotive transportation services and about 1.1 percent for marine transportation services.

7.1 Overview and Results

7.1.1 What is an Economic Impact Analysis?

An EIA is prepared to inform decision makers about the potential economic consequences of a regulatory action. The analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders. These estimated social costs can then be compared with estimated social benefits (as presented in Chapter 6). As defined in EPA's *Guidelines for Preparing Economic Analyses*, social costs are the value of the goods and services lost by society resulting from a) the use of resources to comply with and implement a regulation and b) reductions in output.[1] In this analysis, social costs are explored in two steps. In the *market analysis*, we estimate how prices and quantities of goods and services affected by the new emission control program can be expected to change once the program goes into effect. In the *economic welfare analysis*, we look at the total social costs associated with the program and their distribution across key stakeholders.

[A] All estimates presented in this section are in 2005$.

[B] The estimated 2030 social welfare cost of $738 million is based on draft compliance costs for this final rule, which estimated $740 million engineering costs in 2030 (see Table 7-3). The final compliance cost estimate for 2030 is somewhat higher, at $759 million; see Section 7.3.2 for an explanation of the difference. This difference is not expected to have an impact on the results of the market analysis or on the expected distribution of social costs among stakeholders.

7.1.2 What Methodology Did EPA Use in this Economic Impact Analysis?

The EIM is the behavioral model we developed to estimate market-level impacts (price and quantity changes) and social welfare costs associated with an emission control program. The model relies on basic microeconomic theory to simulate how producers and consumers of products and services affected by the emission requirements can be expected to respond to an increase in production costs as a result of the new emission control program. The economic theory that underlies the model is described in detail in Section 7.2.

The EIM is designed to estimate the economic impacts of the new program by simulating economic behavior. This is done by creating a model of the initial, pre-control market for a product, shocking that model by the estimated compliance costs, and observing the impacts on the market. At the initial, pre-control market equilibrium, a market is characterized by a price and quantity combination at which producers are willing to produce the same amount of a product that consumers are willing to purchase at that price (supply is equal to demand). The control program under consideration would increase the production costs of affected goods by the amount of the compliance costs. This generates a "shock" to the initial equilibrium market conditions (a change in supply). Producers of affected products will try to pass some or all of the increased production costs on to the consumers of these goods through price increases. In response to the price increases, consumers will decrease their demand for the affected good (a change in the quantity demanded). Producers will react to the decrease in quantity demanded by decreasing the quantity they produce; the market will react by setting a higher price for those fewer units. These interactions continue until a new market equilibrium price and quantity combination is achieved. The amount of the compliance costs that can be passed on to consumers is ultimately limited by the price sensitivity of purchasers and producers in the relevant market (represented by the price elasticity of demand and supply). The EIM explicitly models these behavioral responses and estimates new equilibrium prices and output and the resulting distribution of social costs across these stakeholders (producers and consumers).

The EIM is a behavioral model. The estimated social costs of this emission control program are a function of the ways in which producers and consumers of the engines and equipment affected by the standards change their behavior in response to the costs incurred in complying with the standards. These behavioral responses are incorporated in the EIM through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves), which measure the price sensitivity of consumers and producers. An “inelastic” price elasticity (less than one) means that supply or demand is not very responsive to price changes (a one percent change in price leads to less than one percent change in demand). An “elastic” price elasticity (more than one) means that supply or demand is sensitive to price changes (a one percent change in price leads to more than one percent change in demand). A price elasticity of one is unit elastic, meaning there is a one-to-one correspondence between a change in price and change in demand. The price elasticities used in this analysis are described in Section 7.3 and are either from peer-reviewed literature or were estimated using well-established econometric methods. It should be noted that the price elasticity of demand for the locomotive and marine engine and vessel markets is internally derived from the rail and marine transportation service markets as part of the process of running the model. This is an important feature of the EIM, which allows it to link the engine and equipment components of each model and simulate how compliance costs can be expected to ripple through the affected markets.

7.1.3 What Economic Sectors are Included in the Economic Impact Model?

In this EIA we estimate the impacts of the new emission control program on two broad sectors: rail and marine. The characteristics of the markets analyzed that are relevant to the EIM are summarized in Table 7-1, and described in more detail in Section 7.3.

Table 7-1. Summary of Markets in Economic Impact Model

Model Dimension	Rail Sector	Marine Sector
Description of Markets: Supply	Locomotive: locomotive manufacturers (integrated manufacturers); 3 categories Line Haul Passenger Switcher Note: Passenger and switcher markets are combined into one market in this analysis Rail Transportation Services: Entities that provide rail transportation services (railroads, primarily Class I)	Marine Engines: *3 Applications* Commercial Propulsion Recreational Propulsion Auxiliary *7 Engine Sizes* Small: < 50 hp Category 1: 50-200 hp 200-400 hp 400-800 hp 800-2,000 hp > 2,000 hp Category 2: 800-2,000 hp > 2,000 hp Marine Vessels: 7 Applications Tug/tow/pushboats Cargo vessels Ferry vessels Supply/crew boats Other commercial vessels Fishing boats Recreational boats Marine Transportation Services: Entities that provide marine transportation services (excludes small fishing and recreational vessels)
Description of Markets: Demand	Locomotive: Railroads (primarily Class I) Rail transportation services: Entities that use rail transportation services (power, chemical, agricultural companies; personal transportation)	Marine Engines: Vessel manufacturers Marine Vessels: Marine vessel users (owners of all types of marine vessels) Marine transportation services: Entities that use marine transportation services (power, chemical, agricultural companies; personal transportation)
Geographic Scope	50 states	50 states
Market Structure	Perfectly competitive	Perfectly competitive

Model Dimension	Rail Sector	Marine Sector
Baseline Population	Same as locomotive inventory analysis	PSR 2002 OE Link Sales Database
Growth Projections	Based on projected fuel consumption from Energy Information Agency	Commercial marine: 0.9% (0.009); Recreational marine: Based on EPA's Nonroad Model
Supply Elasticity	Locomotives (all): 2.7 (elastic) Rail Transportation Market: 1.6 (inealastic)	Engines: 3.8 (elastic) Vessels: 2.3 (elastic) Marine Transportation Market: 1.6 (inelastic)
Demand Elasticity	Locomotives (all): Derived Rail Transportation Market: -0.5 (inelastic)	Engines: Derived Vessels: Commercial: Derived Recreational and small Fishing : -2.0 (elastic) Marine Transportation Market: -0.5 (inelastic)
Regulatory Shock	Locomotive Market: direct engine and equipment compliance costs cause shift in supply function Rail Transportation Market: direct operating and remanufacturing compliance costs, in addition to higher locomotive prices, cause shift in supply function	Marine diesel engine: direct engine compliance costs cause shift in supply function Marine vessels: direct vessel compliance costs, in addition to higher engine prices, cause shift in supply function Marine Transportation Market: direct operating costs in addition to higher vessel prices cause shift in supply function

7.1.3.1 Rail Sector Component

The rail sector component of the EIM is a two-level model consisting of suppliers and users of locomotives and rail transportation equipment and services.

Locomotive Market. The locomotive market consists of locomotive manufacturers (line haul, switcher, and passenger) on the supply side and railroads on the demand side. The vast majority of locomotives built annually are for line haul applications; a small number of passenger locomotives are built annually, and even fewer switchers. The locomotive market is characterized by integrated manufacturers (the engine and locomotive are made by the same manufacturer) and therefore the engine and equipment impacts are modeled together. The EIM does not distinguish between power bands for locomotives. This is because while there is some variation in power for different engine models, the range is not large. On average line haul locomotives are typically about 4,000 hp, passenger locomotives are about 3,000 hp, and switchers are about 2,000 hp.

Recently, a new switcher market is emerging in which manufacturers are expected to be less integrated, with the manufacturer of the engine expected to be different from the manufacturer of the switcher.[C] Because the characteristics of this new market are speculative at this time, the switcher market component of the EIM is modeled in the same way as line haul locomotives for future years (integrated manufacturers; same behavioral parameters), but with different baseline equilibrium prices and quantities and different compliance costs.

Consistent with the cost analysis, the passenger market is combined with the switcher market in this EIA.

Rail Transportation Services. The rail transportation services market consists of entities that provide and utilize rail transportation services. On this supply side, these are the railroads. On the demand side, these are rail transportation service users such as the chemical and agricultural industries and the personal transportation industry. Most of the goods moved by rail are bulk goods such as coal, chemicals, minerals, petroleum, and the like. About 26 percent of the carloads in 2004 were miscellaneous mixed shipments (mostly intermodal, e.g., containers) and about 6 percent were motor vehicles and equipment. This means that about 68 percent of the goods moved by rail are production inputs.[2] The EIM does not estimate the economic impact of the new emission control program on ultimate finished goods markets that use rail transportation services as inputs. This is because transportation services are only a small portion of the total variable costs of goods and services manufactured using these bulk inputs. Also, changes in prices of transportation services due to the estimated compliance costs are not expected to be large enough to affect the prices and output of goods that use rail transportation services as an input.

7.1.3.2 Marine Sector Component

The marine sector component of the EIM distinguishes between engine, vessel, and ultimate user markets (marine transportation service users, fishing users, recreational users). This is because, in contrast to the locomotive market, manufacturers in the diesel marine market are not integrated. Marine diesel engines and vessels are manufactured by different entities.

Marine Engine Market. The marine engine markets consist of marine engine manufacturers on the supply side and vessel manufacturers on the demand side. The model distinguishes between three types of engines, commercial propulsion, recreational propulsion, and auxiliary. Engines are broken out into eight categories based on horsepower and displacement.

- Small marine diesel engines

[C] Until recently, switchers have typically been converted line haul locomotives and very few, if any, new dedicated switchers were built in any year. Recently, however, the power and other characteristics of line haul locomotives have made them less attractive for switcher usage. Their high power means they consume more fuel than smaller locomotives, and they have less attractive line-of-sight characteristics than what is needed for switchers. Therefore, the industry is anticipating a new market for dedicated switchers.

    - <50 hp
- C1 engines
    - 50-200 hp
    - 200-400 hp
    - 400-800 hp
    - 800-2,000 hp
    - >2,000 hp
- C2 engines
    - 800-2,000 hp
    - >2,000 hp

The engine categories used in this EIA are different from the categories used for the emission limits, both in term of units (horsepower instead of kilowatt) and in terms of the range of power included in each group of engines. The EIA categories were chosen for ease of analysis. Note, however, that the power threshold for the Tier 4 standards is 600 kW or 900 hp, which is consistent with this analysis.

For the purpose of the EIA, the C1/C2 threshold is 5 l/cyl displacement, even though the new C1/C2 threshold is 7 l/cyl displacement. The 5 l/cyl threshold was used because it is currently applicable limit. In addition, there is currently only one engine family in the 5 to 7 l/cyl range, and it is not possible to project what future sales will be in that range or if more engine families will be added.

Marine Vessel Market. The marine vessel market consists of marine vessel manufacturers on the demand side and marine vessel users on the supply side. The model distinguishes between seven vessel categories. Each of these vessels would have at least one propulsion engine and at least one auxiliary engine, although many may have more:

- Recreational
- Fishing
- Tow/tug/push
- Ferry
- Supply/crew
- Cargo
- Other commercial

For recreational applications, the purchasers of those vessels are the end users, and so the EIM is a two-level model for that market. Demand for vessels comes directly from households that use these vessels for recreational activities and acquire them for the personal enjoyment of the owner. For the other commercial vessel markets (tow/tug/push, ferry, supply/crew, cargo, other), demand for those vessels is derived from the transportation services they provide. Therefore it is necessary to include a marine transportation services market in the model.

For the fishing applications, we use a dual approach. Small fishing vessels, those that use engines below 800 hp, are treated like recreational vessels, as a two-level market. The physical and operating characteristics of these vessels are very similar to recreational vessels. Small fishing vessels often have fiberglass hulls, have fewer hours of use per year than large commercial fishing vessels, and their engines have higher power density. Smaller fishing vessels are typically operated for day fishing, their catch is more likely subject to seasonal restrictions, and they have very small or no crew apart from the owner. Demand for these vessels is less likely to be tied to a downstream market like the industrial fish processing or other food or industrial markets and be more a function of the local fish market, the demand for fresh fish for restaurants, and the individual preferences of the owner/operator.

Large fishing vessels, those that use engines above 800 hp, are treated like marine transportation service vessels, as a three-level market. These vessels tend to be uniquely built, used for offshore fishing, and are manned by professional crews. They may be at sea for extended period of time, and many have fish processing facilities onboard. Demand for these vessels is tied more directly to the fish consumption market, including industrial fish processing companies.

Marine Transportation Services. The marine transportation services market consists of entities that provide and utilize marine transportation services: vessel owners on the supply side and marine transportation service users on the demand side. The firms that use these marine transportation services are very similar to those that use locomotive transportation services: those needing to transport bulk chemicals and minerals, coal, agricultural products, etc. These transportation services are production inputs that depend on the amount of raw materials or finished products being transported and thus marine transportation costs are variable costs for the end user. Demand for these transportation services will determine the demand for vessels used to provide these services (tug/tow/pushboats, cargo, ferries, supply/crew, other commercial vessels).

7.1.3.3 Market Linkages

The submarkets in each of the marine and rail markets are linked; this provides feedback mechanism between consumers and producers in the relevant markets, which simulates dynamic interactions in the actual markets. The locomotive and marine components of the EIM are not linked however, meaning there is no feedback mechanism between the locomotive and marine sectors. Although locomotives and marine vessels such as tugs, towboats, cargo, and ferries provide the same type of transportation service, the characteristics of these markets are quite different and are subject to different constraints that limit switching from one type of transportation service to the other. For example, switching from rail services to marine services requires having access to a port and the waterway system; if the production facility is not located on a waterway it would also be necessary to transport the goods to and from port. Similarly, users of marine transportation services typically transport bulk goods in large quantities (by barge or by container); these quantities may be more complicated and costly to transport by rail. Because the services provided by the locomotives and marine markets are not completely interchangeable, a change in the price of one is not expected to have an impact on the price for the other.

For the limited number of cases where there is direct competition between rail and marine transportation services, we do not expect this rule to change the dynamics of the choice between marine or rail providers of these services because 1) the estimated compliance costs imposed by this rule are relatively small in comparison with the total production costs of providing transportation services, and 2) both sectors would be subject to the new standards. So, for example, while an increase in the price of marine diesel engines may lead to an increase in the price of marine transportation services, this will not likely have much impact on the demand for rail services because the rail sector is also expected to see increased costs.

7.1.4 Summary of Results

The EIA consists of two parts: a market analysis and welfare analysis. The market analysis looks at expected changes in prices and quantities for affected products. The welfare analysis looks at economic impacts in terms of annual and present value changes in social costs.

We performed a market analysis for all years and all engines and equipment. The detailed results can be found in the appendices to this chapter. On the marine side, all propulsion markets were modeled even though marine engines below 800 hp are not expected to be affected by the program (they are not subject to Tier 4 standards and the only compliance costs associated with Tier 3 standards are fixed costs). The results for engines less than 800 hp can be found in a Technical Support Document.[3] In addition, to facilitate and accommodate computer programming constraints, only auxiliary engines above 800 hp were included in the model (see section 7.3.2.2).

In this section we present summarized results for selected years: 2012, which illustrates the impacts of the marine and locomotive remanufacture programs (there are no variable costs for the Tier 3 standards, and therefore the Tier 3 standards do not affect market impacts in that year); 2016, which illustrates the market impacts of the Tier 4 standards; and 2030, when per unit compliance costs are stabilized.

Due to the structure of the program, the sources of the estimated social costs impacts of the program change over time. In the early years of the program, prior to 2016, the social costs are due to the fixed and variable costs associated with the phase-in of the new emission standards. By 2016, operating costs and the remanufacture program costs are about half the total costs of the program; the share of these two segments increases to about 83 percent of total program costs in 2030 and 90 percent in 2040. The remainder is due to variable costs for the engine standards. Consequently, a large share of the long-term social costs of the program fall on the marine and rail transportation service sectors. Results for all years can be found in the appendices to this Chapter.

The results of the economic impact analysis presented below are based on an earlier version of the engineering costs developed for this rule (see Section 7.3.2).

7.1.4.1 Market Analysis Results

In the market analysis, we estimate how prices and quantities of goods affected by the new emission control program can be expected to change once the program goes into effect. The analysis relies on the baseline equilibrium prices and quantities for each type of equipment and the price elasticity of supply and demand. It predicts market reactions to the increase in production costs due to the new compliance costs (variable, operating, and remanufacturing costs). It should be noted that this analysis does not allow any other factors to vary. In other words, it does not consider that manufacturers may adjust their production processes or marketing strategies in response to the control program.

The market data presented below is aggregated across sub-markets. The absolute price changes and relative price/quantity changes reported below are production-weighted averages of the individual market-level estimates generated by the model for each group of engine/equipment markets, and not the expected price or quantity change for a particular engine model or vessel market. So, for example, the estimated price changes for marine diesel engines are production-weighted averages of the estimated results for all of the marine diesel engine markets included in that group.[D] The absolute change in quantity reported for each group of engine/equipment markets, on the other hand, is the sum of the decrease in units produced across sub-markets within each engine/equipment group. The aggregated data presented in Table 7-2 is intended to provide a broad overview of the expected market impacts that is useful when considering the impacts of the rule on the economy as a whole and not the impacts on a particular engine or equipment category.

More detailed results for each of the submarkets are presented in the appendices to this chapter and in a Technical Support Document.[4] As explained in Section 7.2.2.1, this is a market-level analysis and the results are not intended to reflect expected price or quantity changes for a particular engine or equipment model.

Locomotive Sector Impacts. On the locomotive side, the new program is expected to have a negligible impact on locomotive prices and quantities. In 2012, the expected impacts are mainly the result of the operating costs associated with locomotive remanufacturing standards. These standards impose an operating cost on railroad transportation providers and are expected to result in a slight increase in the price of locomotive transportation services (about 0.1 percent, on average) and a slight decrease in the quantity of services provided (about 0.1 percent, on average). Due to the decrease in quantity of services provided, the locomotive remanufacturing program is also expected to have a small impact on the new locomotive market. The remanufacturing program will increase railroad operating costs, which expected to result in an increase in the price of transportation services. This increase will results in a decrease in demand for rail transportation services and ultimately in a decrease in the demand for locomotives and a decrease in their price. In other words, the market will contract slightly. We estimate a reduction in the price of locomotives of about 0.03 percent on average.

Beginning in 2016, the market impacts are affected by both the operating costs and the direct costs associated with the Tier 4 standards. As a result of both of these impacts, the price of a new locomotive is expected to increase by about 4.2 percent for a line haul locomotive and one percent for a switcher; the quantity produced of either is expected to

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[D] As a result, estimates for specific types of engines and equipment may be different than the reported group average. The detail results for markets are reported in the Appendices to Chapter 7 of the RIA.

decrease by about 0.1 percent, on average. Locomotive transportation service prices are expected to increase by about 0.3 percent. By 2030, the price increase for a new line haul locomotive is expected to decrease to about 3.2 percent; prices for switchers are expected to increase by about 1.5 percent. The expected quantity decrease for either is approximately 0.3 percent. The price of rail transportation services is expected to increase by about 0.6 percent.

Marine Sector Impacts. On the marine engine side, the expected impacts are different for engines above and below 800 hp.

With regard to engines above 800 hp and the vessels that use them, there are negligible impacts in the early years of the program. The slight expected decrease in prices and in quantity produced is due to the market impacts of the remanufacture program; there are no market impacts for the Tier 3 standards. Beginning in 2016, market impacts due to the Tier 4 standards begin to occur, with expected price increases up to 17 percent for engines and 7 percent for vessels expected to occur. The impact on marine transportation markets, however, is expected to be small, at less than 0.5 percent. The results in 2030 are similar, with expected price increases up to 13 percent for engines and 5 percent for vessels, but marine transportation market price increase of only about 1 percent.

It should be noted that the actual social welfare impacts for producers and consumers of vessels is likely to be less that these estimated impacts, however. By allocating all of the auxiliary engines above 800 hp to the vessels that will be affected by this program, this analysis over-estimates the vessel impacts of the program. In fact, not all of the very large auxiliary engines are actually used on the commercial vessels that are subject to this program; some will be installed on vessels with Category 3 marine diesel engines. While it is appropriate to consider these costs in the economic impact analysis for this program, it is clear that not all of these social costs will be passed on to the producers and users of vessels directly affected by this program.

With regard to engines below 800 hp, the market impacts of the program are expected to be negligible.[E] This is because there are no variable costs associated with the standards for these engines. The market impacts associated with the program are indirect effects that stem from the impacts on the marine service markets for the larger engines that would be subject to direct compliance costs. Changes in the equilibrium outcomes in those marine service markets may lead to reductions for marine services in other marine engine and vessel markets, including the markets for smaller marine diesel engines and vessels. The result is that in some years there may be small declines in the equilibrium price in the markets for marine diesel engines less than 800 hp. This would occur because an increase in the price and a decrease in the quantity of marine transportation services provided by vessels with engines above 800 hp that results in a change in the price of marine transportation services may have follow-on effects in other marine markets and lead to decreases in prices for those markets. For

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[E] The market results for engines and vessels below 800 hp are provided in a Technical Support Document. See U.S. EPA. Technical Support Document for the Final Locomotive /Marine Rule: Detailed Results from Economic Impact Model (EIM). EPA420-R-07-014. December 2007. A copy of this document can be found in the docket for this rule, EPA-HQ-OAR-2004-0190.

example, the large vessels used to provide transportation services are affected by the rule. Their compliance costs lead to a higher vessel price and a reduced demand for those vessels. This reduced demand indirectly affects other marine transportation services that support the larger vessels, and leads to a decrease in price for those markets as well.

Table 7-2. Summary of Estimated Market Impacts for 2011, 2016, 2030 (2005$)

Market	Average Variable Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent
2012					
Rail Sector					
Locomotives	$0	-$535	-0.03%	-1	-0.1%
Switcher/Passenger	$0	-$348	-0.03%	0	-0.1%
Transportation Services	NA	NA[a]	0.1%	NA[a]	-0.1%
Marine Sector					
Engines					
Auxiliary >800 hp	$0	-$47	0.00%	0	-0.1%
Propulsion C1>800 hp	$0	-$8	0.00%	0	0.0%
Propulsion C2>800 hp	$0	-$139	-0.03%	0	- 0.1%
Other marine	$0	$0	0.00%	0	0.0%
Vessels					
C1>800 hp	$0	-$174	-0.01%	0	0.0%
C2>800 hp	$0	-$2,419	-0.07%	0	-0.1%
Other marine	$0	-$3	0.00%	1	0.0%
Transportation Services	NA	NA[a]	0.2%	NA[a]	-0.1%
2016					
Rail Sector					
Locomotives	$84,274	$83,227	4.2%	-1	-0.1%
Switcher/Passenger	$14,175	$13,494	1.0%	0	-0.1%
Transportation Services	NA	NA[a]	0.3%	NA[a]	-0.1%
Marine Sector					
Engines					
Auxiliary >800 hp	$37,097	$35,569	17.1%	-11	-3.4%
Propulsion C1>800 hp	$18,483	$16,384	8.5%	-15	-3.7%
Propulsion C2>800 hp	$71,806	$71,602	16.3%	0	-0.2%
Other marine	$0	$0	0.00%	0	0.0%
Vessels					
C1>800 hp	$8,277	$34,043[b]	2.1%	-14	-3.7%
C2>800 hp	$12,107	$255,143[b]	7.0%	0	-0.2%
Other marine	$0	-$4	0.00%	-1	0.0%
Transportation Services	NA	NA[a]	0.4%	NA[a]	-0.2%
2030					
Rail Sector					

Market	Average Variable Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent
Locomotives	$65,343	$63,019	3.2%	-4	-0.3%
Switcher/Passenger	$21,139	$19,628	1.5%	-1	-0.3%
Transportation Services	NA	NA[a]	0.6%	NA[a]	-0.3%
Marine Sector					
Engines					
Auxiliary >800 hp	$28,359	$27,021	13.0%	-11	-2.8%
Propulsion C1>800 hp	$14,131	$12,479	6.5%	-13	-2.9%
Propulsion C2>800 hp	$54,893	$54,264	12.3%	-1	-0.5%
Other marine	$0	-$1	0.0%	0	0.0%
Vessels					
C1>800 hp	$6,933	$25,768[b]	1.6%	-12	-2.9%
C2>800 hp	$10,169	$164,774[b]	5.1%	0	-0.5%
Other marine	$0	-$12	0.0%	-4	0.0%
Transportation Services	NA	NA[a]	1.1%	NA[a]	-0.5%

[a] The prices and quantities for transportation services are normalized ($1 for 1 unit of services provided) and therefore it is not possible to estimate the absolute change price or quantity; see 7.3.1.5.

[b] The estimated vessel impacts include the impacts of direct vessel compliance costs and the indirect impacts of engine markets for both propulsion and auxiliary engines. See Chapter 7 of the RIA.

7.1.4.2 Economic Welfare Analysis

In the economic welfare analysis we look at the costs to society of the new emission control program in terms of losses to key stakeholder groups that are the producers and consumers in the rail and marine markets. The estimated surplus losses presented below reflect all engineering costs associated with the new program (fixed, variable, operating, and remanufacturing costs). Detailed economic welfare results for the new program for all years are presented in the Appendices to this chapter and are summarized below.

A summary of the estimated annual net social costs is presented in Table 7-3 and Figure 7-1. Table 7-3 shows that total social costs for each year are slightly less than the total engineering costs. This is because the total engineering costs do not reflect the decreased sales of locomotives, engines and vessels that are incorporated in the total social costs. In addition, in the early years of the program the estimated social costs of the program are not expected to increase regularly over time. This is because the compliance costs for the locomotive remanufacture program are not constant over time.

Table 7-3 Estimated Annual Engineering and Social Costs Through 2040 (2005$, $million)

	Marine operating costs	Marine Remanuf. Costs	Marine Engine and Vessel costs	Rail operating costs	Rail Remanuf. costs	Rail New Locomotive costs	Total Engineering	Total Social Costs
2007	$0.0	$22.4	$0.0	$0.0	$0.0	$8.6	$33.5	$33.5
2008	$0.0	$22.4	$18.1	$0.0	$25.8	$8.6	$77.4	$77.4
2009	$0.0	$22.4	$24.1	$0.0	$32.3	$8.6	$89.9	$89.9
2010	$0.0	$22.4	$30.2	$0.0	$58.2	$38.4	$151.7	$151.7
2011	$0.0	$71.0	$36.4	$0.0	$110.1	$41.9	$279.6	$279.5
2012	$0.0	$29.7	$50.4	$0.0	$90.3	$34.7	$221.1	$221.0
2013	$0.0	$29.7	$54.4	$0.0	$82.3	$34.7	$217.1	$217.0
2014	$0.0	$29.7	$54.1	$0.0	$61.0	$40.4	$201.2	$201.1
2015	$0.0	$53.8	$42.1	$14.3	$50.9	$74.9	$258.4	$258.3
2016	$7.2	$35.2	$39.3	$29.3	$80.8	$80.7	$284.9	$284.4
2017	$21.3	$32.5	$35.8	$45.5	$66.1	$59.5	$273.3	$272.8
2018	$38.1	$25.1	$33.5	$61.8	$68.2	$60.6	$297.0	$296.6
2019	$54.8	$25.3	$31.0	$78.4	$62.1	$61.9	$323.4	$322.9
2020	$71.4	$25.5	$29.4	$95.6	$36.7	$63.9	$332.5	$332.0
2021	$88.1	$25.8	$27.8	$113.3	$36.7	$65.9	$367.5	$367.0
2022	$104.6	$26.0	$26.2	$131.9	$57.7	$67.8	$424.2	$423.5
2023	$121.0	$26.2	$24.6	$151.3	$102.8	$71.0	$507.0	$506.1
2024	$137.3	$26.4	$23.0	$170.3	$90.2	$72.3	$529.8	$528.9
2025	$153.5	$26.6	$21.5	$189.7	$94.3	$74.7	$570.6	$569.5
2026	$169.5	$26.8	$19.9	$209.1	$79.6	$76.1	$591.5	$590.4
2027	$185.2	$27.0	$18.4	$228.8	$79.6	$77.9	$627.5	$626.2
2028	$200.7	$27.3	$16.8	$248.5	$94.1	$79.3	$677.2	$675.8
2029	$215.1	$25.0	$15.3	$268.1	$94.5	$80.3	$709.1	$707.6
2030	$228.1	$25.2	$13.8	$287.7	$92.8	$81.3	$739.7	$738.1
2031	$239.8	$25.4	$12.3	$307.4	$92.0	$82.6	$770.5	$768.7
2032	$250.8	$25.7	$10.9	$327.1	$81.4	$83.9	$790.7	$788.9
2033	$261.3	$25.9	$9.4	$346.8	$138.8	$85.2	$878.6	$876.5
2034	$271.5	$26.1	$8.1	$366.5	$147.0	$86.4	$916.7	$914.4
2035	$281.2	$26.4	$6.7	$386.0	$153.9	$86.8	$952.3	$949.9
2036	$290.6	$26.6	$5.6	$404.6	$146.3	$84.4	$969.5	$967.0

2037	$299.6	$26.8	$4.8	$422.6	$148.5	$82.6	$996.5	$993.8
2038	$308.2	$27.1	$4.2	$440.0	$150.7	$80.6	$1,022.5	$1,019.8
2039	$316.0	$27.3	$3.7	$456.7	$153.5	$78.4	$1,047.3	$1,044.5
2040	$322.4	$27.6	$3.3	$472.6	$156.6	$76.0	$1,070.3	$1,067.3
2040 NPV at 3%[a,b]							$9,166.7	$9,149.2
2040 NPV at 7%[a,b]							$4,186.6	$4,179.8
2030 NPV at 3%[a,b]							$5,364.1	$5,356.3
2030 NPV at 7%[a,b]							$2,992.4	$2,988.5

[a] EPA presents the present value of cost and benefits estimates using both a three percent and a seven percent social discount rate. According to OMB Circular A-4, "the 3 percent discount rate represents the 'social rate of time preference'… [which] means the rate at which 'society' discounts future consumption flows to their present value"; "the seven percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy … [that] approximates the opportunity cost of capital."

[b] Note: These NPV calculations are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

Table 7-4 shows how the social costs are expected to be shared across stakeholders, for selected years. According to these results, the rail sector is expected to bear most of the costs of the program, ranging from 56.5 percent in 2012 to 67.0 percent in 2016. Producers and consumers of locomotive transportation services are expected to bear most of those costs, ranging from 31.0 percent in 2012 to 48.8 percent in 2016. The marine sector is expected to bear the remaining social costs, ranging from 43.5 percent in 2012 to 33.0 percent in 2016. Producers of marine diesel engines are expected to bear more of the program costs in the early years (20.7 percent in 2012), but by 2020 producers and consumers in the marine transportation services market are expected to bear a larger share of the social costs, 37.3 percent.

Figure 7-1. Estimated Annual Social Costs, 2007-2040 (2005$, $million)

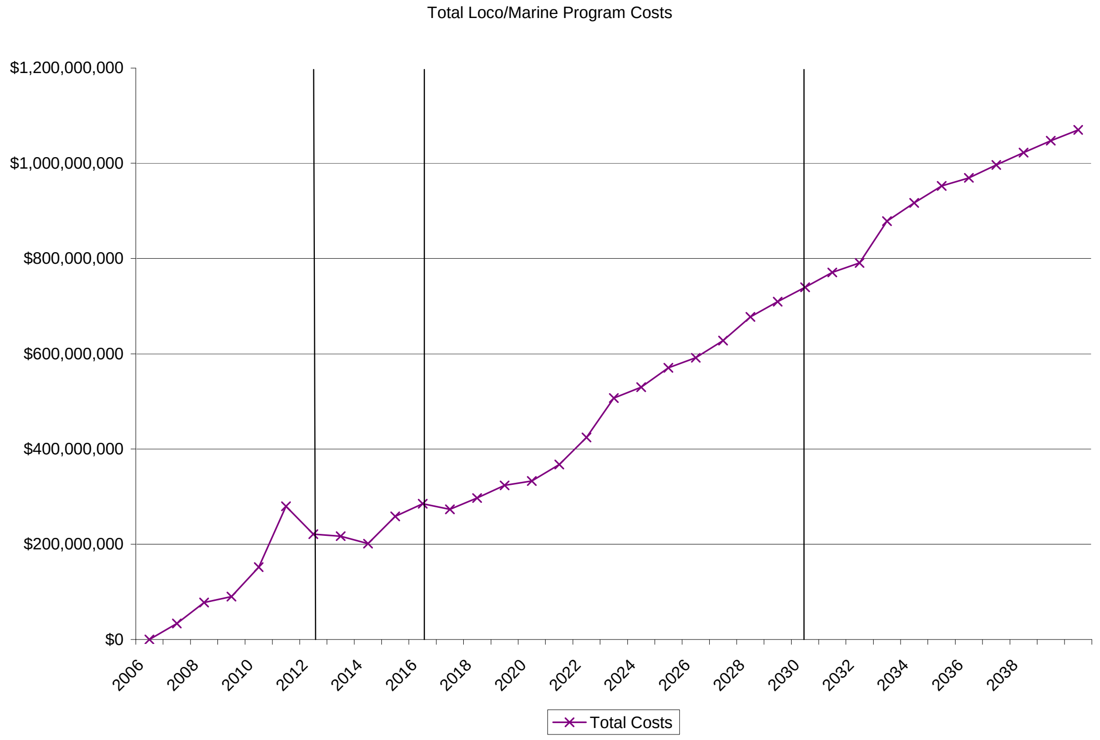


Table 7-4. Summary of Estimated Net Social Costs for 2011, 2016, 2020, 2030 (2005$, $million)

	Surplus Change	Percent	Surplus Change	Percent
	2012		**2016**	
Locomotives				
Locomotive Producers	-$35.1	15.9%	-$8.3	2.9%
Line haul producers	-$27.8	12.6%	-$0.9	0.3%
Switcher/Passenger producers	-$7.2	3.3%	-$7.4	2.6%
Rail transportation service providers	-$21.4	9.7%	-$43.4	15.3%
Rail transportation service consumers	-$68.4	31.0%	-$138.9	48.8%
Total locomotive sector	*-$124.9*	*56.6%*	*-$190.6*	*67.0%*
Marine				
Marine engine producers	-$45.8	20.7%	-$2.1	0.7%
Auxiliary >800 hp	-$16.0	7.3%	-$0.5	0.2%
C1 > 800 hp	-$19.0	8.6%	-$1.6	0.5%
C2 > 800 hp	-$10.7	4.9%	$0.0	0.0%
Other marine	$0.0	0.0%	$0.0	0.0%
Marine vessel producers	-$0.3	0.1%	-$15.8	5.6%
C1 > 800 hp	-$0.1	0.0%	-$13.5	4.7%
C2 > 800 hp	-$0.1	0.1%	-$2.2	0.8%
Other marine	-$0.1	0.0%	-$0.1	0.0%
Recreational and fishing vessel consumers	$0.0	0.0%	$0.0	0.0%
Marine transportation service providers	-$11.9	5.4%	-$18.1	6.4%
Marine transportation service consumers	-$38.1	17.3%	-$57.9	20.3%
Auxiliary Engines <800 hp	-$0.0	0.0%	$0.0	0.0%
Total marine sector	*-$96.1*	*43.5%*	*-$93.8*	*33.0%*
TOTAL PROGRAM	-$221.0		-$284.4	
	Surplus Change	Percent	Surplus Change	Percent
	2020		**2030**	
Locomotives				
Locomotive Producers	-$1.1	0.3%	-$3.1	0.4%
Line haul producers	-$1.0	0.3%	-$2.7	0.4%
Switcher/Passenger producers	-$0.1	0.0%	-$0.4	0.1%
Rail transportation service providers	-$46.4	14.0%	-$109.0	14.8%
Rail transportation service consumers	-$148.6	44.8%	-$348.9	47.3%
Total locomotive sector	-$196.1	59.1%	-$461.1	62.5%
Marine				
Marine engine producers	-$1.8	0.5%	-$2.0	0.3%
Auxiliary >800 hp	-$0.4	0.1%	-$0.5	0.1%
C1 > 800 hp	-$1.3	0.4%	-$1.4	0.2%
C2 > 800 hp	$0.0	0.0%	-$0.1	0.0%
Other marine	$0.0	0.0%	$0.0	0.0%
Marine vessel producers	-$10.3	3.1%	-$9.2	1.2%
C1 > 800 hp	-$8.8	2.7%	-$8.2	1.1%
C2 > 800 hp	-$1.3	0.4%	-$0.7	0.1%
Other marine	-$0.1	0.0%	-$0.3	0.0%
Recreational and fishing vessel consumers	$0.0	0.0%	$0.0	0.0%
Marine transportation service providers	-$29.5	8.9%	-$63.3	8.6%

	Surplus Change	Percent	Surplus Change	Percent
Marine transportation service consumers	-$94.4	28.4%	-$202.5	27.4%
Auxiliary Engines <800 hp	$0.0	0.0%	$0.0	0.0%
Total marine sector	-$135.9	40.9%	-277.0	37.5%
TOTAL PROGRAM	$332.0		$738.1	

Table 7-5 provides additional detail about the sources of surplus changes, for 2020 when the per unit compliance costs are stable. On the marine side, this table shows that engine and vessel producers are expected to pass along much of the engine and vessel compliance costs to the marine transportation service providers who purchase marine vessels. These marine transportation service providers, in turn, are expected to pass some of the costs to their customers. This is also expected to be the case in the rail sector.

Table 7-5. Distribution of Estimated Surplus Changes by Market and Stakeholder for 2020 (2005$, $million)

	Total Engineering Costs	**Surplus Change**
Marine Markets		
Engine Producers	*$29.4*	*–$1.8*
Vessel Producers	*$6.0*	*–$10.3*
Engine price changes		–$1.7
Equipment cost changes		–$8.6
Recreational and Fishing Consumers	*$0*	*$0*
Engine price changes		$0
Equipment cost changes		$0
Transportation Service Providers	*$100.8*	*–$34.3*
Increased price vessels		–$6.0
Operating costs		–$16.7
Remanufacture costs		$6.9
Transportation Service Consumers		*–$41.2*
Increased price vessels		–$19.1
Operating costs		–$53.4
Remanufacture costs		$21.9
Rail Markets		
Locomotive Producers	*$63.9*	*–$1.1*
Rail Service Providers	*$132.3*	*–$46.4*
Increased price new locomotives		–$15.1
Operating costs		–$22.6
Remanufacture costs		–$8.7
Rail Transportation Service Consumers		*–$148.6*
Increased price new locomotives		–$48.4
Operating costs		–$72.4
Remanufacture costs		–$27.8
TOTAL	***$332.5***	***$332.0***

The present value of net social costs of the new standards through 2040, shown in Table 7-3, is estimated to be is estimated to be $9.1 billion (2005$).[F] This present value is calculated using a social discount rate of 3 percent and the stream of social welfare costs from 2006 through 2040. We also performed an analysis using a 7 percent social discount rate.[G] Using that discount rate, the present value of the net social costs through 2040 is estimated to be $4.2 billion (2005$).

Table 7-6 shows the distribution of total surplus losses for the program from 2007 through 2040. This table shows that the rail sector is expected to bear about 62 percent of the total program social costs through 2040 (NPV 3%), and that most of the costs are expected to be borne by the rail transportation consumers. The marine sector is expected to bear about 38 percent of the total program social costs through 2040 (NPV 3%), most of which are also expected to be borne by the marine transportation consumers. This is consistent with the structure of the program, which leads to high compliance costs for those stakeholder groups.

Table 7-6 Estimated Net Social Costs Through 2040 by Stakeholder ($million, 2005$)

Stakeholder Groups	Surplus Change	Percent of Total Surplus	Surplus Change	Percent of Total Surplus
Locomotives	NPV 3%		NPV 7%	
Locomotive producers	-$221.1	2.4%	-$160.4	3.8%
Line Haul	-$172.2		-$124.5	
Switcher/Passenger	-$48.9		-$35.9	
Rail trans. service providers	-$1,302.7	14.2%	-$568.6	13.6%
Rail trans. service consumers	-$4,168.7	45.6%	-1,819.5	43.5%
Total locomotive sector	*-$5,692.6*	*62.2%*	*-$2,548.5*	*61.0%*
Marine				
Marine engine producers	-$307.5	3.4%	-$229.4	5.5%
Auxiliary >800 hp	-$87.3		-$64.0	
C1 > 800 hp	-$106.8		-$74.6	
C2 > 800 hp	-$56.8		-$42.6	
Other marine	-$56.7		-$48.1	
Marine vessel producers	-$150.0	1.6%	-$72.5	1.7%
C1 > 800 hp	-$126.8		-$60.8	
C2 > 800 hp	-$19.7		-$10.2	
Other marine	-$3.5		-$1.5	

[F] Note: These NPV calculations are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[G] EPA has historically presented the present value of cost and benefits estimates using both a 3 percent and a 7 percent social discount. The 3 percent rate represents a demand-side approach and reflects the time preference of consumption (the rate at which society is willing to trade current consumption for future consumption). The 7 percent rate is a cost-side approach and reflects the shadow price of capital.

Recreational and small fishing vessel consumers	$0.2		$0.1	
Marine trans. service providers	-$704.6	7.7%	-$308.4	7.4%
Marine trans. service consumers	-$2,254.7	24.6%	-$986.9	23.6%
Auxiliary Engines <800 hp[a]	-$40.2	0.4%	-$34.2	-0.8%
Total marine sector	*$3,456.7*	*37.8%*	*-$1,631.3*	*39.0%*
TOTAL PROGRAM	-$9.149.2		-$4,179.8	

[a] Marine auxiliary engines <800 hp are not subject to Tier 4 standards, and there are no variable costs associated with the Tier 3 standards. Consequently, there would be no direct compliance impacts for producers or users of these engines. Social costs are limited to fixed costs associated with tooling and certification for Tier 3 standards (those costs occur 2007-2011).

7.2 Economic Methodology

Economic impact analysis uses a combination of theory and econometric modeling to evaluate potential behavior changes associated with a new regulatory program. As noted above, the goal is to estimate the impact of the regulatory program on affected markets (prices and quantities) and stakeholder groups (the share of total social costs to be borne by producers and consumers). This is done by creating a mathematical model based on economic theory and populating the model using publicly available price and quantity data. A key factor in this type of analysis is the responsiveness of the quantity of engines, equipment, and transportation services demanded by consumers or supplied by producers to a change in the price of that product. This relationship is called the price elasticity of demand or supply.

The EIM's methodology is rooted in applied microeconomic theory and was developed following the *OAQPS Economic Analysis Resource Document*.[5] This section discusses the economic theory underlying the modeling for this EIA and several key issues that affect the way the model was developed.

7.2.1 Behavioral Economic Models

Models incorporating different levels of economic decision making can generally be categorized as *with*-behavior responses or *without*-behavior responses. The EIM is a behavioral model.

Engineering cost analysis is an example of the latter and provides detailed estimates of the cost of a regulation based on the projected number of affected units and engineering estimates of the annualized costs. The result is an estimate of the total compliance costs for a program. However, these models do not attempt to estimate how a regulatory program will change the prices or output of an affected industry. Therefore, the results may over-estimate the total costs of a program because they do not take decreases in quantity produced into account. In addition, engineering cost analysis does not address which stakeholders are expected to bear the costs of the regulation.

The *with*-behavior response approach builds on the engineering cost analysis and incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers.[6] In behavioral models, manufacturers of goods affected by a regulation are economic agents who can make adjustments, such as changing production rates or altering input mixes, that will generally affect the market environment in which they operate. As producers change their production levels in response to a new regulation, consumers of the affected goods are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output resulting from the market adjustments are used to estimate the distribution of social costs between consumers and producers.

If markets are competitive and per-unit regulatory costs are small, the behavioral approach will yield approximately the same total cost impact as the engineering cost approach. However, the advantage of the *with*-behavior response approach is that it illustrates how the costs flow through the economic system and it identifies which stakeholders (producers and consumers) are most likely to be affected.

7.2.2 What is the Economic Theory Underlying the EIM?

The EIM is a multi-market partial equilibrium numerical simulation model that estimates price and quantity change in the intermediate run under competitive market conditions. Each of these model features is described in this section.

7.2.2.1 Partial Equilibrium Multi-Market Model

In the broadest sense, all markets are directly or indirectly linked in the economy, and a new regulatory program will theoretically affect all commodities and markets to some extent. However, not all regulatory programs have noticeable impacts on all markets. For example, a regulation that imposes significant per unit direct compliance costs on the production of an important manufacturing input, such as steel, would be expected to have a large impact on the national economy. However, a regulation that imposes a small direct compliance cost on an important input, or any direct compliance costs on an input that is only a small share of production costs would be expected to have less of an impact on all markets in the economy.

The appropriate level of market interactions to be included in an economic impact analysis is determined by the number of industries directly affected by the requirements and the ability of affected firms to pass along the regulatory costs in the form of higher prices. There are at least three alternative approaches for modeling interactions between economic sectors, which reflect three different levels of analysis.

In a *partial equilibrium* model, individual markets are modeled in isolation. The only factor affecting the market is the cost of the regulation on facilities in the industry being modeled; there are no interaction effects with other markets. Conditions in other markets are assumed either to be unaffected by a policy or unimportant for cost estimation.

In a *multi-market* model, a subset of related markets is modeled together, with sector linkages, and hence selected interaction effects, explicitly specified. This approach represents an intermediate step between a simple, single-market partial equilibrium approach and a full general equilibrium approach. This technique has most recently been referred to in the literature as "partial equilibrium analysis of multiple markets."[7]

In a *general equilibrium* model, all sectors of the economy are modeled together, incorporating interaction effects between all sectors included in the model. General equilibrium models operationalize neoclassical microeconomic theory by modeling not only the direct effects of control costs but also potential input substitution effects, changes in production levels associated with changes in market prices across all sectors, and the associated changes in welfare economy-wide. A disadvantage of general equilibrium modeling is that substantial time and resources are required to develop a new model or tailor an existing model for analyzing regulatory alternatives.

This analysis uses a multi-market partial equilibrium approach in that it models only those markets that are directly affected by the new emission control program: producers and consumers in the rail and marine sectors. These two sectors are modeled separately, and the locomotive and marine components of the EIM are not linked (there is no feedback mechanism between the locomotive and marine diesel market segments; see Section 7.1.3.3). The results of the analysis will be estimated price and quantity changes in the locomotive and rail transportation services markets and in the marine engine, vessel, and transportation services markets, as well as estimates of how the compliance costs will be shared between producers and consumers in the relevant markets.

The EIM does not estimate the economic impact of the new emission control program on finished goods that use rail or marine transportation services as inputs. For example, while we look at the impacts of the program on locomotive transportation costs, we do not look at the impacts of the controls on electricity produced using coal transported by rail, or on manufactured products that use that electricity. Similarly, while we look at the impacts of the control program on the price of large fishing vessels, we do not look at the impacts of the controls on the prices of food products that use fish as an input. This is because these inputs (rail transportation, fishing vessel) are only a small portion of the total inputs of the final goods and services produced using them. Therefore, a change in the price of these inputs on the order anticipated by this program would not be expected to significantly affect the prices and quantities of finished products that use transportation or other services provided by locomotives or marine vessels as an input.

It should also be noted that the economic impact model employed for this analysis estimates the aggregate economic impacts of the control program on the relevant markets. It is not a firm-level analysis and therefore the supply elasticity or individual compliance costs facing any particular manufacturer may be different from the market average. This difference can be important, particularly where the rule affects different firms’ costs over different volumes of production. However, to the extent there are differential effects, EPA believes that the wide array of flexibilities provided in this rule are adequate to address any cost inequities that may arise.

7.2.2.2 Perfect Competition Model

For all markets that are modeled, the analyst must characterize the degree of competition within each market. The discussion generally focuses on perfect competition (price-taking behavior) versus imperfect competition (the lack of price-taking behavior). This EIM relies on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices.

In a perfectly competitive market at equilibrium the market price equals the value society (consumers) places on the marginal product, as well as the marginal cost to society (producers). Producers are price takers, in that they respond to the value that consumers put on the product. It should be noted that the perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[H] Finally, according to contestable market theory, oligopolies and even monopolies will behave very much like firms in a competitive market if it is possible to enter particular markets costlessly (i.e., there are no sunk costs associated with market entry or exit). This would be the case, for example, when products are substantially similar (e.g., a recreational vessel and a commercial vessel).

In contrast, imperfect competition implies firms have some ability to influence the market price of output they produce. One of the classic reasons firms may be able to do this is their ability to produce commodities with unique attributes that differentiate them from competitors' products. This allows them to limit supply, which in turn increases the market price, given the traditional downward-sloping demand curve. Decreasing the quantity produced increases the monopolist's profits but decreases total social surplus because a less than optimal amount of the product is being consumed. In the monopolistic equilibrium, the value society (consumers) places on the marginal product, the market price, exceeds the marginal cost to society (producers) of producing the last unit. Thus, social welfare would be increased by inducing the monopolist to increase production. Social cost estimates associated with an emission control program would be larger with monopolistic market structures and other forms of imperfect competition because the regulation exacerbates the existing social inefficiency of too little output from a social perspective. The Office of Management and Budget (OMB) explicitly mentions the need to consider these market power-related welfare costs in evaluating regulations under Executive Order 12866.[8]

Perfect competition is widely accepted for this type of analysis and only in rare cases are other approaches used.[9] For the markets under consideration in this EIA we assume the perfectly competitive market structure. This is because these markets do not exhibit evidence of noncompetitive behavior: there are no indications of barriers to entry, the firms in these markets are not price setters, and there is no evidence of high levels of strategic behavior in the price and quantity decisions of the firms.

[H] The number of firms in a market is not a necessary condition for a perfectly competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Inc., p 333.

On the marine side, the markets included in this analysis do not exhibit evidence of noncompetitive behavior. On the engine side, these markets are matured, as evidenced by unit sales growing at the rate of population increases. Pricing power in such markets is typically limited. There is also excess capacity, especially on the engine side. Marine diesel engines are typically marinized land-based highway or nonroad engines, and it is possible for marine diesel engine manufacturers to produce additional marine engines with minimal production constraints if a high demand is present. On the vessel side, there are hundreds of shipyards that can be engaged in the production of vessels, and vessels from one firm can be purchased instead of engines and vessels from another firm. Finally, there are hundreds of marine transportation service providers, ranging from individuals who own their own tug or supply boat to firms that employ a fleet. It is also not uncommon for owners to move vessels among coasts and waterways to take advantage of local markets. For all of these reasons it is appropriate to model the market markets as competitive.

The locomotive markets are also modeled as competitive. While there are two main locomotive producers, EMD and GE, their products are homogeneous and railroads can easily purchase locomotives from one or the other. The high cost of fuel for the rail transportation services sector also contributes to competition among locomotive manufacturers, in that railroads will shift their purchases from one manufacturer to the other if they can achieve a reduction in fuel costs. The new switcher market will add to the competitive pressure in this market as well. On the rail transportation side, although the Government Accountability Office (GAO) has expressed concerns regarding the amount of competition in the rail road industry due to mergers over the past decades, it also acknowledges that a more "rigorous analysis of competitive markets" was needed to show the industry was not competitive.[10] The Association of American Railroads (AAR), a trade group representing the freight railroads of North America, has suggested that mergers have actually made the rail road industry more competitive. According to the AAR, most mergers have been "end-to-end" mergers that reduce the need to interchange traffic to a connecting railroad (creating a single line service), as opposed to the merger of competing railroads with parallel lines. These mergers increase competition by creating more efficient, lower cost railway networks.[11] AAR also argues that recent mergers have not given railroads excessive market power that would come with uncompetitive markets. They note that productivity is up, prices are down, innovative new operating strategies are being tested, profits are not in excess of a competitive rate of return, and they do not have an excessive share of the national transportation market.[12]

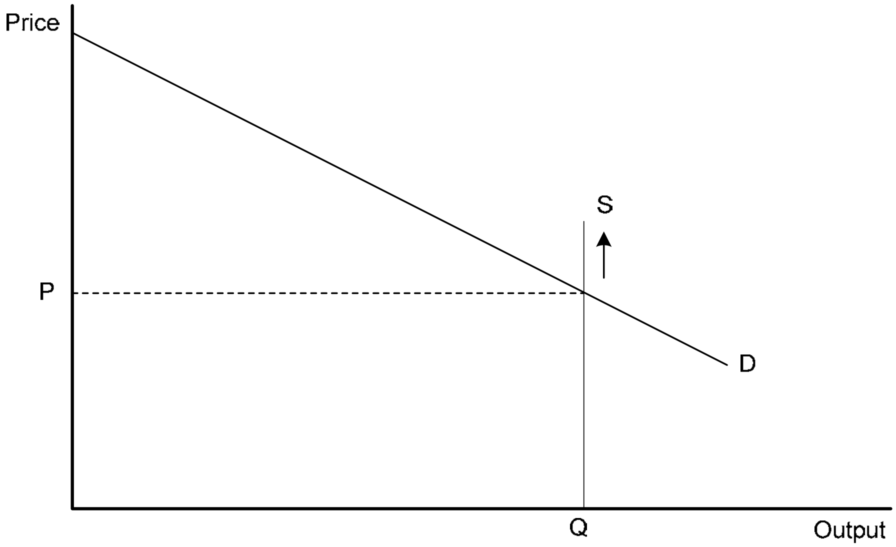
7.2.2.3 Intermediate-Run Model

In developing a multi-market partial equilibrium model, the choices available to producers must be considered. For example, are producers able to increase their factors of production (e.g., increase production capacity) or alter their production mix (e.g., substitution between materials, labor, and capital)? These modeling issues are largely dependent on the time horizon for which the analysis is performed. Three benchmark time horizons are discussed below: the very short run, the long run, and the intermediate run. This discussion relies in large part on the material contained in the *OAQPS Economic Analysis Resource Guide*.[13]

The EIM models market impacts in the intermediate run. The use of the intermediate run means that some factors of production are fixed and some are variable. This modeling period allows analysis of the economic effects of the rule's compliance costs on current producers. As described below, a short-run analysis imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

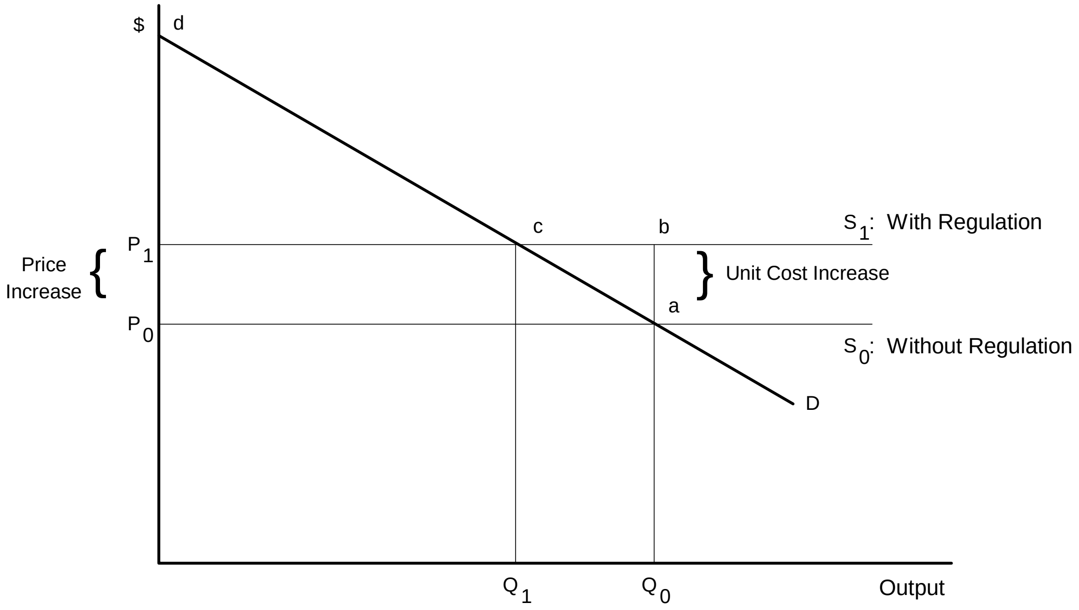
In the very short run, all factors of production are assumed to be fixed, leaving producers with no means to respond to the increased costs associated with the regulation (e.g., they cannot adjust labor or capital inputs). Within a very short time horizon, regulated producers are constrained in their ability to adjust inputs or outputs due to contractual, institutional, or other factors and can be represented by a vertical supply curve, as shown in Figure 7-2. In essence, this is equivalent to the nonbehavioral model described earlier. Neither the price nor quantity changes and the manufacturer’s compliance costs become fixed or sunk costs. Under this time horizon, the impacts of the regulation fall entirely on the regulated entity. Producers incur the entire regulatory burden as a one-to-one reduction in their profit. This is referred to as the “full-cost absorption” scenario and is equivalent to the engineering cost estimates. Although there is no hard and fast rule for determining what length of time constitutes the very short run, it is inappropriate to use this time horizon for this type of analysis because it assumes economic entities have no flexibility to adjust factors of production.

Figure 7-2. Short Run: All Costs Borne By Producers



In the long run, all factors of production are variable, and producers can be expected to adjust production plans in response to cost changes imposed by a regulation (e.g., using a different labor/capital mix). Figure 7-3 illustrates a typical, if somewhat simplified, long-run industry supply function. The supply function is horizontal, indicating that the marginal and average costs of production are constant with respect to output.[I] This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market.

Figure 7-3 Long-Run: Full-Cost Pass-Through



Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation's effect on production costs. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P_0 to P_1). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q_0 to Q_1). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P_0ac P_1). In the nomenclature of EIAs, this long-run scenario is typically referred to as "full-cost pass-through" and is illustrated in Figure 7-3.

Taken together, impacts modeled under the long-run/full-cost-pass-through scenario reveal an important point: under fairly general economic conditions, a regulation's impact on producers is transitory. Ultimately, the costs are passed on to consumers in the form of higher prices. However, this does not mean that the impacts of a regulation will have no impact on

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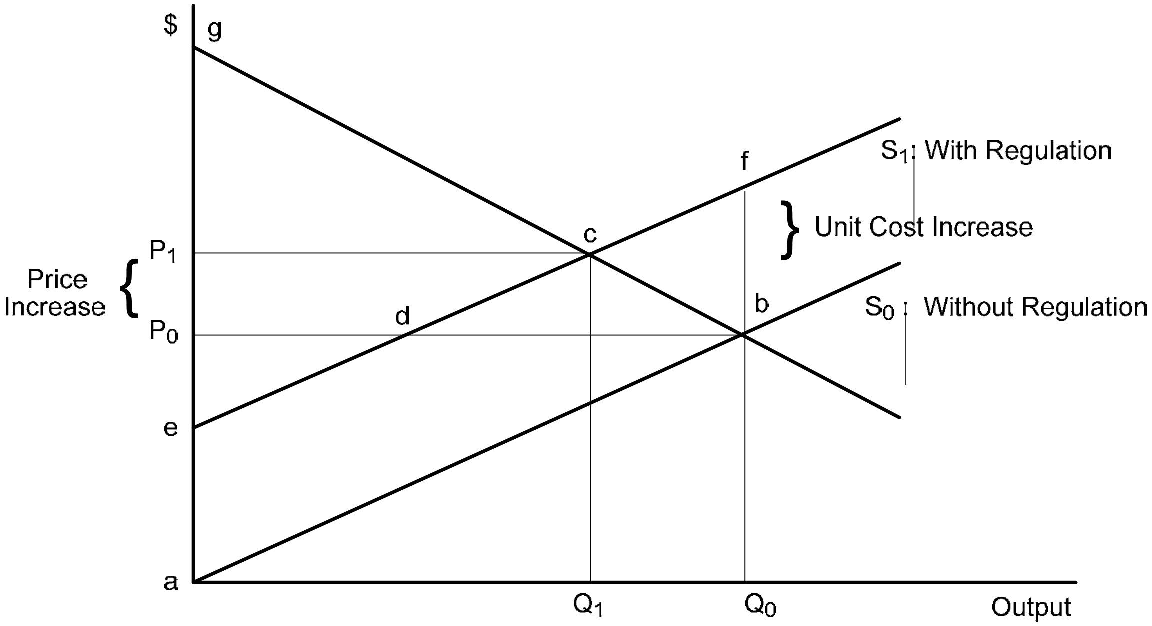
[I] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

producers of goods and services affected by a regulation. For example, the long run may cover the time taken to retire today's entire capital equipment, which could take decades. Therefore, transitory impacts could be protracted and could dominate long-run impacts in terms of present value. In addition, to evaluate impacts on current producers, the long-run approach is not appropriate. Consequently a time horizon that falls between the very short-run/full-cost-absorption case and the long-run/full-cost-pass-through case is most appropriate for this EIA.

The intermediate run time frame allows examination of impacts of a regulatory program during the transition between the short run and the long run. In the intermediate run, there is some resource immobility which may cause producers to suffer producer surplus losses. Specifically, producers may be able to adjust some, but not all, factors of production, and they therefore will bear some portion of the costs of the regulatory program. The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost (supply) function that rises with the output rate, as shown in Figure 7-4.

Figure 7-4 Intermediate Run: Partial-Cost Pass-Through



Again, the regulation causes an upward shift in the supply function. The lack of resource mobility may cause producers to suffer profit (producer surplus) losses in the face of regulation; however, producers are able to pass through some of the associated costs to consumers, to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P_0 to P_1) that is less than the per-unit increase in costs, so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In other words, there is a loss of both producer and consumer surplus.

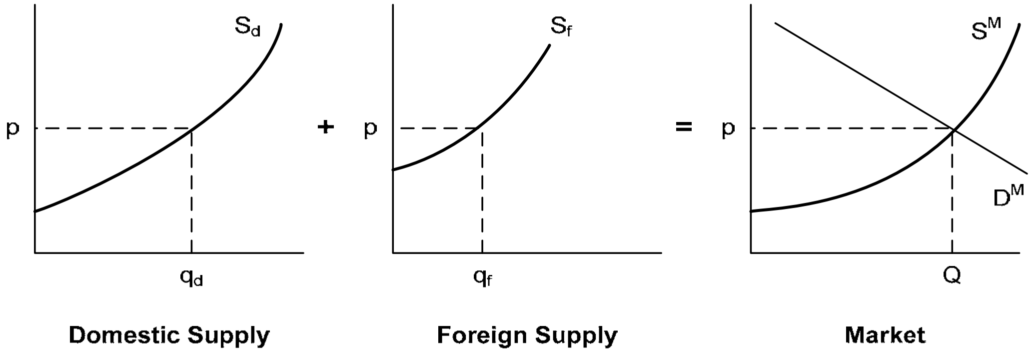
Consistent with other economic impact analyses performed by EPA, this EIM uses an intermediate run approach. This approach allows us to examine the market and social welfare impacts of the program as producers adjust their output and consumers adjust their consumption of affected products in response to the increased production costs. During this period, the distribution of the welfare losses between producer and consumer depends in large part on the relative supply and demand elasticity parameters used in the model. For example, if demand for marine vessels or locomotives is relatively inelastic (i.e., demand does not decrease much as price increases), then most of the direct compliance costs on vessel or locomotive manufacturers will be passed along to the owners and operators of this equipment in the form of higher prices.

7.2.3 How Is the EIM Used to Estimate Economic Impacts?

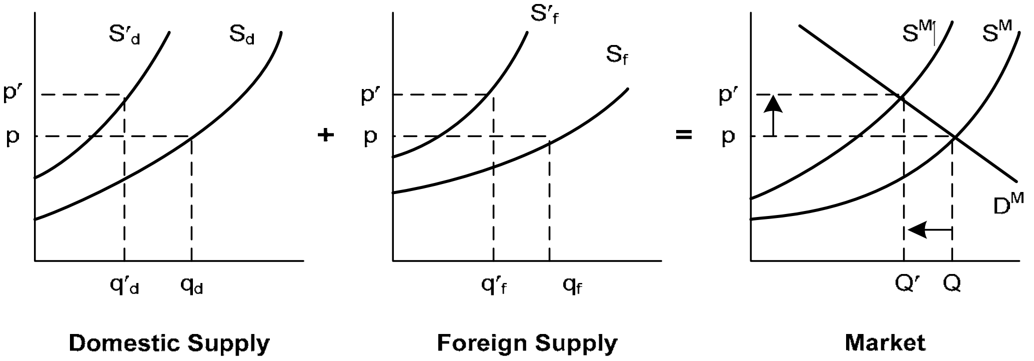
7.2.3.1 Estimation of Market Impacts (Single Market)

A graphical representation of a general economic competitive model of price formation, as shown in Figure 7-5(a), posits that market prices and quantities are determined by the intersection of the market supply and market demand curves. Under the baseline scenario, a market price and quantity (p,Q) are determined by the intersection of the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M). The market supply curve reflects the sum of the domestic (S_d) and import (S_f) supply curves.

Figure 7-5 Market Equilibrium Without and With Regulation



a) Baseline Equilibrium



b) With-Regulation Equilibrium

With the regulation, the costs of production increase for suppliers. The imposition of these regulatory control costs is represented as an upward shift in the supply curve for domestic and import supply by the estimated compliance costs. As a result of the upward shift in the supply curve, the market supply curve will also shift upward as shown in Figure 7-5(b) to reflect the increased costs of production.

At baseline without the new standards, the industry produces total output, Q, at price, p, with domestic producers supplying the amount q_d and imports accounting for Q minus q_d, or q_f. With the regulation, the market price increases from p to p′, and market output (as determined from the market demand curve) decreases from Q to Q′. This reduction in market output is the net result of reductions in domestic and import supply.

As indicated in Figure 7-5, when the new standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however, does not shift in this analysis. This is explained by the dynamics underlying the demand curve. The demand curve represents the relationship between prices and quantity demanded. Changes in prices lead to changes in the quantity demanded and are illustrated by *movements along* a constant demand curve. In contrast, changes in any of the other variables would lead to change in demand and are illustrated as *shifts* in the position of the demand curve.[J] For example, an increase in the number of consumers in a market would cause the demand curve to shift outward because there are more individuals willing to buy the good at every price. Similarly, an exogenous increase in average income would also lead the demand curve to shift outward as people choose to buy more of a good at a given price. Changes in the prices of related good and tastes or preferences can also lead to demand curve shifts.

The new standards are expected to increase the costs of production in all the affected markets (locomotive, rail transportation services, marine engines, marine vessels, and marine transportation services) and ultimately lead to higher equilibrium prices in the affected markets. As these prices increase, the quantity demanded falls (i.e., the price change leads to a movement along the demand curve). However, the new emission control program is not expected to lead to shifts in the locomotive and marine transportation service market demand curves for several reasons. First, the demand for transportation services is determined by the national economy. The growth in the size of the national economy determines the demand for transportation services. We presume the cost of the new standards will not change the size of the national economy in measurable ways since these sectors are relatively small contributors to GDP. Therefore, we do not expect a change in demand in these sectors. Second, the business decisions of users of rail and marine transportation services will not be changed due to the new standards. These users will still need to use rail and marine transportation services to ship their products to their destinations for intermediate or final users of those products. In this sense, transportation services are part of an integrated production process that will not be changed by this program. For all of these reasons, it would be inappropriate to shift the demand curve for this analysis.

7.2.3.2 Incorporating Multi-Market Interactions

The above description is typical of the expected market effects for a single product markets considered in isolation (for example the locomotive or engine markets). However, the markets considered in this EIA are more complicated because of the need to investigate impacts on each component of the affected markets (engine, vessel and transportation services on the marine side and locomotives and transportation services on the locomotive side) and the relationships between those components.

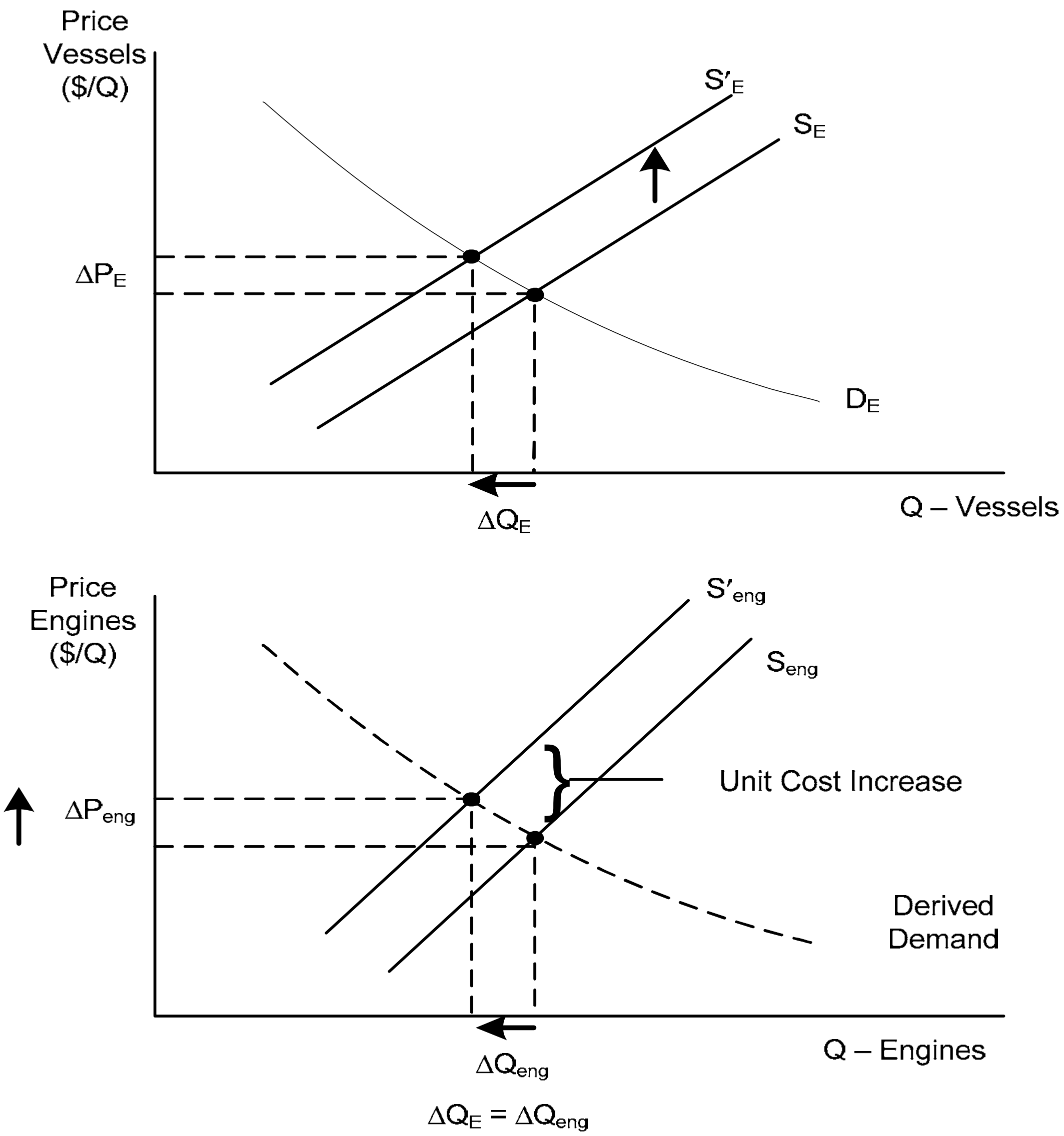
For example, with regard to the commercial vessel markets, the new emission control program is expected to affect vessel producers in two ways. First, these producers are affected by higher input costs (increases in the price of marine diesel engines) associated with the rule. Second, the standards will also impose additional production costs on vessel producers associated with vessel changes necessary to accommodate compliant engines. Similarly, the rail and marine transportation services markets will be affected by increases in the price of engines and equipment (locomotives and marine vessels) as well as direct increases in operating costs.

[J] An accessible detailed discussion of these concepts can be found in Chapters 5-7 of Nicholson's (1998) intermediate microeconomics textbook.

In the marine market case, the demand for engines is directly linked to the production of vessels that uses those engines.[K] For this reason, it is reasonable to assume that the input-output relationship between the marine diesel engines and vessels is strictly fixed and that the demand for engines varies directly with the demand for vessels. A demand curve specified in terms of its downstream consumption is referred to as a derived demand curve. Figure 7-6 illustrates how a derived demand curve is identified.

[K] In the marine vessel market, one or two engines are used per vessel, depending on its intrinsic design, and this configuration is insensitive to small changes in the engine used.

Figure 7-6 Derived-Demand Curve for Engines



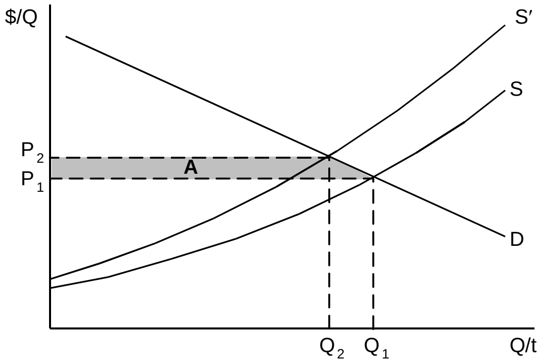
Consider an event in the marine equipment market (vessel market) that causes the price of equipment to increase by ΔP (such as an increase in the price of engines). This increase in the price of equipment will cause the supply curve in the equipment market to shift up, leading to a decreased quantity (ΔQ_E). The change in equipment production leads to a decrease in the demand for engines (ΔQ_{Eng}). The new point ($Q_E - \Delta Q_E$, P – ΔP) traces out the derived demand curve. Note that the supply and demand curves in the marine equipment markets are needed to identify the derived demand in the engine market. All of the market supply and demand curves and the elasticity parameters are described in Appendix 7F.

7.2.3.3 Estimation of Social Costs

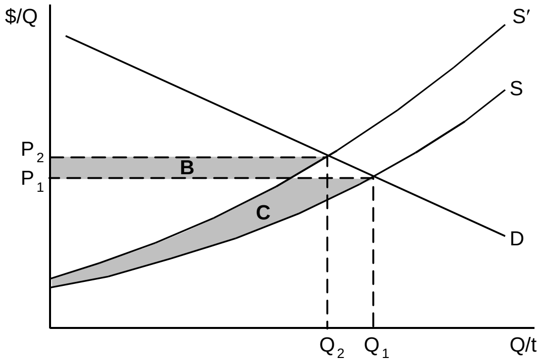
The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net “surplus” changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred to as the “social cost” of a regulation. It is important to emphasize that this measure does not include the benefits that occur outside of the market, that is, the value of the reduced levels of air pollution with the regulation. Including this benefit will reduce the net cost of the regulation and even make it positive.

The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 7-7).

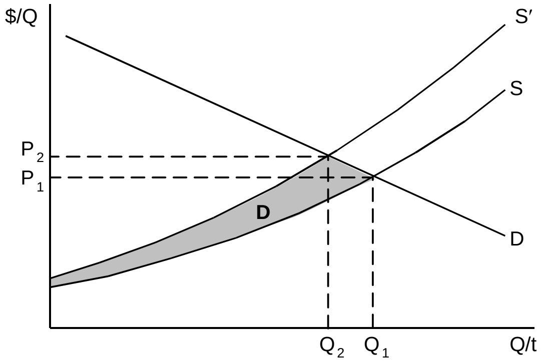
Figure 7-7. Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as “consumer surplus.” Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as “producer surplus.” Producer surplus is measured as the area above the supply curve below the price of the product. These areas can be thought of as consumers’ net benefits of consumption and producers’ net benefits of production, respectively.

In Figure 7-7, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_l with quantity Q_l. The increased cost of production with the regulation will cause the market supply curve to shift upward to S′. The new equilibrium price of the product is P_2. With a higher price for the product there is less consumer welfare, all else being unchanged. In Figure 7-7(a), area A represents the dollar value of the annual net loss in consumers' welfare associated with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed due to the price increase, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, $Q_l – Q_2$.

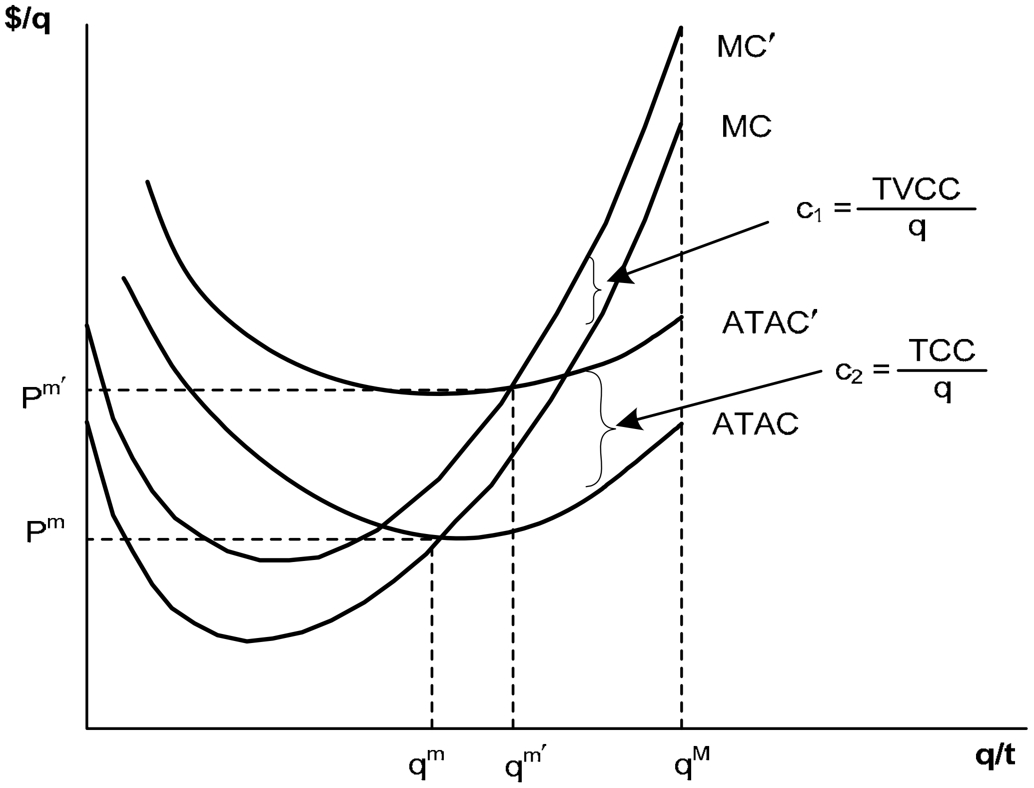
In addition to the changes in consumers' welfare, there are also changes in producers' welfare with the regulatory action. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure 7-7(b), area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producers' welfare is represented by area B – C.

The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, –(A) + (B–C). Figure 7-7(c) shows the net (negative) change in economic welfare associated with the regulation as area D.

7.2.3.4 Fixed and Variable Costs in a Competitive Market

The estimated engineering compliance costs, consisting of fixed costs (R&D capital/tooling, certification costs), variable costs, and operational costs provide an initial measure of total annual compliance costs without accounting for behavioral responses. The starting point for assessing the social costs and market impacts of a regulatory action is to incorporate the regulatory compliance costs into the production decision of the firm.

Figure 7-8 Modeling Fixed Regulatory Costs



In general, shifting the supply curve by the total cost per unit implies that both capital and operating costs vary with output levels. At least in the case of capital, this raises some questions. In the long run, all inputs (and their costs) can be expected to vary with output. But a short(er)-run analysis typically holds some capital factors fixed. For instance, to the extent that a market supply function is tied to existing facilities, there is an element of fixed capital (or one-time R&D). As indicated above, the current market supply function might reflect these fixed factors with an upward slope. As shown in Figure 7-8, the marginal cost (MC) curve will only be affected, or shift upwards, by the per-unit variable compliance costs (c_1=TVCC/q), while the average total cost (ATAC) curve will shift up by the per-unit total compliance costs (c_2=TCC/q). Thus, the variable costs will directly affect the production decision (optimal output rate), and the fixed costs will affect the closure decision by establishing a new higher reservation price for the firm (i.e., p_m'). In other words, the fixed costs are important in determining whether the firm will stay in this line of business (i.e., produce anything at all), and the variable costs determine the level (quantity) of production.

Depending on the industry type, fixed costs associated with complying with a new regulation are generally treated differently in an analysis of market impacts. In a competitive market, the industry supply curve is generally based on the market's marginal cost curve; fixed costs do not influence production decisions at the margin. Therefore, the market analysis for a competitive market is based on variable costs only.

Implicit in this approach is the assumption that manufacturers do not recover their production fixed costs by passing all or part of them to consumers through new price increases. Yet, production fixed costs must be recovered; otherwise, manufacturers would go out of business. Manufacturers in any industry are likely to have ongoing product development programs the costs of which are included in the current market price structure. It is expected that the resources for those programs would be re-oriented toward compliance with the regulatory program until those costs are recovered for each manufacturer. If this is the case, then the rule would have the effect of shifting product development resources to regulatory compliance from other market-based investment decisions. Thus, fixed costs are a cost to society because they displace other product development activities that may improve the quality or performance of engines and equipment. In this EIA, fixed costs are accounted for in the year in which they occur and are attributed to the respective locomotive, marine engine, and vessel manufacturers. These manufacturers are expected to see losses of producer surplus as early as 2007.

7.3 EIM Data Inputs and Model Solution

The EIM is a computer model comprised of a series of spreadsheet modules that simulate the supply and demand characteristics of the markets under consideration. The model equations, presented in Appendix 7E, are based on the economic relationships described in Section 7.2. The EIM analysis consists of four basic steps:

- Define the initial market equilibrium conditions of the markets under consideration (equilibrium prices and quantities and behavioral parameters; these yield equilibrium supply and demand curves).
- Introduce a policy "shock" into the model based on estimated compliance costs that shift the supply functions.
- Use a solution algorithm to estimate a new, with-regulation equilibrium price and quantity for all markets.
- Estimate the change in producer and consumer surplus in all markets included in the model.

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium reflects the new market prices where total market supply equals market demand.

This section describes the markets and data used to construct the EIM: initial equilibrium market conditions (equilibrium prices and quantities), compliance cost inputs, and model elasticity parameters. Also included is a brief discussion of the solution algorithm used to estimate with-regulation market conditions.

7.3.1 Market Equilibrium Conditions

The starting point for the economic impact analysis is initial market equilibrium conditions (prices and quantities) that exist prior to the implementation of the new standards. At pre-control market equilibrium conditions, consumers are willing to purchase the same amount of a product that producers are willing to produce at that market price.

7.3.1.1 Locomotive Initial Equilibrium Quantities

For equilibrium baseline sales for the locomotive markets, the EIM uses the same locomotive sales quantities that are used in the locomotive engineering cost analysis presented in Chapter 5. These sales were derived using the inputs for our locomotive emissions inventory analysis. In that analysis, we projected future locomotive populations and the number of locomotives remanufactured for given years. An estimated sales figure can be derived from those projected populations by comparing the given year's population to the prior year's population. The difference, after backing out the number of older locomotives that are projected to be removed from services, can be considered the new sales for the given year. Locomotive sales for all years of the analysis are contained in Table 7-7. Note that, to be consistent with the engineering costs analysis, passenger locomotives sales are included with the switcher locomotive sales.

Table 7-7 Locomotive Sales (2007 through 2040)

Year	Line Haul Sales	Switcher/Passenger Sales
2007	646	92
2008	666	92
2009	693	92
2010	729	92
2011	751	92
2012	767	92
2013	765	92
2014	780	93
2015	816	93
2016	854	94
2017	877	94
2018	894	94
2019	917	94
2020	948	94
2021	979	94
2022	1,007	95
2023	1,034	160
2024	1,048	183
2025	1,078	201
2026	1,096	212
2027	1,119	227
2028	1,136	239
2029	1,150	247
2030	1,158	263
2031	1,173	281

Year	Line Haul Sales	Switcher/Passenger Sales
2032	1,190	292
2033	1,209	296
2034	1,223	305
2035	1,231	302
2036	1,197	294
2037	1,172	287
2038	1,144	278
2039	1,112	269
2040	1,078	263

7.3.1.2 Locomotive Initial Equilibrium Prices

The baseline equilibrium price used for new line-haul locomotives used in the EIM is $2 million (2005$). The baseline equilibrium price for the switcher/passenger category is $1.3 million (2005$). These prices are based on conversations with the locomotive manufacturers. These prices are used for all years of the analysis. The analysis assumes a constant (real) price of goods and services over time and so equilibrium prices for future years are the same as the initial year equilibrium prices. This is reasonable because, in the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time (see Appendix 7G for a discussion of the constant price assumption).

7.3.1.3 Marine Engine and Vessel Initial Equilibrium Quantities

Propulsion Engine Quantities. For baseline equilibrium sales for the marine propulsion engine markets, the EIM uses the same marine engine sales quantities that are used in the marine engineering cost analysis presented in Chapter 5. These are based on the Power Systems Research OELink database, for 2002. These sales figures are reproduced in Table 7-8.

Table 7-8. Marine Diesel Engine Sales (2002)

Marine Diesel Engine Categories (by hp)	Annual Sales Auxiliary	Annual Sales Commercial Propulsion	Annual Sales Recreational Propulsion	Total
< 50 hp[a]	9,332	67	3,924	13,323
50-200 hp	4,019	2,665	6,294	12,978
200-400 hp	1,773	1,398	2,663	5,834
400-800 hp	956	1,634	4,220	6,810
C1 800-2,000 hp	142	472	598	1,212
C1 >2,000 hp	13	196	177	386
C2 800-2,000 hp	56	6	0	62

C2 >2,000 hp	86	125	0	211
Total	16,377	6,563	17,876	40,816

[a] The cost analysis does not differentiate between auxiliary, commercial propulsion, and recreational propulsion engines <50 hp; these engines were allocated to the engine categories based on PSR OELink sales splits for 2002.

Vessel Quantities. Baseline equilibrium vessel sales for the commercial vessel markets were derived by apportioning the commercial propulsion engine sales in Table 7-8 to vessel types based on the characteristics of the current vessel populations. This yields the number of propulsion engines by application. We then assumed the average number of propulsion engines per vessel and applied that value to the number of engines by application (one or two) to obtain the number of vessels by application.[14]

For the recreational vessel market, baseline equilibrium vessels sales were estimated by assuming one engine per vessel for engines up to 200 hp, and 2 engines per vessel for larger vessels. There are no Category 2 recreational vessels because our program does not allow Category 2 engines to be categorized as recreational. Consequently, any recreational vessels with Category 2 engines would be included in the commercial vessel categories. This approach is not expected to affect the results of the analysis because the number of vessels that use Category 2 marine diesel engines is small (less than 200 in 2002) and it is unlikely that recreational vessels that use engines of this size would number more than a few, if any.

The estimated vessel sales for 2002 are reproduced in Table 7-9.

Table 7-9. Marine Vessel Sales (2002)

Hp Bin	Fishing	Tow/Tug / Push	Ferries	Supply/ Crew	Cargo	Other Commerc'l	Recreatn'l	Total
0-50	65	0	1	0	0	1	3,924	3,991
50–200	2,293	247	40	41	13	31	6,294	8,959
200–400	602	65	10	11	3	8	1,332	2,031
400–800	702	76	12	13	4	10	2,110	2,927
C1 800–2,000	202	22	4	4	1	3	299	535
C1 >2,000	85	9	1	2	0	1	89	187
C2 800–2,000	0	1	0	2	0	0	0	3
C2 >2,000	10	29	3	16	4	1	0	63
Total	3,958	449	71	88	25	55	14,047	18,695

Auxiliary Engine Quantities. In general, every marine vessel has at least one auxiliary engine (and often two, in the case of commercial vessels) to provide power in case of emergency and/or to power various electric equipment that the operator may want to use without running the main propulsion engine (for example, galley equipment on a recreational vessel or various crew support equipment on a commercial vessel). The 16,377 auxiliary engines set out in Table 7-8, are those specifically produced and identified as marine auxiliary engines. This is fewer that the minimum number that would be required to provide two auxiliary engines for each commercial vessels and one for each fishing and recreational vessel. This discrepancy is explained by the fact that not all auxiliary engines used onboard marine vessels are marine-specific; instead, some may be non-installed nonroad engines, which are not required to be certified as marine diesel engines in our marine diesel engine emission control program.

The existence of separate marine auxiliary engines creates a complication when estimating the economic impacts of the new standards, since increases in auxiliary engine prices will have a separate impact on vessel markets. To estimated the combined effects of the indirect impacts of propulsion and auxiliary engine prices increases and the direct impacts of vessel compliance costs, it is necessary to allocate auxiliary as well as propulsion engines to vessels.

Because there are no variable costs associated with auxiliary engine below 800 hp, it is not necessary to allocate those engines to vessels.[L] The only auxiliary engines that must be allocated to vessels are those larger than 800 hp (those that will need to comply with the Tier 4 standards). These auxiliary engines are distributed as follows, for the purpose of this anlaysis:

- All auxiliary engines from 800 to 2,000 hp are allocated to vessels with C1 propulsion engines above 2,000 hp (except tows) and supply and crew vessels with C2 propulsion engines above 2,000 hp

- All auxiliary engines above 2,000 hp are allocated to vessels with C2 propulsion engines above 2,000 hp (except supply and crew vessels and those in the “other” category).

The results of this allocation scheme are set out in Table 7-10. Note that this approach modifies the auxiliary engine sales from the Power Systems Research OELink database, for 2002 set out in Table 7-8, although the total number of auxiliary engines from 600 to 2,000 hp (198 engines) and above 2,000 hp (99 engines) are the same.

Table 7-10 Adjusted Auxiliary Engine Sales (2002)

Vessel Type	Number of Vessels	Auxiliary Engine Per Vessel	Total Auxiliary Engines
Auxiliary engines 600-2,000 hp			**198**
C1 >2000 hp Fishing	85	1.9	159
C1 >2000 hp Ferries	1	1.9	2
C1 >2000 hp Supply/Crew	2	1.9	4

[L] There are no variable costs associated with marine auxiliary engines <800 hp because there are no variable costs associated with the Tier 3 standard and these engines are not subject to Tier 4 standards. Since there are no direct compliance costs, it is not necessary to allocate these auxiliary engines to vessels. There are fixed costs associated with the Tier 3 standards, however, and these costs are appropriately included in the total social welfare impacts of the program. These costs are incurred in 2007 through 2011.

C1 >2000 hp Other	1	1.9	2
C2 >2000 hp Supply/Crew	16	1.9	30
C2 > 2000 hp Other	1	1.9	2
Auxiliary Engines >2000 hp			**99**
C2 >2000 hp Fishing	10	2.2	22
C2 >2000 hp Tow/Tug	29	2.2	62
C2 >2000 hp Ferries	3	2.2	6
C2 >2000 Cargo	4	2.2	9

By allocating all of the auxiliary engines above 800 hp to the vessels that will be affected by this program, this analysis over-estimates the vessel impacts of the program. In fact, not all of the very large auxiliary engines are actually used on the commercial vessels that are subject to this program; some will be installed on vessels with Category 3 marine diesel engines. However, it is appropriate to consider these costs in the economic impact analysis for this program.

Projected Sales for Future Years. To project marine engine sales for future years, the EIM uses the same technique as is used in the cost analysis, which consists of applying a 1.009 growth factor to the 2002 sales, for commercial marine diesel engines, and by applying the NONROAD model growth rate to the 2002, for recreational marine engines. Note that for the purpose of this analysis, small engine projections are estimated using only the commercial growth factor of 1.009.

To project marine vessel sales for future years, the same technique was used as for the baseline equilibrium vessel sales described above.

7.3.1.4 Marine Engine and Vessel Initial Equilibrium Prices

Propulsion Engine Prices. The baseline equilibrium engine prices for C1 commercial propulsion engines used in the EIM were obtained from an internet search of engine prices.[15] The baseline equilibrium prices for C2 propulsion engines were estimated by multiplying the C1 commercial propulsion engine prices by 1.5. This reflects the larger cylinder displacement of these engines and the fact that they are built for longer hours of use. The baseline equilibrium prices for recreational propulsion engines were estimated by multiplying the C1 commercial propulsion engine prices by 1.25. This reflects the fact that while recreational engines are often similar to commercial engines they are designed for higher power and use at higher engine load. Recreational engines also often have esthetic features (e.g., chrome fixtures) that set them apart from their recreational counterparts. There are no prices for Category 2 recreational vessels; all engines with per cylinder displacement above 7 liters are considered to be commercial regardless of the application in which they are used. The baseline equilibrium prices for marine diesel propulsion engines are set out in Table 7-11.

Table 7-11. Per Unit Marine Diesel Propulsion Engine Prices (2005$)

Marine Diesel Engine Categories (by hp)	Commercial Propulsion	Recreational
< 50 hp	$7,000	$8,750
50-200 hp	$16,000	$20,000
200-400 hp	$21,000	$26,250
400-800 hp	$50,000	$62,500
C1 800-2,000 hp	$155,000	$193,750
C1 > 2,000 hp	$300,000	$375,000
C2 800-2,000 hp	$230,000	NA
C2 > 2,000 hp	$450,000	NA

Auxiliary Engine Prices. With the exception of auxiliary engine above 2,000 hp, the estimated baseline equilibrium prices for auxiliary engines are the same as similar propulsion engines. Engine manufacturers indicated that for engines in this size range, the propulsion and auxiliary engines are typically very similar packages. For the larger engines, those above 2,000 hp, engine manufacturers informed us that the price of an auxiliary engine is typically slightly less than for propulsion, with the price of an auxiliary engine at about 85 percent of the price for a propulsion engine. While they are the same base engine, they have a different package of accessories.

As described above, auxiliary engines are allocated among commercial vessels based on power and not based on engine category. Therefore, it is necessary to adjust the auxiliary engine baseline equilibrium prices for auxiliary engines to reflect a weighted average price for Category 1 and Category 2 auxiliary engines. The weights used in the calculation reflect the estimated share of engines for each hp category in the baseline population. It is not necessary to construct a weighted price for engines above 2,000 hp; all of these engines are assumed to be Category 2 engines, and their price is $385,000 (85 percent of the price of a propulsion engine, $450,000).

Average auxiliary engine price (800-2,000 hp) = 0.84×$155,000 + 0.16×$230,000 = $167,000

Table 7-12 Per Unit Marine Auxiliary Diesel Engine Prices

Auxiliary Engine Market in EIM	Propulsion Engine Baseline Price	Auxiliary Engine Baseline Quantity	Share	Auxiliary Engine Baseline Price
800-2,000 hp		198 engines	100%	$167,000
C1 800 to 2000 hp	$155,000	166 engines	(166/198) = 84%	
C2 800 to 2000 hp	$230,000	32 engines	(32/198) =16%	
>2,000 hp	$385,000	99 engines	100%	$385,000

Vessel Prices. The estimated baseline equilibrium price for marine vessels used in the EIM were estimated based on the engine prices, by applying an assumed ratio of the price of a vessel to the price of the propulsion engines onboard. Table 7-13 sets out the ratios used to estimate the vessel prices, and Table 7-14 sets out the vessel prices used in the EIA.

Table 7-13. Ratio of Vessel Price to Marine Diesel Engine Price

Hp Bin	Fishing	Tow/Tug/ Push Boat	Ferries	Supply/ Crew	Cargo	Other Commercial	Recreational
0-50	5		6			5	6
50-200	5	6	6	6	6	5	6
200-400	3.5	4	4	8	4	3.5	4
400-800	3.5	4.5	4.5	9	4.5	3.5	4
C1 800-2,000	3.5	5	5	10	10	3.5	4
C1 >2,000	3.5	5	5	10	10	3.5	4
C2 800-2,000	3.5	5	5	10	10	3.5	4
C2 >2,000	3.5	5	5	10	10	3.5	4

Table 7-14. Per Unit Marine Vessel Prices (2005$)

Hp Bin	Fishing	Tow/Tug/ Push Boat	Ferries	Supply/ Crew	Cargo	Other Commercial	Recreational
0-50	$35,000		$42,000			$35,000	$52,500
50-200	$80,000	$96,000	$96,000	$96,000	$96,000	$80,000	$120,000
200-400	$147,000	$168,000	$168,000	$336,000	$168,000	$147,000	$210,000
400-800	$350,000	$450,000	$450,000	$900,000	$450,000	$350,000	$500,000
C1 800-2,000	$1,085,000	$1,550,000	$1,550,000	$3,100,000	$3,100,000	$1,085,000	$1,550,000
C1 >2,000	$2,100,000	$3,000,000	$3,000,000	$6,000,000	$6,000,000	$2,100,000	$3,000,000
C2 800-2,000	$1,610,000	$2,300,000	$2,300,000	$2,300,000	$4,600,000	$1,610,000	NA
C2 >2,000	$3,150,000	$4,500,000	$4,500,000	$4,500,000	$9,000,000	$3,150,000	NA

With respect to future prices, this analysis assumes a constant (real) price of goods and services over time and the equilibrium prices for future years are the same as the baseline equilibrium prices. This is reasonable because, in the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time (see Appendix 7G for a discussion of the constant price assumption).

7.3.1.5 Baseline Quantities and Equilibrium Prices for Transportation Markets

The nature of the locomotive and marine transportation services markets makes it difficult to identify the baseline equilibrium prices and quantities for this analysis. Instead of trying to estimate these values, the EIM uses an alternative approach based on total revenues for each sector. In this approach, annual revenue data is used as a proxy for production data. This data is normalized such that the baseline price is set equal to $1/unit and the baseline quantity is then equal to the annual revenue. This allows estimation of the relative price change and the relative quantity change due to the new standards, although it does not allow estimation of the absolute price and absolute quantity change.

Baseline data for the EIM's railroad and marine service revenues are reported in Table 7-15.[16] Revenue data for the rail transportation services market for 2005 comes from the Association of American Railroads Freight Railroad Statistics, Condensed Income Statement.[17] The data for revenue for freight and passenger services are used.[M].

Revenue data for the marine transportation services sector come from the U.S. Census reports revenues for the marine service sector for 2002.[N] Revenue data for 2002 was obtained for the marine transportation sectors that are likely to be affected by this rule.[18] These are:

- 4831: Deep sea, coastal, and Great Lakes transportation – 2 sectors were used:
    - 483113: Coast and Great Lakes Freight
    - 483114: Coast and Great Lakes Passenger
- 4832: Inland water transportation
- 4872: Scenic & sightseeing transportation, water
- 4883: Support activity for water transportation – the revenue for this sector was adjusted to reflect only the portion of support activity that would be associated with sectors 4831 and 4832 (water transportation excluding deep sea), by applying the ratio of affected water transportation revenue to total revenues for Sectors 4831 and 4832.

Table 7-15. Railroad and Marine Service Markets Baseline Revenue Data ($billions)

Transportation Service Market	2002	Annual Growth Rate	2005
Railroad Services Market Freight revenue: $44,457M Passenger revenue: $65M	NR	0.9%	$44.5
Marine Services Market	$13.8	0.9%	$15.4

The 2002 marine revenue data was adjusted for 2005 using the GDP deflator index. To estimate revenue for 2005, we applied growth rates used for engine sales. Revenue for all future years of the analysis (2007 to 2040) were calculated by applying annual growth rates to the 2005 data set as follows:

$$\text{Revenue}_{200X} = \text{Revenue}_{2005} \times (1+0.009)^{(200X-2005)}$$

[M] It should be noted that this revenue estimate includes a return on investment, which reflects the prices for transportation services experienced by rail transportation service consumers.

[N] The revenue estimate for the marine transportation sector used in this analysis is based on an earlier estimate of revenues from the affected marine transportation sectors. Our final draft estimate is slightly lower. The difference is less than 5 percent and will not change the conclusions of this economic impact analysis .

This data suggests that the rail transportation sector is much larger than the marine transportation sector. However, the difference in the amount of tons of goods moved is smaller. According to AAR, the rail transportation sector moved about 1,844.2 million tons of freight in 2004.[19] The marine sector accounted for about 1,047.1 million tons in that year.[20] This suggests that while some of the difference in revenue is due to differences in the amount of freight transported, part of the difference is due to differences in the characteristics of each sector. For example, railroads are responsible for maintaining the rail system; they pass some of those costs to their customers through higher prices. The marine system, in contrast, is maintained by public authorities (U.S. Army Corps of Engineers, state and local governments), and so those costs would not be reflected in the prices of marine transportation services. Similarly, while rail yards are maintained by railroads, ports are owned and operated by various public and private authorities. Finally, marine transportation is somewhat more fuel efficient than rail, with one tug or towboat able to transport more goods than one locomotive.

7.3.2 Compliance Costs

The social costs of the new standards are estimated by shocking the initial market equilibrium conditions by the amount of the compliance costs.

The engineering costs we used in the EIA are an earlier version of the estimated compliance costs developed for this rule. The net present value of the engineering costs used in the EIA is estimated to be approximately $9.17 billion (NPV over the period of analysis at 3 percent discount rate), which is about $240 million less than the net present value of the final estimated engineering costs of about $9.41 billion. This difference is the sum of various cost adjustments, the largest of which are an increase of about $222 million in operating costs for the marine markets and $42 million in the operating costs for the rail markets (NPV over the period of analysis at 3 percent discount rate). These changes are not expected to have a substantial impact on the market level results because the differences are relatively small on an annual basis. For example, operating costs for C2 marine markets increase by about 15 percent in 2030 (from $107 million to $123 million). The previous estimate of $107 million was associated with an increase of approximately 1.1 in the price of marine transportation services and a decrease of approximately 0.5 percent in the quantity of marine transportation services provided. A small increase in operating costs is not likely to change those results by very much. The market-level impacts on the other downstream markets are also likely to be very small and not economically significant. Finally, the difference in compliance costs will not affect the distribution of social costs, which is a function of the price elasticity of supply and demand.

Table 7-16 summarizes how the compliance costs are applied to each component of the EIM to simulate the effect of the emission control program. On the supply side, only variable costs are used to shift the supply curve in the relevant markets (see Section 7.2.3.4). Fixed costs are added to the social costs of the program as a separate line item. In this model, the demand curves are not shifted because the program does not regulate consumers or impose direct compliance costs on them and therefore would not cause a change in demand (see Section 7.2.3.1).

Table 7-16. Summary of Types of Compliance Costs

Market	Category	Supply Shift			Demand Shift
		Entity	Direct Costs	Indirect Costs	
Rail	Locomotive	Loco Mfr	Variable costs	N/A	No demand shift; see 7.2.3.1
	Transportation Services	Railroad	Reductant, fuel, remanufacture kit	Higher locomotive prices	
Marine	<800 hp	Engine Mfr	Variable costs = 0	N/A	
		Vessel	Variable costs = 0	Higher engine prices	
	>800 hp	Engine mfr	Variable costs	N/A	
		Vessel	Variable costs	Higher engine prices	
	Transportation Services	Vessel Owner	Reductant, fuel, remanufacture kit	Higher engine and vessel prices	

The compliance costs used in the EIM are based on the estimated engineering compliance costs described in Chapter 5.

For marine diesel engine variable costs, we used the piece costs shown in Table 5-29. Note that, as explained in Chapter 5, there are no variable costs associated with the Tier 3 standards for the marine program. We do not expect the prices of engine components used to meet the Tier 3 standards will be different from those used to meet the Tier 2 standards. For marine diesel engine fixed costs in the EIA, we simply divided the annual engine fixed costs presented in Tables 5-3, 5-10, 5-14, and 5-17 by the projected sales for the given year. When doing this, it is important to stay within category (e.g., marine C1 annual costs should be divided by marine C1 annual sales). This makes the fixed costs per engine appear rather large in the EIA since those costs are being spread over a relatively small number of engines during the years in which the cost are incurred.

On the vessel side, there are no compliance costs, fixed or variable, associated with the Tier 3 standards since the engine-based controls are not expected to affect the footprint of the engine. For the Tier 4 compliance costs we used the vessel hardware costs shown in Tables 5-38 and 5-39. Importantly, the costs associated with engines (discussed above) are incurred for every engine (auxiliary and propulsion), while the vessel hardware costs show in Tables 5-38 and 5-39 are incurred for every vessel. To arrive at a per vessel cost for the EIA, we added the aftertreatment housing costs shown in Table 5-38 to the reductant system costs shown in Table 5-39, keeping in mind the near-term (years one and two) and long-term (years three and later) costs presented in Table 5-39. The vessel fixed costs are the annual redesign costs shown in Table 5-36 divided by the projected number of vessel sales during the given years as shown in Tables 5-41 and 5-42. Tier 4 marine vessel compliance costs (costs for vessel redesign) are incurred over an 18-year period that is derived from the number of vessel types that will have to be modified (see Chapter 5 for an explanation of how these costs are calculated).

For locomotives, we used essentially the same methodology. The variable costs are taken from Tables 5-29, 5-38, and 5-39. Annual fixed costs are simply divided by the sales for the given year in which the costs are incurred. In the EIA, since the locomotive and its engine are considered to be one in the same, there was no need to differentiate between purely engine costs and equipment costs.

For all markets, fixed costs are allocated to the year in which they occur. For this analysis, fixed costs are spread over five years in advance of the applicable standards with the exception of tooling and certification costs, which are allocated to the year before the standards are effective. Variable costs begin to be incurred only when the programs go into effect. For simplicity of presentation, we have estimated marine engine and equipment costs as though all marine Tier 3 standards begin in 2011 and all marine Tier 4 standards begin in 2016. For locomotives and marine diesel engines, this means a staggered set of fixed costs, as described in Table 7-17, with the compliance costs for the different tiers overlapping on some years.

The annual compliance costs used to shock the model are the sum of the relevant compliance costs for a given year. The staggered nature of the emission control programs means that for the initial years of the program the annual estimated variable costs may include fixed costs for complying with both Tier 3 and Tier 4 requirements. Similarly, fixed costs may combine Tier 3 and Tier 4 compliance costs, depending on which programs are phased-in for that year. As a result, the compliance costs described below may be due to Tier 3 costs, Tier 4 costs, or both. This approach is appropriate because the EIA is intended to look at the social costs of the regulatory program as a whole and not by tier of standards.

Table 7-17 Examples of Locomotive and Marine Engine Staggered Compliance Costs Schedule

	Line haul Locomotive		Commercial Marine 3.5-7 l/cyl, 1,400-2,000 hp	
	Tier 3	Tier 4	Marine T3	Marine T4
2007	Fixed		Fixed	
2008	Fixed		Fixed	
2009	Fixed		Fixed	
2010	Fixed	Fixed	Fixed	
2011	Fixed (inc. cert.)	Fixed	Fixed (inc. cert.)	Fixed
2012	Effective Date; Variable	Fixed	Effective Date; Variable	Fixed
2013	Variable	Fixed	Variable	Fixed
2014	Variable	Fixed (inc. cert.)	Variable	Fixed
2015	Variable	Effective Date; Variable	Variable	Fixed (inc. cert.)
2016	Variable	Variable	Variable	Effective Date; Variable
2017	Variable	Variable	Variable	Variable

7.3.2.1 Locomotive Compliance Costs

The estimated per unit compliance costs for new locomotives used in the EIM are summarized in Table 7-18. These costs are dominated by fixed costs in the early years of the program. Variable costs do not occur until 2015, when the aftertreatment standards begin. This reflects the fact that there are no variable costs associated with the Tier 3 standards. Fixed costs reflect both the Tier 3 and Tier 4 costs.

Table 7-18 Estimated Per Unit Compliance Costs – New Locomotives (2005$)

	Line Haul Locomotive			Switcher, Passenger Locomotive		
Year	Variable	Fixed	Total	Variable	Fixed	Total
2007	$0	$9,294	$9,294	$0	$27,904	$27,904
2008	$0	$9,007	$9,007	$0	$27,904	$27,904
2009	$0	$8,657	$8,657	$0	$27,904	$27,904
2010	$0	$45,894	$45,894	$0	$53,856	$53,856
2011	$0	$46,534	$46,534	$0	$75,341	$75,341
2012	$0	$35,791	$35,791	$0	$78,642	$78,642
2013	$0	$35,878	$35,878	$0	$78,175	$78,175
2014	$0	$39,278	$39,278	$0	$104,927	$104,927
2015	$84,274	$0	$84,274	$14,175	$51,847	$66,023
2016	$84,274	$0	$84,274	$14,175	$78,520	$92,695
2017	$65,343	$0	$65,343	$23,682	$0	$23,682
2018	$65,343	$0	$65,343	$23,682	$0	$23,682
2019+	$65,343	$0	$65,343	$21,139	$0	$21,139

7.3.2.2 Marine Diesel Engine Compliance Costs

The estimated per unit compliance costs for new marine diesel engines used in the EIM are summarized in Table 7-19 (C2 propulsion engines), Table 7-20 (C1 propulsion engines), Table 7-21 (recreational engines), and Table 7-22 (small engines). In the early years, 2007 through 2011, there are fixed costs associated with the Tier 3 standards. Beginning in 2012, there are no compliance costs associated with the Tier 3 standards because there are no variable costs for those standards. The Tier 4 standards apply only to engines above 800 hp. As a result, there are fixed costs attributed to those engines through 2015, after which time the only costs are variable costs associated with the aftertreatment devices.[O]

In our engineering cost analysis, propulsion and auxiliary engines have the same compliance costs. To facilitate and accommodate computer programming constraints, however, it was necessary to run the model using a simplified approach for the auxiliary engine markets, in which the compliance costs are a weighted average of all compliance costs

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[O] For simplicity, the marine engine and equipment standards are estimated as though all marine Tier 4 standards begin in 2016 even though some Tier 4 standards for very large engines begin in 2014. While this affects the individual year results for early years, the differences disappear by 2016 at which time all marine diesel engines above 800 hp are subject to aftertreatment standards.

for engines above 800 hp. This weighted average is applied to auxiliary engines 800-2,000 hp and those above 2,000 hp. This means that the supply shift is the same for both of the auxiliary engine markets even though the actual program impacts are different for them. The weighted average compliance costs was obtained by dividing the total compliance costs for engines above 800 hp by the number of engines above 800 hp. This results in estimated compliance costs of $37,097 in 2016, the first year of the Tier 4 program. If separate compliance costs had been used for the two auxiliary engine markets, they would have been $19,073 for 800-2,000 hp, and $67,255 for above 2,000 in that year. The aggregated compliance costs approach results in a higher price impact for auxiliary engines 800-2,000 hp and a smaller price impact for auxiliary engines above 2,000 hp. These price impacts would be passed along to the vessel markets as indirect costs of the program, with associated impacts. We performed a sensitivity analysis that examines the impact of this approach; the results of that analysis, reported in Appendix H, suggest that the results of the analysis would not change very much if this simplifying approach were not used.

Table 7-19 Estimated Per Unit Compliance Costs - C2 Commercial Propulsion Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$14,571	$14,441	$14,312	$14,184	$99,121	$74,808
	Total	$14,571	$14,441	$14,312	$14,184	$99,121	$74,808
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$14,571	$14,441	$14,312	$14,184	$99,121	$74,808
	Total	$14,571	$14,441	$14,312	$14,184	$99,121	$74,808

Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
800-2,000	Variable	$0	$0	$0	$39,428	$39,428	$30,142
	Fixed	$74,140	$73,479	$102,680	$0	$0	$0
	Total	$74,140	$73,479	$102,680	$39,428	$39,428	$30,142
>2,000	Variable	$0	$0	$0	$73,360	$73,360	$56,081
	Fixed	$74,140	$73,479	$102,680	$0	$0	$0
	Total	$74,140	$73,479	$102,680	$73,360	$73,360	$56,081

Table 7-20 Estimated Per Unit Compliance Costs – C1 Commercial Propulsion Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$836	$829	$822	$814	$1,549	$0
	Total	$836	$829	$822	$814	$1,549	$0
200-400	Variable	$0	$0	$0	$0	$0	$0

	Fixed	$836	$829	$822	$814	$1,549	$0
	Total	$836	$829	$822	$814	$1,549	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$836	$829	$822	$814	$1,549	$0
	Total	$836	$829	$822	$814	$1,549	$0
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$2,710	$2,686	$2,662	$2,638	$29,554	$25,963
	Total	$2,710	$2,686	$2,662	$2,638	$29,554	$25,963
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$2,710	$2,686	$2,662	$2,638	$29,554	$25,963
	Total	$2,710	$2,686	$2,662	$2,638	$29,554	$25,963
Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$0	$0	$15,196	$15,196	$11,618
	Fixed	$25,732	$25,502	$34,190	$0	$0	$0
	Total	$25,732	$25,502	$34,190	$15,196	$15,196	$11,618
>2,000	Variable	$0	$0	$0	$26,401	$26,401	$20,183
	Fixed	$25,732	$25,502	$34,190	$0	$0	$0
	Total	$25,732	$25,502	$34,190	$26,401	$26,401	$20,183

Table 7-21 Estimated Per Unit Compliance Costs – Recreational Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
0-50	Variable	$0	$0	$0	$0	$0	$0
	Fixed	286	279	272	266	486	$0
	Total	286	279	272	266	486	$0
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$286	$279	$272	$266	$486	$0
	Total	$286	$279	$272	$266	$486	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$286	$279	$272	$266	$486	$0
	Total	$286	$279	$272	$266	$486	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$286	$279	$272	$266	$486	$0
	Total	$286	$279	$272	$266	$486	$0
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$286	$279	$272	$266	$486	$0
	Total	$286	$279	$272	$266	$486	$0

>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$286	$279	$272	$266	$486	$0
	Total	$286	$279	$272	$266	$486	$0
Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
0-50 hp	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0

Table 7-22 Estimated Per Unit Compliance Costs – Small Marine Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
0-50	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$178	$176	$175	$173	$365	$0
	Total	$178	$176	$175	$173	$365	$0
Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
0-50	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0

7.3.2.3 Marine Vessel Compliance Costs

There are no direct vessel compliance costs associated with the Tier 3 standards. This is because the Tier 3 engine footprint (engine size and weight) is not expected to be modified from the Tier 2 configuration and therefore no vessel redesign or modification will be required to accommodate Tier 3 engines. There are also no indirect vessel compliance costs associated with the Tier 3 standards as there are no variable costs to the engine manufacturers for the Tier 3 standards (the only Tier 3 compliance costs are fixed costs).

Direct vessel compliance costs are associated with the Tier 4 aftertreatment standards. These compliance costs are not differentiated by vessel application; they are the same for all commercial vessels that use Tier 4 propulsion engines. The magnitude of the compliance costs varies depending on if they are Category 1 or Category 2 engines. The vessel compliance costs begin to occur in 2015, with the fixed costs, which continue through 2028, depending on the size of the engine.[P] Variable costs begin to occur in 2016 and continue for all years of the analysis.

Table 7-23 Per Unit Compliance Costs – Vessels with C2 Propulsion Engines (2005$; vessel equipped with 2 propulsion engines)

Hp Category	Cost Type	2015	2016	2017	2018	2019	2020	2021	2022
50-200	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$6,586	$6,586	$5,503	$5,503	$5,503	$5,503	$5,503
	Fixed	$50,000	$26,935	$13,347	$13,228	$13,110	$12,993	$12,877	$12,762
	Total	$50,000	$33,520	$19,933	$18,731	$18,613	$18,496	$18,380	$18,265
>2,000	Variable	$0	$12,358	$12,358	$10,385	$10,385	$10,385	$10,385	$10,385
	Fixed	$50,000	$26,935	$13,347	$13,228	$13,110	$12,993	$12,877	$12,762
	Total	$50,000	$39,293	$25,705	$23,614	$23,496	$23,379	$23,263	$23,148
Hp Category	Cost Type	2023	2024	2025	2026	2027	2028	2029	2030+
50-200	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0

[P] For simplicity, the marine engine and equipment standards are estimated as though all marine Tier 4 standards begin in 2016 even though some Tier 4 standards for very large engines begin in 2014. While this affects the individual year results for early years, the differences disappear by 2016 at which time all marine diesel engines above 800 hp are subject to aftertreatment standards.

800-2,000	Variable	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503
	Fixed	$12,649	$12,536	$12,424	$12,313	$12,203	$12,095	$0	$0
	Total	$18,152	$18,039	$17,927	$17,816	$17,706	$17,597	$5,503	$5,503
>2,000	Variable	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385
	Fixed	$12,649	$12,536	$12,424	$12,313	$12,203	$12,095	$0	$0
	Total	$23,034	$22,921	$22,809	$22,699	$22,589	$22,480	$10,385	$10,385

Table 7-24 C1 Per Unit Compliance Costs – Vessels with C1 Propulsion Engines (2005$; vessel equipped with 2 propulsion engines)

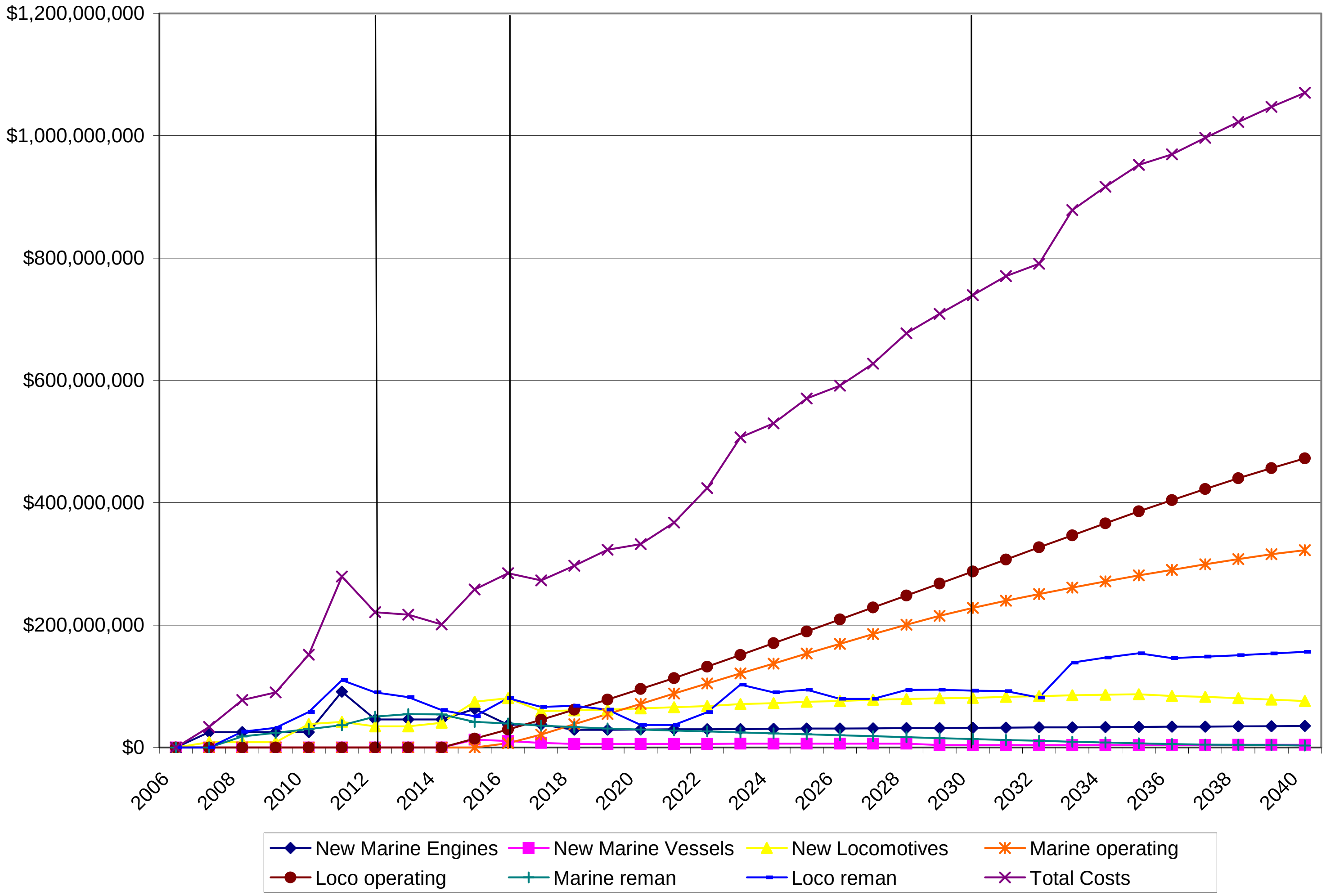
Hp Category	Cost Type	2015	2016	2017	2018	2019	2020	2021	2022
50-200	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$6,586	$6,586	$5,503	$5,503	$5,503	$5,503	$5,503
	Fixed	$25,000	$11,885	$6,544	$3,891	$3,857	$3,822	$3,788	$3,754
	Total	$25,000	$18,470	$13,129	$9,394	$9,359	$9,325	$9,291	$9,257
>2,000	Variable	$0	$12,358	$12,358	$10,385	$10,385	$10,385	$10,385	$10,385
	Fixed	$25,000	$11,885	$6,544	$3,891	$3,857	$3,822	$3,788	$3,754
	Total	$25,000	$24,243	$18,902	$14,277	$14,242	$14,208	$14,173	$14,140
Hp Category	Cost Type	2023	2024	2025	2026	2027	2028	2029	2030+
50-200	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503	$5,503
	Fixed	$3,721	$3,688	$3,655	$3,622	$3,590	$3,558	$0	$0
	Total	$9,224	$9,191	$9,158	$9,125	$9,093	$9,061	$5,503	$5,503
>2,000	Variable	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385	$10,385
	Fixed	$3,721	$3,688	$3,655	$3,622	$3,590	$3,558	$0	$0
	Total	$14,106	$14,073	$14,040	$14,007	$13,975	$13,943	$10,385	$10,385

In addition to the direct vessel costs for Tier 4, there are also indirect costs associated with the Tier 4 engine standards, for both propulsion and auxiliary engines. This means it is necessary to shift the supply curve by the increase in price for both the propulsion and auxiliary engines on the vessel that occurs as a result of the engine compliance costs. As explained in Section 7.3.1.3, we assume each affected vessel has 2 propulsion engines and an average of about 2 marine auxiliary engines. We allocated all auxiliary engines above 800 hp to the vessels in this analysis even though some of these large auxiliary engines will be installed on vessels with Category 3 propulsion engines that are not part of this rule. As a result, while this rule considers the costs of all auxiliary engines, in fact not all of those costs will be borne by stakeholders included in this rulemaking, and the share of the costs for marine stakeholders is likely to be less.

7.3.2.4 Operating Costs

There are two types of operating costs that are affected by the control program: the additional costs associated with operating vessels and locomotives equipped with the emission control technologies that would be required by the program, and the additional costs associated with the locomotive and marine remanufacture programs. Each of these is described below. In the EIA, each of these is applied to the transportation markets because they are costs that accrue to the operators of the regulated locomotives or marine vessels.

Figure 7-9. Estimated Total Compliance Costs by Type, 2007-2040



Operating Costs. As explained in Chapter 5, we anticipate three sources of increased costs associated with operating vessels and locomotives equipped with the emission control technologies that would be required by the program: reductant use, DPF maintenance, and fuel consumption. The costs associated with reductant use would affect only those locomotives or vessels equipped with a SCR engine. Maintenance costs associated with the DPF (for periodic cleaning of accumulated ash resulting from unburned material that accumulates in the DPF) would occur only in those locomotives or vessels equipped with a DPF engine. Thus, those costs are limited to Tier 4 engines. Fuel consumption impacts are limited to Tier 4 locomotives and marine engines and, to a much smaller extent, for remanufactured Tier 0 locomotives. As explained in section 5.4.3, and discussed in sections 4.2 and 5.2.2, Tier 3 engine are not expected to have a fuel impact. As illustrated in Figure 7-9, the estimated operating costs are substantial when compared with the compliance costs associated with engine and equipment modifications.

The EIM applies the operational costs solely to the rail and marine transportation services markets.[Q] This is accomplished by shifting the transportation service sector supply curves by the amount of the operating costs for that sector for that year. This was done by dividing the total operating costs for each service sector by the revenue for that year, where revenue represents the quantity produced in each service sector (due to normalized costs; see 7.3.1.4). The operating costs per unit are then interpreted as costs per dollar of output.

Applying these costs to the locomotive transportation market, in the rail sector case, is appropriate because all locomotives built after the Tier 4 standards go into effect will incur these operating costs. On the marine side, the EIM uses a simplifying assumption that applies all marine operating costs to the marine transportation services market and large fishing sector (marine vessels that use engines >800 hp) and does not allocate any of these costs to the recreational or small fishing sectors. This approach is appropriate because the operating costs (fuel and reductant consumption) are estimated based on fuel consumption and most of the fuel consumed in the marine sector is by vessels in the marine transportation services sector. While many of the new non-recreational vessels built each year are small fishing vessels, the use of fishing vessels is highly seasonal and hence they would not be expected to use as much fuel as the other commercial vessels (tug/tow/pushboats, ferries, cargo vessels, and supply/crew boats) that are used extensively all year around. Nevertheless, there are expected to be some Tier 4 engines used in the fishing sector and depending on the extent to which this occurs the estimated impacts on the marine transportation service market may be somewhat over-estimated.

[Q] As explained above, the marine transportation market also includes large fishing vessels.

Table 7-25 Marine and Locomotive Operating Costs 2007-2040 (2005$)

	Marine C1>800Hp	Marine C2	Loco-Line haul	Loco-Switcher & Passenger	Total
2006	$0	$0	$0	$0	$0
2007	$0	$0	$0	$0	$0
2008	$0	$0	$0	$0	$0
2009	$0	$0	$0	$0	$0
2010	$0	$0	$0	$0	$0
2011	$0	$0	$0	$0	$0
2012	$0	$0	$0	$0	$0
2013	$0	$0	$0	$0	$0
2014	$0	$0 [a]	$0	$0	$0
2015	$0	$0 [a]	$14,185,772	$123,493	$14,309,265
2016	$3,870,419	$3,293,306	$29,032,183	$247,890	$36,443,798
2017	$10,570,247	$10,712,210	$44,269,726	$1,271,179	$66,823,362
2018	$19,868,812	$18,184,444	$59,812,022	$1,964,807	$99,830,086
2019	$29,127,012	$25,658,771	$75,760,270	$2,663,752	$133,209,805
2020	$38,333,253	$33,115,211	$92,240,224	$3,368,108	$167,056,796
2021	$47,486,990	$40,569,128	$109,253,188	$4,077,974	$201,387,280
2022	$56,568,548	$48,025,843	$126,758,381	$5,181,423	$236,534,195
2023	$65,562,936	$55,465,093	$144,738,379	$6,548,724	$272,315,132
2024	$74,437,500	$62,887,279	$162,686,068	$7,632,591	$307,643,438
2025	$83,177,448	$70,294,373	$180,873,965	$8,803,576	$343,149,362
2026	$91,751,957	$77,704,458	$199,101,463	$10,036,091	$378,593,969
2027	$100,108,209	$85,118,907	$217,434,039	$11,329,994	$413,991,150
2028	$108,149,904	$92,522,545	$235,760,387	$12,693,251	$449,126,087
2029	$115,215,712	$99,897,508	$254,018,232	$14,115,012	$483,246,465
2030	$120,856,169	$107,239,121	$272,104,628	$15,635,903	$515,835,820
2031	$125,288,414	$114,551,129	$290,126,726	$17,261,263	$547,227,532
2032	$128,976,388	$121,812,042	$308,100,481	$18,968,553	$577,857,463
2033	$132,310,485	$129,005,921	$326,059,441	$20,726,018	$608,101,865
2034	$135,336,373	$136,127,702	$343,920,178	$22,559,417	$637,943,670
2035	$138,043,673	$143,164,690	$361,555,878	$24,413,611	$667,177,853
2036	$140,480,248	$150,075,487	$378,402,501	$26,218,259	$695,176,495
2037	$142,716,999	$156,843,456	$394,649,956	$27,989,727	$722,200,137
2038	$144,794,853	$163,398,588	$410,285,116	$29,715,888	$748,194,446
2039	$146,732,986	$169,244,421	$425,260,693	$31,393,184	$772,631,284
2040	$148,542,610	$173,848,627	$439,565,559	$33,044,952	$795,001,748

[a] For simplicity, the marine engine and equipment standards are estimated as though all marine Tier 4 standards begin in 2016 even though some Tier 4 standards for very large engines begin in 2014. While this affects the individual year results for early years, the differences disappear by 2016 at which time all marine diesel engines above 800 hp are subject to aftertreatment standards.

Remanufacturing Costs. The rail and marine transportation markets are also subject to costs associated with the remanufacture standards for their existing engines. Locomotive owners are currently required to use certified remanufacture kits when they rebuild engines originally built in 1973 through 2001 (called Tier 0 locomotives). This program will extend the remanufacturing requirements both to tighten the standards associated with Tier 0 locomotives and to add requirements for engines built after 2001 (Tier 1 and Tier 2 locomotives). The new emission control program also includes a program for existing marine diesel engines, according to which owners would be required to use a certified remanufacture system when they rebuild their engines if such a system is available. This program applies only to marine diesel engines above 800 hp that were manufactured from 1973 through Tier 2.

In the EIM, these remanufacture costs are treated as operating costs and applied to the rail and marine transportation sectors along with the reductant and fuel costs. This approach was chosen because these costs are periodic and recurring throughout the life of the engine, at five to seven year intervals. An important consequence of this modeling approach is that it assumes that the owner bears the full cost of the remanufacturing kit and that the kit manufacturer does not bear any of the cost. This simplifying assumption is appropriate because the mandatory nature of the requirement results in a price elasticity of demand that is close to zero (inelastic): if a railroad owns a Tier 0, Tier 1, or Tier 2 locomotive it very simply must purchase a kit or it can no longer operate the locomotive. Similarly, if a vessel operator owns an engine for which a kit is available, he or she is required use that kit when rebuilding the engine. The cost of a remanufacture kit would have to be very high before the option of pulling a locomotive or marine vessel out of service or purchasing a new engine one would become attractive.

As explained in Chapter 5, the remanufacturing costs for Tier 0 and Tier 1 locomotives represent the difference between the cost of current remanufacture kits and those that will be required pursuant to the standards. For these kits, first time rebuilds will require additional fuel system components that are not required in subsequent rebuilds and therefore the cost for the initial rebuild is more than for future rebuilds. For Tier 2 locomotives, there are additional costs for the initial rebuild, but not for future rebuilds. There are no additional costs associated with Tier 3 rebuilds because these locomotives have all of the essential components when they are built new. Finally, there are rebuild costs for Tier 4 locomotives associated with the aftertreatment devices. Tier 4 locomotives begin to be rebuilt in 2023. For marine diesel engines, there is currently only one tier of requirements.

Tables 7-26 and 7-27 set out the estimated compliance costs for the locomotive remanufacture program for line haul and switcher/passenger locomotives. These tables reflect both the year in which the costs apply and the cost per unit. Also included are the fuel costs associated with the use of Tier 0 remanufacture systems.

Table 7-26 Line Haul Locomotive Remanufacture Costs – Per Unit and Total Fuel Costs

Year	Tier 0	Tier 1	Tier 2	Tier 4	Tier 0 Fuel Costs ($MM)
2006					
2007					
2008	$33,800				$2,302,054
2009		$33,800			$2,282,427
2010	$33,800				$5,890,678
2011	$33,800	$33,800			$12,215,776
2012	$33,800	$33,800			$14,835,459
2013	$33,800		$11,749		$18,419,581
2014	$33,800		$11,749		$19,255,764
2015	$33,800		$11,749		$19,332,128
2016	$33,800		$11,749		$21,973,242
2017	$22,300		$11,749		$24,371,317
2018	$22,300		$11,749		$23,707,717
2019	$22,300	$22,300	$11,749		$22,654,591
2020	$22,300				$20,943,018
2021		$22,300			$19,132,536
2022	$22,300	$22,300			$17,393,944
2023	$22,300			$67,534	$15,727,242
2024	$22,300			$67,534	$14,132,429
2025	$22,300			$67,534	$12,621,451
2026				$67,534	$11,145,346
2027				$67,534	$9,760,539
2028	$22,300			$67,534	$8,459,667
2029	$22,300			$67,534	$7,255,299
2030	$22,300			$67,534	$6,169,878
2031		$22,300		$67,534	$5,180,024
2032				$67,534	$4,280,592
2033				$67,534	$3,461,230
2034		$22,300		$67,534	$2,640,362
2035		$22,300		$67,534	$1,944,832
2036				$67,534	$1,380,746
2037				$67,534	$906,104
2038				$67,534	$524,244
2039				$67,534	$246,131
2040				$67,534	$74,669

Table 7-27 Switcher and Passenger Remanufacture Costs – Per Unit and Total Fuel Costs

Year	Tier 0 & 1	Tier 2	Tier 4	Tier 0 Fuel Costs ($MM)
2006				
2007				
2008	$33,800			$75,733
2009	$33,800			$265,064
2010	$33,800			$452,881
2011	$33,800			$627,823
2012	$33,800			$695,983
2013	$33,800			$752,782
2014	$33,800			$798,979
2015	$33,800			$740,665
2016	$33,800	$8,728		$761,113
2017	$22,300	$8,728		$773,987
2018	$22,300	$8,728		$685,380
2019	$22,300	$8,728		$602,074
2020	$22,300	$8,728		$518,011
2021	$22,300	$8,728		$433,190
2022	$22,300			$347,613
2023	$22,300			$274,152
2024	$22,300			$212,051
2025	$22,300		$21,937	$153,737
2026	$22,300		$21,937	$106,026
2027	$22,300		$21,937	$68,159
2028	$22,300		$21,937	$39,381
2029	$22,300		$21,937	$18,933
2030	$22,300		$21,937	$6,059
2031	$22,300		$21,937	
2032	$22,300		$21,937	
2033	$22,300		$21,937	
2034	$22,300		$21,937	
2035	$22,300		$21,937	
2036	$22,300		$21,937	
2037	$22,300		$21,937	
2038	$22,300		$21,937	
2039	$22,300		$21,937	
2040	$22,300		$21,937	

Table 7-28 sets out the estimated compliance costs for the marine remanufacture program locomotives. This table reflect both the year in which the costs apply and the cost per unit. Also included are the fuel costs associated with the program.

Table 7-28 Marine Remanufacture Costs - Per Unit and Total al Fuel Costs

Year	Category 1	Category 2	Fuel Costs ($MM)
2006			
2007			
2008		$33,800	$5,644,717
2009		$33,800	$11,391,038
2010		$33,800	$17,240,336
2011		$33,800	$23,193,999
2012	$16,900	$33,800	$29,253,431
2013	$16,900	$33,800	$34,882,042
2014	$16,900	$33,800	$39,067,796
2015	$16,900		$37,438,192
2016	$16,900		$35,809,907
2017	$11,150		$34,190,014
2018	$11,150		$32,575,327
2019			$30,962,228
2020			$29,357,401
2021			$27,761,110
2022			$26,173,086
2023			$24,593,388
2024			$23,021,891
2025			$21,458,087
2026			$19,900,133
2027			$18,351,377
2028			$16,812,402
2029			$15,290,458
2030			$13,788,862
2031			$12,311,399
2032			$10,857,990
2033			$9,442,047
2034			$8,067,051
2035			$6,749,194
2036			$5,591,972
2037			$4,774,057
2038			$4,211,541
2039			$3,723,095
2040			$3,286,099

7.3.3 Behavioral Parameters

A key feature of the EIM is that it is a behavioral model in that it incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As explained in 7.2.1, a behavioral model allows us to examine how manufacturers of affected goods make out adjustments in response to higher production costs due to complying with the control program, and how consumers can be expected to change their consumption choices in response to higher prices resulting from producers passing along at least some part of the compliance costs. The result of these market interactions determines both the new market equilibrium price and quantity and the portion of the compliance costs that will be born by producers and consumers. Thus, the price elasticity of supply and demand are important parameters in behavioral models such as the EIM because they represent how much production and consumption can be expected to change as a result of a price increase.

Tables 7-29 and 7-30 provide a summary of the price elasticities of demand and supply that are used as behavioral parameters in the EIM. Elasticities from peer-reviewed literature were used when possible. If no peer-reviewed elasticities were available, they were estimated for this economic impact analysis using generally accepted empirical methods (see Appendix 7F for a discussion of how they were estimated). Several demand elasticities (those for locomotives, commercial marine vessels, and marine diesel engines) are derived internally by the EIM based on upstream markets (transportation markets). This is another behavioral feature of the model that allows linkages between the different components of the model.

It should be noted that the price elasticities of supply and demand used in the model reflect intermediate-run behavioral changes. This is appropriate because the EIM is intended to estimate economic impacts as markets adjust to increases in compliance costs. In the long run, supply and demand behavioral responses are expected to be more elastic since more changes can be made to production processes.

7.3.3.1 Price Elasticity of Demand for Affected Markets

The EIM requires that values be specified for the price elasticity of demand for the rail and marine transportation markets, the recreational vessel market, and the small fishing vessel markets.

The price elasticity for rail transportation services demand is from the peer-reviewed literature and is inelastic (-0.5).[21] This means that the quantity demanded is not expected to be sensitive to price changes (a one percent increase in price is expected to result in a 0.5 percent decrease in the quantity demand). This is reasonable because, as described above, users of these transportation services typically chose them because they are the best solution for transporting their goods. The decision to choose rail transportation services is a function of many things and the price may not be the most important factor.

We were unable to find a price elasticity of demand for the marine transportation sector in the peer-reviewed literature. Due to difficulties in gathering the appropriate data to estimate this elasticity, we instead use the same demand elasticity as the rail transportation services market. This is reasonable because a significant portion of the marine transportation sector is engaged in the same basic activity, although with different geographic constraints. Like locomotives, vessels used in marine transportation services (e.g., cargo vessels, ferries, supply/crew boats, and tow/tug/pushboats) are engaged in transporting materials and people, and the demand for those services is likely to be inelastic because the users have few, if any, alternatives.

For the recreational vessel market, we used the same price elasticity of demand used in the Economic Impact Analysis for our recently proposed SI marine standards.[22] This price elasticity of demand is elastic (-2.0), meaning that consumers are expected to be sensitive to a change in price (a one percent increase in price is expected to result in a two percent decrease in the quantity demanded). This is reasonable because recreational marine vessels are a discretionary purchase and consumers have other recreational alternatives.

We were also unable to find a price elasticity of demand for the fishing sector in the peer-reviewed literature. In this analysis, we used a dual approach. Specifically, for large fishing vessels (those with propulsion engines above 800 hp) we applied the same price elasticity of demand as for commercial vessels (as explained elsewhere, this demand elasticity is derived as part of the model from the transportation services sector); for small fishing vessels (those with propulsion engines below 800 hp) we applied the same price elasticity of demand as for recreational vessels. This approach is appropriate because smaller fishing vessels are not used in the same way as larger fishing vessels. Smaller vessels are often personally operated by the owner of the vessel; if there is a crew it would be very small. These vessels are used for specific applications in which catches are small and speed is essential (e.g., lobster fishing). This market can very competitive: the catch is bought the same day as the vessel returns to port, with the earliest arrivers getting the best price. Because of these dynamics, the price elasticity of fishing vessels is likely to be fairly elastic (fish vessel purchasers likely to be sensitive to an increase in the price of a vessel). Vessels with larger engines, on the other hand, are likely to be part of a large commercial operation, making them less sensitive to vessel price changes. These vessels have larger crews and will go out for several weeks or months. The catch will be larger and may even be processed onboard the vessel or frozen for shore processing. For these vessels, we used the same approach as commercial vessels, in which the price elasticity of demand for the equipment is derived from the transportation market. This approach implies that the price elasticity of demand for final consumers of fish is inelastic (-0.5); this is reasonable given a previously-estimated price elasticity of demand for the agricultural products market estimated for our 2004 Nonroad Rule (-0.2).[23]

7.3.3.2 Supply Elasticities

Unlike the price elasticity of demand, the EIM requires that values be specified for the price elasticity of supply for each of the markets included in the model; none of these values are derived by the model.

The price elasticity of supply for the rail transportation service market is the same as that estimated for the economic impact analysis for our Clean Air Nonroad Diesel (Nonroad Tier 4) rule. [24] This price elasticity of supply is elastic (1.6), meaning that producers are expected to be sensitive to a change in price (a 1 percent price increase is expected to result in a 1.6 increase in the quantity produced). This reflects extra production capacity in the market and the relative ease with which railroads can alter their production of transportation services (e.g., by making trains longer or shorter).

A published estimate of the price elasticity of supply for the locomotive market was unavailable. Therefore we estimated a value for this parameter using the calibration method approach (this approach and the results are described in Appendix 7F). At 2.7, the price elasticity of supply for the locomotive market is elastic, meaning that producers are expected to be sensitive to changes in price (a one percent increase in price is expected to result in a 2.7

percent increase in quantity produced). This reflects extra production capacity in the market. The EIM uses the same value for the price elasticity of supply for all locomotive markets: line haul, switcher, and passenger. Using this estimated price elasticity of supply for the switcher market is somewhat speculative since that market is currently not very developed (most existing switchers are modified line haul locomotives; see above).

For the marine transportation services market, we used the same approach as for the economic impact analysis for our Clean Air Nonroad Diesel rule and applied the price elasticity of supply used for the train transportation market.[25] This approach is reasonable because the marine transportation service sector provides a similar service, although with different geographic constraints.

A published estimate of the price elasticity of supply for the commercial vessel market was unavailable. Therefore we estimated a value for this parameter using the calibration method approach (this approach and the results are described in Appendix 7F). At 2.3, the price elasticity of supply for the locomotive market is elastic, meaning that producers are expected to be sensitive to changes in price (a one percent increase in price is expected to result in a 2.3 percent increase in quantity produced). This reflects excess production capacity in the market.

For the recreational vessel market, we used the same price elasticity of supply used in the Economic Impact Analysis for our recently proposed SI marine standards.[26] This price elasticity of supply is elastic (2.3), meaning that producers are expected to be sensitive to a change in price (a one percent increase in price is expected to result in a 2.3 percent increase in the quantity produced). This is reasonable since recreational vessels are typically serially produced with no specific buyer in mind, using fiberglass molds. Therefore a price increase may have to be higher before affecting production. Also, to some extent, these vessels are more “portable” and can be inventoried, although model year and design may limit the ability of manufacturers to inventory large numbers of these vessels.

For the fishing vessel market, we used the same approach described above for the supply elasticity of demand, applying the price elasticity of supply for commercial vessels to fishing vessels with engines greater than 800 hp, and the price elasticity of supply for recreational vessels for fishing vessels with engines less than 800 hp. This is reasonable because smaller vessels have many of the same characteristics as recreational vessels (high-speed planning vessels with fiberglass hulls), while larger vessels are produced more like commercial vessels (uniquely built for an identified purchaser based on designs that are typically modified by the purchaser before production). Because of these similarities, the processes used to produced small and large fishing vessels would be more like recreational and commercial vessels, respectively. It should be noted that, in this case, the price elasticities of supply for both markets are the same (2.3).

For the marine diesel engine market, we used the same price elasticity of supply for diesel engines that was estimated for the economic impact analysis for our 2004 Clean Air Nonroad Diesel rule.[27] This approach is reasonable because the vast majority of marine diesel engines affected by this rule are derived from land-based marine or highway diesel engines. This price elasticity of supply is elastic (3.8), meaning that producers are expected to be sensitive to a change in price (a one percent increase in price is expected to result in a 3.8 increase in supply). This is due to excess production capacity.

Because the price elasticity of demand and supply are key inputs to the model, a sensitivity analysis was performed to consider the uncertainty that is associated with the estimation process. The sensitivity analysis includes alternative values for the price elasticity of supply for locomotives and marine vessels estimated using an alternative method in lieu of the calibration method. The results are presented in Appendix 7H.

Table 7-29. Price Elasticities of Demand Used in EIM

Market	Estimate	Source	Method	Data Source
Rail				
Rail Transp. Svcs	-0.5	Literature estimate	Literature review	Boyer, K.D. 1997. *Principles of Transportation Economics*. Reading, MA: Addison-Wesley.
Locomotives	Derived			
Marine				
Marine Transp. Svcs	-0.5	Literature estimate	Assumed value	Uses the same elasticity as the locomotive transportation services sector.
Vessels—Commercial Fishing (>800 hp)	Derived			
Vessels—Fishing (<800 hp)	-2.0	Econometric estimate	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	-2.0	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2007. *Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment Draft Regulatory Impact Analysis*. EPA420-D-07-004. Available at <http://www.epa.gov/otaq/regs/nonroad/marinesi-equipld/420d07004.pdf>.
Engines	Derived			

Table 7-30. Supply Elasticities Used in EIM

Market	Estimate	Source	Method	Input Data Source
Rail				

Rail Transp. Svcs	1.6	Literature estimate	Method based on cost elasticities reported in Ivaldi and McCollough (2001)	Ivaldi, M. and McCullough, G. 2001. "Density and Integration Effects on Class I U.S. Freight Railroads." Journal of Regulatory Economics 19:161-162.
Locomotives	2.7	EPA estimate	Calibration method	U.S. Bureau of the Census. 2004a. “Railroad Rolling Stock Manufacturing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004” Annual Survey of Manufacturers. M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Marine				
Marine Transp. Svcs	1.6	Assumed value; uses the same elasticity as the rail transportation services sector		
Vessels—Commercial and large fishing	2.3	EPA estimate	Calibration method	U.S. Bureau of the Census. 2004b. “Ship Building and Repairing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004” Annual Survey of Manufacturers. M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Vessels—Recreational and small fishing	2.3	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2007. *Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment Draft Regulatory Impact Analysis*. EPA420-D-07-004. Available at <http://www.epa.gov/otaq/regs/nonroad/marinesi-equipld/420d07004.pdf>.
Engines	3.8	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.

7.3.4 Economic Impact Model Structure

7.3.3.1 Estimating With-Regulation Equilibrium Conditions

The economic impact analysis is conducted using the data and the supply and demand framework described above. The price and quantity data, along with the supply and demand elasticities, are used to identify the market supply and demand curves. The regulatory costs are then used to shift the supply curve, and the resulting new equilibrium determines the market impacts and distribution of social impacts.

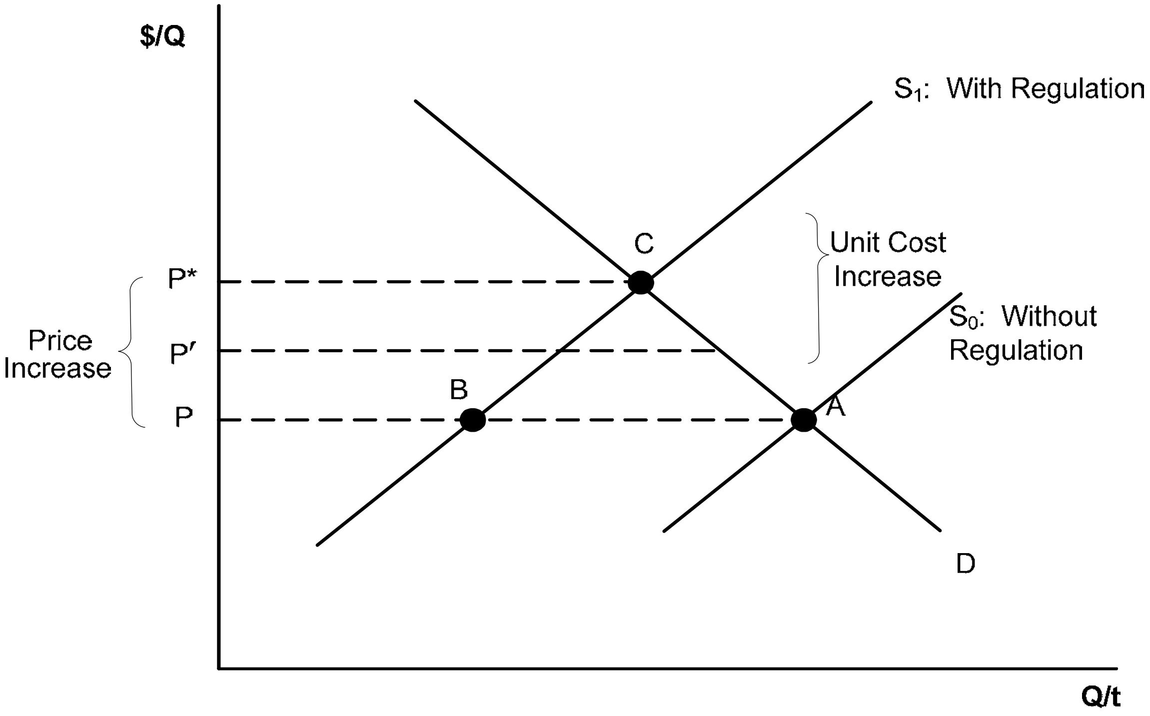
Figure 7-10 illustrates the economic impact modeling structure. Point A represents the initial baseline equilibrium price and quantity (corresponding to the prices and quantities presented in section 7.3.1). The slope of the supply and demand curves passing through the baseline point A are determined by applying the appropriate supply and demand elasticities presented in section 7.3.2.6. These slopes reflect the responsiveness of producers and consumers when prices change and determine how much of the compliance costs producers are able to pass along to consumers in the with-regulation equilibrium.

The compliance costs associated with the regulation (presented in Section 7.3.2) enter the model expressed as per-unit costs and result in an upward shift in the supply curve from S_0 to S_1 in Figure 7-10. Note that the demand curve does not shift because consumer preferences and income are not affected by the regulation (see Section 7.3.2.1)

With the addition of the compliance costs, if prices were not allowed to adjust demanders would still want to consume the quantity at point A, but suppliers would only be willing to supply the quantity at point B (i.e., demand exceeds supply at the baseline price, P). The model then solves for the new equilibrium price (P*) where the quantity demanded equals the quantity supplied. The movement from the baseline equilibrium point A to with-regulation equilibrium point C determines the market impacts (changes in price and quantity) as well as the distribution of social costs. Appendix 7E describes the set of supply and demand equations included in the model. Given the number of equations included in the model, the solution algorithm described below is used to identify the new with-regulation set of equilibrium prices and quantities (Point C).

The analysis illustrated in Figure 7-10 is repeated for each year included in the period of analysis. For future years, a projected time series of prices and quantities are developed and used as the baseline (point A) from which market changes are evaluated. The engineering cost analysis provides quantities for future years using historical annual growth rates. In contrast, there is much more uncertainty surrounding future prices for these markets. As a result, we use a constant 2005 observed prices for the relevant markets during the period of analysis.

Figure 7-10 Estimating With-Regulation Equilibrium



7.3.3.2 Solution Algorithm

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium is the result of a series of iterations in which price is adjusted and producers and consumers respond, until a set of stable market prices arises where total market supply equals market demand. Market price adjustment takes place based on a price-revision rule, described below, that adjusts price upward (downward) by a given percentage in response to excess demand (excess supply).

The EIM model uses a similar type of algorithm for determining with-regulation equilibria and the process can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.

2. Recalculate the market supply in each market. Excess demand currently exists.

3. Determine the new prices via a price revision rule. We use a rule similar to the factor price revision rule described by Kimbell and Harrison.[28] P_i is the market price at iteration I, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z$$

4. Recalculate market supply with new prices,

5. Compute market demand in each market.

6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one). When the ratio is appropriately close to one, the market- clearing condition of supply equals demand is satisfied.

7.3.5 Estimating Impacts

Using the static partial equilibrium analysis, the EIM model loops through each year calculating new market equilibriums based on the projected baseline economic conditions and compliance cost estimates that shift the supply curves in the model. The model calculates price and quantity changes and uses these measures to estimate the social costs of the rule and partition the impact between producers and consumers. This approach follows the classical treatment of tax burden distribution in the public finance literature.[29]

7.4 Methods for Describing Uncertainty

Every economic impact analysis examining the market and social welfare impacts of a regulatory program is limited to some extent by limitations in model capabilities, deficiencies in the economic literatures with respect to estimated values of key variables necessary to configure the model, and data gaps. In this EIA, there are three main potential sources of uncertainty: (1) uncertainty resulting from the way the EIM is designed, particularly from the use of a partial equilibrium model; (2) uncertainty resulting from the values for key model parameters, particularly the price elasticity of supply and demand; and (3) uncertainty resulting from the values for key model inputs, particularly baseline equilibrium price and quantities. Sources of uncertainty that have a bearing on the results of the EIA for the new emission control program are listed and described in more detail in Table 7-31.

The values used for the price elasticities of supply and demand are critical parameters in the EIM. The values of these parameters have an impact on both the estimated change in price and quantity produced expected as a result of compliance with the new standards and on how the burden of the social costs will be shared among producer and consumer groups. In selecting the values to use in the EIM it is important that they reflect the behavioral responses of the industries under analysis.

The first source of values for elasticities of supply and demand is the published economic literature. These estimates are peer reviewed and generally constitute reasonable estimates for the industries in question. In this analysis, we use published elasticity from peer-reviewed literature for the rail transportation services sector, for both demand and supply.[30] We used these elasticities for the marine transportation sector as well.

When published elasticities of supply or demand are not available, it is necessary to estimate these values econometrically.

We used previously-estimated values for the price elasticity of supply for engines and recreational vessels in this analysis, (see Appendix 7F). These estimates reflect a production function approach using data at the aggregate industry level. This method was chosen because of limitations with the available data: we were not able to obtain firm-level or plant-level production data for companies that operate in the affected sectors. However, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To estimate the price elasticity of supply for the locomotive and commercial marine vessel markets, we used a calibration method. This involves specifying an economic model of supply, treating some of the parameters of the model as fixed using secondary data, and solving for unknown parameters that replicate a benchmark data set (see Appendix F). This approach introduces uncertainty in that the results are dependent on the underlying assumptions and data used to construct the economic model. In our proposal, we noted that we intended investigate alternative estimates for the price elasticity of supply for these two industries, using the production function approach and cross-sectional data model at either the firm-level or plant level from the U.S. Census. Because the results of that analysis have not yet been peer reviewed, we did not use them in our primary analysis. However, we performed a sensitivity analysis using those alternative values (see Appendix H).

Table 7-31 Primary Sources of Uncertainty in the Economic Impact Analysis

Source of Uncertainty	Description	Potential Impact
UNCERTAINTIES ASSOCIATED WITH ECONIMIC IMPACT MODEL STRUCTURE		
Partial equilibrium model –	The EIM domain is limited to the economic sectors directly affected by the emission control program; impacts on secondary markets are not accounted for. However, the impacts are not expected to be large as directly affected products and services (locomotives and marine engines and vessels) are production inputs (transportation services) and are not a large share of total production costs for final goods and services, or are final goods for household consumption	Results may understate social costs; magnitude of impact is uncertain
National level model	The EIM considers only national-level impacts; regional impacts are not modeled. This is appropriate because locomotive and marine engine and vessel markets are national markets. While there may be some regional differences these are likely to be small due to the competitive nature of the transportation industry.	Impacts uncertain
Supply side assumptions	On the supply side, industries are assumed to be mature and behave linearly within the range of analysis; no substitution between production inputs. This is appropriate because per unit compliance costs are not large enough to prompt a major change in product design or assembly.	Impacts uncertain
Demand side assumptions	On the demand side, end consumer preferences or consumption patterns are assumed to be constant and behave linearly within the range of analysis. This is appropriate because all other factors in the demand function will not be changed by the new standards.	Impacts uncertain
Constant price assumption	Prices are assumed to be constant across the period of analysis. This is a reasonable assumption since it is not possible to predict changes in these prices over time (see Appendix 7H).	Impacts uncertain
Period of analysis	Each period of analysis is assumed to be independent of previous period and producers are assumed to not engage in long-term planning. This means the impacts of multi-tier standards are not smoothed among periods. Because the new engine standards will not go into effect for several years after the program is finalized, producers may in fact take the full program into account in production plans to minimize their costs	Estimated price changes may be too high for early periods, too low for later periods; magnitude of impact is uncertain

Market shock	In the EIM, the market shocked by variable costs only; fixed costs do not disturb the market equilibrium. This is a result of the perfect competition assumption implies market supply curve is the industry average marginal cost curve. This is appropriate because producers in these industries generally plan for R&D and model changes. A sensitivity analysis performed that includes fixed costs in supply shift	Results may overstate distribution of social costs to some producers, understate market impacts; magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH PRICE ELASTICITY ESTIMATION		
	Uncertainty resulting from the functional form used in the estimation, the data used (aggregate or firm-level), the time period involved, sample size.	Impacts on distribution of social costs among stakeholders (e.g., higher supply elasticity would result in less social costs for manufacturers and more social costs for consumers) Impacts on market analysis (change in price, change in quantity produced) ; magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH DATA INPUTS		
Submarket groupings	Submarket data is assumed to be representative and capture the range of affected equipment. However, the product groupings in NAICS or SIC 4-digit categories may include other engines or equipment that may not have the same production or consumption characteristics; these groupings not behave the same way as the directly-affected industries.	Impacts on social welfare and market analyses uncertain
Baseline equilibrium prices	Estimated baseline equilibrium prices are assumed to be representative and capture the range of affected equipment, and reflect actual transaction prices. However, the actual prices paid by consumers may be different. Also, the mix of products included in price analysis may not be representative of the population.	Impacts on market analysis uncertain
Baseline equilibrium quantities	Estimated baseline equilibrium quantities and future quantities assumed to be representative; these are the same as the cost analysis	Impacts on market analysis uncertain

To explore the effects of key sources of uncertainty, we performed a sensitivity analysis in which we examine the results of using alternative values for the price elasticity of supply and demand and alternative methods to shock to the market equilibrium (fixed and variable costs). We also examined the results of using alternative values for the equipment supply elasticities (locomotives and marine vessels) estimated using an alternative methodology, and we examined the impacts of using a weighted average compliance cost for auxiliary marine engines above 800 hp. These analysis and their results are described in more detail in Appendix 7H. A summary of the results are presented in Table 7-32.

Table 7-32. Results of Sensitivity Analysis

Parameter	Year	Change in Value	Impact
Price Elasticity of Supply	2020	More elastic	Negligible impact on expected price increase and quantity decrease Higher value associated with increase in social cost burden for users of rail and marine transportation services
	2020	Less elastic	Negligible impact on expected price increase and quantity decrease Lower value associated with increase in social cost burden for suppliers of marine vessels and providers of rail and marine transportation services
Price Elasticity of Demand	2020	More elastic	Negligible impact on expected price increase and quantity decrease Higher value associated with increase in social cost burden for suppliers of marine vessels and providers of rail and marine transportation services
	2020	Less elastic	Negligible impact on expected price increase and quantity decrease Lower value associated with increase in social cost burden for users of rail and marine transportation services
Market Supply Shift	2014	Include fixed and variable costs; analysis performed for locomotive and propulsion marine >800 hp only	Price increase larger than primary case, but decrease in quantity produced remains small, less than 3.5 percent (less than 20 units) for commercial marine engines and vessels. Negligible change in locomotive markets. Distribution of social costs shifts from manufacturers to user groups.

Alternative Method of Estimating Price Elasticity of Supply – Equipment Markets	2020	Supply elasticites for locomotives and marine vessels more elastic	Differences in market impacts (price and quantity changes) and distribution of costs among stakeholders are negligible. The share of compliance costs borne by vessel manufacturers is slightly less, and the share of engine manufactures and rail transportation service providers and users increases slightly. Similarly, the share of locomotive producers is slightly less than the primary case, and the share of rail transportation service producers and consumers is slightly more.
Alternative Compliance Cost for Auxiliary Marine Engines Above 800 hp	2016, 2030	Separate compliance costs for auxiliary engines 800-2,000 hp and above 2,000 hp	Market impacts are different, with smaller price increase for auxiliary engines 800 to 2,000 hp and larger price increase for auxiliary engines above 2,000 hp. Slight reduction in the decrease in quantity produced for small engines; no change for larger engines. Slight shift in social welfare cost burden from marine engine and vessel producers to marine transportation service producers and consumers.

Appendix 7A: Impacts on Marine Engine Markets

This appendix provides the time series of impacts from 2007 through 2040 for selected auxiliary and propulsion marine engines markets.[R] Table 7A-1 through Table 7A-6 provide the time series of impacts and include the following:

- average engineering costs (variable) per engine
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in engine manufacturer surplus

All prices, costs, and surplus changes are presented in 2005 dollars, and real engine or equipment prices are assumed to be constant during the period of analysis. Net present values for 2006 were calculated using social discount rates of 3% and 7% over the 2007 and 2040 time period.

Results are presented for only those markets that are expected to incur direct variable costs under Tier 3 or Tier 4 standards. This means that results are not presented for marine engine markets less than 800 hp or for recreational propulsion engine markets. For these engine markets, the results are expected to be negligible and any change in price or quantity would be incidental to the changes in the larger engine markets. It should also be noted that all engine markets would incur fixed costs. However, as explained in 7.2.3.4, fixed costs are not included in the EIM.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[R] The engineering costs we used in the EIA are an earlier version of the estimated compliance costs developed for this rule; see Section 7.3.2 for an explanation of the difference. This difference is not expected to have an impact on the results of the market analysis or on the expected distribution of social costs among stakeholders.

Table 7A-1. Impact on Auxiliary Engine Market: 800–2000 hp (Average Price per Engine = $167,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.7	–$1.7
2008	$0	–$4	0.0%	0.0%	$1.7	–$1.7
2009	$0	–$5	0.0%	0.0%	$1.7	–$1.7
2010	$0	–$6	0.0%	0.0%	$1.7	–$1.7
2011	$0	–$7	0.0%	0.0%	$13.5	–$13.5
2012	$0	–$10	0.0%	0.0%	$10.7	–$10.7
2013	$0	–$10	0.0%	0.0%	$10.7	–$10.7
2014	$0	–$10	0.0%	0.0%	$10.7	–$10.7
2015	$0	–$8	0.0%	0.0%	$14.9	–$14.9
2016	$37,097	$34,894	20.9%	–5.0%	$8.3	–$0.5
2017	$37,096	$34,891	20.9%	–5.0%	$8.4	–$0.5
2018	$28,360	$26,653	16.0%	–3.9%	$6.5	–$0.4
2019	$28,359	$26,650	16.0%	–3.9%	$6.5	–$0.4
2020	$28,363	$26,652	16.0%	–3.9%	$6.6	–$0.4
2021	$28,360	$26,646	16.0%	–3.9%	$6.7	–$0.4
2022	$28,359	$26,643	16.0%	–3.9%	$6.7	–$0.4
2023	$28,363	$26,644	16.0%	–3.9%	$6.8	–$0.4
2024	$28,360	$26,639	15.9%	–3.9%	$6.8	–$0.4
2025	$28,361	$26,638	15.9%	–3.9%	$6.9	–$0.4
2026	$28,361	$26,635	15.9%	–3.9%	$7.0	–$0.4
2027	$28,359	$26,631	15.9%	–3.9%	$7.0	–$0.4
2028	$28,361	$26,632	15.9%	–3.9%	$7.1	–$0.4
2029	$28,360	$26,628	15.9%	–3.9%	$7.2	–$0.4
2030	$28,359	$26,626	15.9%	–3.9%	$7.2	–$0.4
2031	$28,360	$26,626	15.9%	–3.9%	$7.3	–$0.4
2032	$28,359	$26,624	15.9%	–3.9%	$7.3	–$0.4
2033	$28,359	$26,622	15.9%	–4.0%	$7.4	–$0.4
2034	$28,360	$26,622	15.9%	–4.0%	$7.5	–$0.4
2035	$28,359	$26,620	15.9%	–4.0%	$7.5	–$0.5
2036	$28,361	$26,622	15.9%	–4.0%	$7.6	–$0.5
2037	$28,359	$26,619	15.9%	–4.0%	$7.7	–$0.5
2038	$28,360	$26,619	15.9%	–4.0%	$7.8	–$0.5
2039	$28,357	$26,616	15.9%	–4.0%	$7.8	–$0.5
2040	$28,362	$26,620	15.9%	–4.0%	$7.9	–$0.5
NPV at 3%					$147.5	–$59.5
NPV at 7%					$83.4	–$43.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-2. Impact on Auxiliary Engine Market: >2000 hp (Average Price per Engine = $385,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.9	–$0.9
2008	$0	–$45	0.0%	0.0%	$0.9	–$0.9
2009	$0	–$60	0.0%	–0.1%	$0.9	–$0.9
2010	$0	–$74	0.0%	–0.1%	$0.9	–$0.9
2011	$0	–$88	0.0%	–0.1%	$6.7	–$6.8
2012	$0	–$122	0.0%	–0.1%	$5.3	–$5.4
2013	$0	–$130	0.0%	–0.1%	$5.3	–$5.4
2014	$0	–$128	0.0%	–0.1%	$5.3	–$5.4
2015	$0	–$99	0.0%	–0.1%	$7.4	–$7.5
2016	$37,097	$36,919	9.6%	–0.2%	$4.2	Loss less than $0.1
2017	$37,096	$36,895	9.6%	–0.2%	$4.2	Loss less than $0.1
2018	$28,360	$28,142	7.3%	–0.2%	$3.2	Loss less than $0.1
2019	$28,359	$28,111	7.3%	–0.2%	$3.3	Loss less than $0.1
2020	$28,363	$28,083	7.3%	–0.3%	$3.3	Loss less than $0.1
2021	$28,360	$28,049	7.3%	–0.3%	$3.3	Loss less than $0.1
2022	$28,359	$28,017	7.3%	–0.3%	$3.4	Loss less than $0.1
2023	$28,363	$27,991	7.3%	–0.4%	$3.4	Loss less than $0.1
2024	$28,360	$27,959	7.3%	–0.4%	$3.4	Loss less than $0.1
2025	$28,361	$27,932	7.3%	–0.4%	$3.5	–$0.1
2026	$28,361	$27,904	7.2%	–0.5%	$3.5	–$0.1
2027	$28,359	$27,876	7.2%	–0.5%	$3.5	–$0.1
2028	$28,361	$27,853	7.2%	–0.5%	$3.5	–$0.1
2029	$28,360	$27,829	7.2%	–0.5%	$3.6	–$0.1
2030	$28,359	$27,809	7.2%	–0.5%	$3.6	–$0.1
2031	$28,360	$27,793	7.2%	–0.6%	$3.6	–$0.1
2032	$28,359	$27,778	7.2%	–0.6%	$3.7	–$0.1
2033	$28,359	$27,764	7.2%	–0.6%	$3.7	–$0.1
2034	$28,360	$27,753	7.2%	–0.6%	$3.7	–$0.1
2035	$28,359	$27,740	7.2%	–0.6%	$3.8	–$0.1
2036	$28,361	$27,732	7.2%	–0.6%	$3.8	–$0.1
2037	$28,359	$27,719	7.2%	–0.6%	$3.8	–$0.1
2038	$28,360	$27,710	7.2%	–0.6%	$3.9	–$0.1
2039	$28,357	$27,698	7.2%	–0.7%	$3.9	–$0.1
2040	$28,362	$27,697	7.2%	–0.7%	$3.9	–$0.1
NPV at 3%					$73.8	–$27.7
NPV at 7%					$41.7	–$20.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-3. Impact on C1 Commercial Propulsion Engine Market: 800–2000 hp (Average Price per Engine = $155,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.3	–$1.3
2008	$0	–$2	0.0%	0.0%	$1.3	–$1.3
2009	$0	–$3	0.0%	0.0%	$1.3	–$1.3
2010	$0	–$4	0.0%	0.0%	$1.3	–$1.3
2011	$0	–$5	0.0%	0.0%	$15.1	–$15.1
2012	$0	–$7	0.0%	0.0%	$13.4	–$13.4
2013	$0	–$7	0.0%	0.0%	$13.4	–$13.4
2014	$0	–$7	0.0%	0.0%	$13.4	–$13.4
2015	$0	–$5	0.0%	0.0%	$18.1	–$18.1
2016	$15,196	$13,995	9.0%	–2.9%	$8.1	–$0.6
2017	$15,196	$13,993	9.0%	–2.9%	$8.2	–$0.6
2018	$11,618	$10,680	6.9%	–2.3%	$6.3	–$0.5
2019	$11,618	$10,678	6.9%	–2.3%	$6.4	–$0.5
2020	$11,618	$10,677	6.9%	–2.3%	$6.4	–$0.5
2021	$11,618	$10,675	6.9%	–2.3%	$6.5	–$0.5
2022	$11,618	$10,673	6.9%	–2.3%	$6.6	–$0.5
2023	$11,618	$10,672	6.9%	–2.3%	$6.6	–$0.5
2024	$11,618	$10,670	6.9%	–2.3%	$6.7	–$0.5
2025	$11,618	$10,669	6.9%	–2.3%	$6.7	–$0.5
2026	$11,618	$10,667	6.9%	–2.3%	$6.8	–$0.5
2027	$11,618	$10,666	6.9%	–2.3%	$6.9	–$0.6
2028	$11,618	$10,664	6.9%	–2.3%	$6.9	–$0.6
2029	$11,618	$10,663	6.9%	–2.3%	$7.0	–$0.6
2030	$11,618	$10,662	6.9%	–2.3%	$7.0	–$0.6
2031	$11,618	$10,661	6.9%	–2.3%	$7.1	–$0.6
2032	$11,618	$10,660	6.9%	–2.3%	$7.2	–$0.6
2033	$11,618	$10,660	6.9%	–2.3%	$7.2	–$0.6
2034	$11,618	$10,659	6.9%	–2.4%	$7.3	–$0.6
2035	$11,618	$10,658	6.9%	–2.4%	$7.4	–$0.6
2036	$11,618	$10,658	6.9%	–2.4%	$7.4	–$0.6
2037	$11,618	$10,657	6.9%	–2.4%	$7.5	–$0.6
2038	$11,618	$10,657	6.9%	–2.4%	$7.6	–$0.6
2039	$11,618	$10,656	6.9%	–2.4%	$7.6	–$0.6
2040	$11,618	$10,656	6.9%	–2.4%	$7.7	–$0.6
NPV at 3%					$154.1	–$70.1
NPV at 7%					$88.6	–$50.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-4. Impact on C1 Commercial Propulsion Engine Market: >2000 hp (Average Price per Engine = $300,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.6	–$0.6
2008	$0	–$4	0.0%	0.0%	$0.6	–$0.6
2009	$0	–$6	0.0%	0.0%	$0.6	–$0.6
2010	$0	–$7	0.0%	0.0%	$0.6	–$0.6
2011	$0	–$8	0.0%	0.0%	$6.3	–$6.3
2012	$0	–$11	0.0%	0.0%	$5.6	–$5.6
2013	$0	–$12	0.0%	0.0%	$5.6	–$5.6
2014	$0	–$12	0.0%	0.0%	$5.6	–$5.6
2015	$0	–$9	0.0%	0.0%	$7.5	–$7.5
2016	$26,401	$22,137	7.4%	–5.4%	$5.9	–$0.9
2017	$26,401	$22,134	7.4%	–5.4%	$5.9	–$0.9
2018	$20,183	$16,886	5.6%	–4.2%	$4.6	–$0.7
2019	$20,183	$16,884	5.6%	–4.2%	$4.6	–$0.7
2020	$20,183	$16,880	5.6%	–4.2%	$4.6	–$0.7
2021	$20,183	$16,878	5.6%	–4.2%	$4.7	–$0.8
2022	$20,183	$16,875	5.6%	–4.2%	$4.7	–$0.8
2023	$20,183	$16,872	5.6%	–4.2%	$4.8	–$0.8
2024	$20,183	$16,869	5.6%	–4.2%	$4.8	–$0.8
2025	$20,183	$16,867	5.6%	–4.2%	$4.9	–$0.8
2026	$20,183	$16,864	5.6%	–4.2%	$4.9	–$0.8
2027	$20,183	$16,862	5.6%	–4.2%	$4.9	–$0.8
2028	$20,183	$16,859	5.6%	–4.2%	$5.0	–$0.8
2029	$20,183	$16,857	5.6%	–4.2%	$5.0	–$0.8
2030	$20,183	$16,855	5.6%	–4.2%	$5.1	–$0.8
2031	$20,183	$16,854	5.6%	–4.2%	$5.1	–$0.8
2032	$20,183	$16,853	5.6%	–4.2%	$5.2	–$0.8
2033	$20,183	$16,851	5.6%	–4.2%	$5.2	–$0.8
2034	$20,183	$16,850	5.6%	–4.2%	$5.3	–$0.9
2035	$20,183	$16,849	5.6%	–4.2%	$5.3	–$0.9
2036	$20,183	$16,848	5.6%	–4.2%	$5.4	–$0.9
2037	$20,183	$16,847	5.6%	–4.2%	$5.4	–$0.9
2038	$20,183	$16,846	5.6%	–4.2%	$5.5	–$0.9
2039	$20,183	$16,845	5.6%	–4.2%	$5.5	–$0.9
2040	$20,183	$16,845	5.6%	–4.2%	$5.6	–$0.9
NPV at 3%					$92.0	–$36.6
NPV at 7%					$49.5	–$24.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-5. Impact on C2 Commercial Propulsion Engine Market: 800–2000 hp (Average Price per Engine = $230,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.1	–$0.1
2008	$0	–$27	0.0%	0.0%	$0.1	–$0.1
2009	$0	–$36	0.0%	–0.1%	$0.1	–$0.1
2010	$0	–$44	0.0%	–0.1%	$0.1	–$0.1
2011	$0	–$53	0.0%	–0.1%	$0.6	–$0.6
2012	$0	–$73	0.0%	–0.1%	$0.5	–$0.5
2013	$0	–$78	0.0%	–0.1%	$0.5	–$0.5
2014	$0	–$76	0.0%	–0.1%	$0.5	–$0.5
2015	$0	–$59	0.0%	–0.1%	$0.7	–$0.7
2016	$39,428	$39,322	17.1%	–0.2%	$0.3	Loss less than $0.1
2017	$39,428	$39,308	17.1%	–0.2%	$0.3	Loss less than $0.1
2018	$30,142	$30,012	13.0%	–0.2%	$0.2	Loss less than $0.1
2019	$30,142	$29,994	13.0%	–0.2%	$0.2	Loss less than $0.1
2020	$30,142	$29,975	13.0%	–0.3%	$0.2	Loss less than $0.1
2021	$30,142	$29,956	13.0%	–0.3%	$0.2	Loss less than $0.1
2022	$30,142	$29,938	13.0%	–0.3%	$0.2	Loss less than $0.1
2023	$30,142	$29,920	13.0%	–0.4%	$0.2	Loss less than $0.1
2024	$30,142	$29,902	13.0%	–0.4%	$0.2	Loss less than $0.1
2025	$30,142	$29,886	13.0%	–0.4%	$0.2	Loss less than $0.1
2026	$30,142	$29,869	13.0%	–0.5%	$0.2	Loss less than $0.1
2027	$30,142	$29,854	13.0%	–0.5%	$0.2	Loss less than $0.1
2028	$30,142	$29,838	13.0%	–0.5%	$0.2	Loss less than $0.1
2029	$30,142	$29,825	13.0%	–0.5%	$0.2	Loss less than $0.1
2030	$30,142	$29,813	13.0%	–0.5%	$0.2	Loss less than $0.1
2031	$30,142	$29,804	13.0%	–0.6%	$0.2	Loss less than $0.1
2032	$30,142	$29,795	13.0%	–0.6%	$0.2	Loss less than $0.1
2033	$30,142	$29,787	13.0%	–0.6%	$0.2	Loss less than $0.1
2034	$30,142	$29,779	12.9%	–0.6%	$0.2	Loss less than $0.1
2035	$30,142	$29,772	12.9%	–0.6%	$0.2	Loss less than $0.1
2036	$30,142	$29,766	12.9%	–0.6%	$0.2	Loss less than $0.1
2037	$30,142	$29,759	12.9%	–0.6%	$0.2	Loss less than $0.1
2038	$30,142	$29,753	12.9%	–0.6%	$0.2	Loss less than $0.1
2039	$30,142	$29,748	12.9%	–0.7%	$0.3	Loss less than $0.1
2040	$30,142	$29,745	12.9%	–0.7%	$0.3	Loss less than $0.1
NPV at 3%					$5.6	–$2.6
NPV at 7%					$3.3	–$1.9

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-6. Impact on C2 Commercial Propulsion Engine Market: >2000 hp (Average Price per Engine = $450,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.9	–$1.9
2008	$0	–$53	0.0%	0.0%	$1.9	–$1.9
2009	$0	–$70	0.0%	–0.1%	$1.9	–$1.9
2010	$0	–$87	0.0%	–0.1%	$1.9	–$1.9
2011	$0	–$103	0.0%	–0.1%	$13.4	–$13.4
2012	$0	–$142	0.0%	–0.1%	$10.2	–$10.2
2013	$0	–$152	0.0%	–0.1%	$10.2	–$10.2
2014	$0	–$150	0.0%	–0.1%	$10.2	–$10.2
2015	$0	–$115	0.0%	–0.1%	$14.4	–$14.4
2016	$73,360	$73,152	16.3%	–0.2%	$10.4	Loss less than $0.1
2017	$73,360	$73,125	16.2%	–0.2%	$10.5	Loss less than $0.1
2018	$56,081	$55,827	12.4%	–0.2%	$8.1	Loss less than $0.1
2019	$56,081	$55,791	12.4%	–0.2%	$8.2	Loss less than $0.1
2020	$56,081	$55,753	12.4%	–0.3%	$8.2	Loss less than $0.1
2021	$56,081	$55,717	12.4%	–0.3%	$8.3	–$0.1
2022	$56,081	$55,681	12.4%	–0.3%	$8.4	–$0.1
2023	$56,081	$55,646	12.4%	–0.4%	$8.5	–$0.1
2024	$56,081	$55,612	12.4%	–0.4%	$8.5	–$0.1
2025	$56,081	$55,579	12.4%	–0.4%	$8.6	–$0.1
2026	$56,081	$55,547	12.3%	–0.5%	$8.7	–$0.1
2027	$56,081	$55,516	12.3%	–0.5%	$8.8	–$0.1
2028	$56,081	$55,487	12.3%	–0.5%	$8.8	–$0.1
2029	$56,081	$55,460	12.3%	–0.5%	$8.9	–$0.1
2030	$56,081	$55,437	12.3%	–0.5%	$9.0	–$0.1
2031	$56,081	$55,418	12.3%	–0.6%	$9.1	–$0.1
2032	$56,081	$55,401	12.3%	–0.6%	$9.2	–$0.1
2033	$56,081	$55,385	12.3%	–0.6%	$9.3	–$0.1
2034	$56,081	$55,371	12.3%	–0.6%	$9.3	–$0.1
2035	$56,081	$55,357	12.3%	–0.6%	$9.4	–$0.1
2036	$56,081	$55,345	12.3%	–0.6%	$9.5	–$0.1
2037	$56,081	$55,332	12.3%	–0.6%	$9.6	–$0.1
2038	$56,081	$55,320	12.3%	–0.6%	$9.7	–$0.1
2039	$56,081	$55,310	12.3%	–0.7%	$9.8	–$0.1
2040	$56,081	$55,303	12.3%	–0.7%	$9.9	–$0.1
NPV at 3%					$169.9	–$54.2
NPV at 7%					$93.4	–$40.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7B: Impacts on the Equipment Markets

This appendix provides the time series of impacts from 2007 through 2040 for selected equipment markets (vessels and locomotives).[S] Results are presented for 21 separate equipment markets: 2 locomotive markets (line-haul and switchers) and 19 vessel markets. Table 7B-1 through Table 7B-21 provide the time series of impacts and include the following:

- average engineering costs (variable) per equipment
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in equipment manufacturer surplus (selected commercial vessel and locomotive markets)
- changes in total surplus (fishing markets only)

All prices, costs, and surplus changes are presented in 2005 dollars, and real equipment prices are assumed to be constant during the period of analysis. Net present values for 2006 were calculated using social discount rates of 3% and 7% over the 2007 and 2040 time period.

Results are presented for only those markets that are expected to incur direct variable costs under Tier 3 or Tier 4 standards. This means that results are not presented for marine vessel markets for vessels that have propulsion engines less than 800 hp or for recreational vessel markets. For these vessel markets, the results are expected to be negligible and any change in price or quantity would be incidental to the changes in the larger vessel markets. It should also be noted that fixed costs are limited to only the Tier 4 standards. There are no fixed costs associated with the Tier 3 standards because Tier 3 engines are expected to have the same engine footprint as Tier 2 engines. For Tier 4 vessels, as explained in 7.2.3.4, fixed costs are not included in the EIM.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[S] The engineering costs we used in the EIA are an earlier version of the estimated compliance costs developed for this rule; see Section 7.3.2 for an explanation of the difference. This difference is not expected to have an impact on the results of the market analysis or on the expected distribution of social costs among stakeholders.

Table 7B-1. Impact on Locomotive Market: Line-Haul (Average Price per Locomotive = $2,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$6.0	–$6.0
2008	$0	–$158	0.0%	0.0%	$6.0	–$6.1
2009	$0	–$197	0.0%	0.0%	$6.0	–$6.1
2010	$0	–$351	0.0%	0.0%	$33.4	–$33.7
2011	$0	–$658	0.0%	–0.1%	$35.0	–$35.5
2012	$0	–$535	0.0%	–0.1%	$27.4	–$27.8
2013	$0	–$483	0.0%	–0.1%	$27.4	–$27.8
2014	$0	–$355	0.0%	0.0%	$30.7	–$30.9
2015	$84,274	$83,494	4.2%	–0.1%	$68.8	–$0.6
2016	$84,274	$83,227	4.2%	–0.1%	$72.0	–$0.9
2017	$65,343	$64,374	3.2%	–0.1%	$57.3	–$0.8
2018	$65,343	$64,273	3.2%	–0.1%	$58.4	–$1.0
2019	$65,343	$64,217	3.2%	–0.2%	$59.9	–$1.0
2020	$65,343	$64,261	3.2%	–0.1%	$61.9	–$1.0
2021	$65,343	$64,163	3.2%	–0.2%	$64.0	–$1.2
2022	$65,343	$63,950	3.2%	–0.2%	$65.8	–$1.4
2023	$65,343	$63,600	3.2%	–0.2%	$67.6	–$1.8
2024	$65,343	$63,574	3.2%	–0.2%	$68.5	–$1.9
2025	$65,343	$63,454	3.2%	–0.3%	$70.4	–$2.0
2026	$65,343	$63,439	3.2%	–0.3%	$71.6	–$2.1
2027	$65,343	$63,345	3.2%	–0.3%	$73.1	–$2.2
2028	$65,343	$63,181	3.2%	–0.3%	$74.2	–$2.5
2029	$65,343	$63,093	3.2%	–0.3%	$75.1	–$2.6
2030	$65,343	$63,019	3.2%	–0.3%	$75.7	–$2.7
2031	$65,343	$62,939	3.1%	–0.3%	$76.7	–$2.8
2032	$65,343	$62,909	3.1%	–0.3%	$77.8	–$2.9
2033	$65,343	$62,547	3.1%	–0.4%	$79.0	–$3.4
2034	$65,343	$62,431	3.1%	–0.4%	$79.9	–$3.6
2035	$65,343	$62,328	3.1%	–0.4%	$80.4	–$3.7
2036	$65,343	$62,313	3.1%	–0.4%	$78.2	–$3.6
2037	$65,343	$62,252	3.1%	–0.4%	$76.6	–$3.6
2038	$65,343	$62,196	3.1%	–0.4%	$74.8	–$3.6
2039	$65,343	$62,144	3.1%	–0.4%	$72.7	–$3.6
2040	$65,343	$62,095	3.1%	–0.4%	$70.4	–$3.5
NPV at 3%					$1,102.4	–$172.2
NPV at 7%					$553.6	–$124.5

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-2. Impact on Locomotive Market: Switcher/Passenger (Average Price per Locomotive = $1,300,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$2.6	–$2.6
2008	$0	–$103	0.0%	0.0%	$2.6	–$2.6
2009	$0	–$128	0.0%	0.0%	$2.6	–$2.6
2010	$0	–$228	0.0%	0.0%	$4.9	–$5.0
2011	$0	–$428	0.0%	–0.1%	$6.9	–$7.0
2012	$0	–$348	0.0%	–0.1%	$7.2	–$7.2
2013	$0	–$314	0.0%	–0.1%	$7.2	–$7.2
2014	$0	–$231	0.0%	0.0%	$9.7	–$9.8
2015	$14,175	$13,668	1.1%	–0.1%	$6.2	–$4.9
2016	$14,175	$13,494	1.0%	–0.1%	$8.7	–$7.4
2017	$23,682	$23,052	1.8%	–0.1%	$2.2	–$0.1
2018	$23,682	$22,986	1.8%	–0.1%	$2.2	–$0.1
2019	$21,139	$20,407	1.6%	–0.2%	$2.0	–$0.1
2020	$21,139	$20,436	1.6%	–0.1%	$2.0	–$0.1
2021	$21,139	$20,372	1.6%	–0.2%	$2.0	–$0.1
2022	$21,139	$20,233	1.6%	–0.2%	$2.0	–$0.1
2023	$21,139	$20,006	1.5%	–0.2%	$3.4	–$0.2
2024	$21,139	$19,989	1.5%	–0.2%	$3.9	–$0.2
2025	$21,139	$19,911	1.5%	–0.3%	$4.2	–$0.2
2026	$21,139	$19,901	1.5%	–0.3%	$4.5	–$0.3
2027	$21,139	$19,840	1.5%	–0.3%	$4.8	–$0.3
2028	$21,139	$19,734	1.5%	–0.3%	$5.0	–$0.3
2029	$21,139	$19,676	1.5%	–0.3%	$5.2	–$0.4
2030	$21,139	$19,628	1.5%	–0.3%	$5.6	–$0.4
2031	$21,139	$19,576	1.5%	–0.3%	$5.9	–$0.4
2032	$21,139	$19,557	1.5%	–0.3%	$6.2	–$0.5
2033	$21,139	$19,321	1.5%	–0.4%	$6.3	–$0.5
2034	$21,139	$19,246	1.5%	–0.4%	$6.4	–$0.6
2035	$21,139	$19,179	1.5%	–0.4%	$6.4	–$0.6
2036	$21,139	$19,169	1.5%	–0.4%	$6.2	–$0.6
2037	$21,139	$19,130	1.5%	–0.4%	$6.1	–$0.6
2038	$21,139	$19,093	1.5%	–0.4%	$5.9	–$0.6
2039	$21,139	$19,059	1.5%	–0.4%	$5.7	–$0.6
2040	$21,139	$19,028	1.5%	–0.4%	$5.6	–$0.6
NPV at 3%					$99.0	–$48.9
NPV at 7%					$56.7	–$35.9

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-3. Impact on C1 Fishing Vessel Market: 800–2000 hp (Average Price per Vessel = $1,085,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0	$0.0
2008	$0	–$3	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2009	$0	–$3	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2010	$0	–$4	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2011	$0	–$5	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2012	$0	–$7	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2013	$0	–$8	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2014	$0	–$7	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2015	$0	–$6	0.0%	0.0%	$5.7	–$5.7	–$5.7
2016	$6,585	$18,493	1.7%	–3.4%	$4.2	–$6.3	–$6.4
2017	$6,587	$18,493	1.7%	–3.4%	$3.0	–$5.2	–$5.2
2018	$5,504	$14,369	1.3%	–2.6%	$2.2	–$3.8	–$3.8
2019	$5,501	$14,366	1.3%	–2.6%	$2.2	–$3.8	–$3.8
2020	$5,503	$14,365	1.3%	–2.6%	$2.2	–$3.8	–$3.8
2021	$5,504	$14,363	1.3%	–2.6%	$2.2	–$3.9	–$3.9
2022	$5,504	$14,362	1.3%	–2.6%	$2.2	–$3.9	–$3.9
2023	$5,504	$14,360	1.3%	–2.6%	$2.3	–$3.9	–$3.9
2024	$5,504	$14,358	1.3%	–2.6%	$2.3	–$3.9	–$3.9
2025	$5,503	$14,356	1.3%	–2.6%	$2.3	–$4.0	–$4.0
2026	$5,502	$14,354	1.3%	–2.6%	$2.3	–$4.0	–$4.0
2027	$5,504	$14,354	1.3%	–2.6%	$2.3	–$4.0	–$4.0
2028	$5,502	$14,351	1.3%	–2.6%	$2.3	–$4.1	–$4.0
2029	$5,504	$14,351	1.3%	–2.6%	$1.4	–$3.2	–$3.2
2030	$5,505	$14,350	1.3%	–2.6%	$1.4	–$3.2	–$3.2
2031	$5,501	$14,347	1.3%	–2.6%	$1.4	–$3.2	–$3.2
2032	$5,501	$14,347	1.3%	–2.6%	$1.5	–$3.3	–$3.3
2033	$5,505	$14,348	1.3%	–2.6%	$1.5	–$3.3	–$3.3
2034	$5,504	$14,346	1.3%	–2.6%	$1.5	–$3.3	–$3.3
2035	$5,503	$14,345	1.3%	–2.6%	$1.5	–$3.3	–$3.3
2036	$5,505	$14,346	1.3%	–2.6%	$1.5	–$3.4	–$3.4
2037	$5,503	$14,344	1.3%	–2.6%	$1.5	–$3.4	–$3.4
2038	$5,504	$14,344	1.3%	–2.6%	$1.5	–$3.4	–$3.4
2039	$5,504	$14,344	1.3%	–2.6%	$1.6	–$3.5	–$3.5
2040	$5,504	$14,343	1.3%	–2.6%	$1.6	–$3.5	–$3.5
NPV at 3%					$31.5	–$54.5	–$54.5
NPV at 7%					$16.2	–$26.7	–$26.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-4. Impact on C1 Fishing Vessel Market: >2000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0	$0.0
2008	$0	–$8	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2009	$0	–$11	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2010	$0	–$13	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2011	$0	–$16	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2012	$0	–$22	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2013	$0	–$23	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2014	$0	–$23	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2015	$0	–$18	0.0%	0.0%	$2.4	–$2.4	–$2.4
2016	$12,359	$65,202	3.1%	–6.2%	$2.3	–$6.4	–$6.4
2017	$12,362	$65,198	3.1%	–6.2%	$1.8	–$6.0	–$6.0
2018	$10,383	$50,284	2.4%	–4.8%	$1.4	–$4.6	–$4.6
2019	$10,382	$50,278	2.4%	–4.8%	$1.4	–$4.6	–$4.6
2020	$10,389	$50,279	2.4%	–4.8%	$1.4	–$4.6	–$4.6
2021	$10,386	$50,270	2.4%	–4.8%	$1.4	–$4.7	–$4.7
2022	$10,382	$50,261	2.4%	–4.8%	$1.4	–$4.7	–$4.7
2023	$10,387	$50,262	2.4%	–4.8%	$1.4	–$4.8	–$4.8
2024	$10,382	$50,251	2.4%	–4.8%	$1.5	–$4.8	–$4.8
2025	$10,385	$50,248	2.4%	–4.8%	$1.5	–$4.8	–$4.8
2026	$10,387	$50,244	2.4%	–4.8%	$1.5	–$4.9	–$4.9
2027	$10,389	$50,239	2.4%	–4.8%	$1.5	–$4.9	–$4.9
2028	$10,389	$50,237	2.4%	–4.8%	$1.5	–$4.9	–$4.9
2029	$10,389	$50,231	2.4%	–4.8%	$1.1	–$4.6	–$4.6
2030	$10,388	$50,227	2.4%	–4.8%	$1.1	–$4.6	–$4.7
2031	$10,386	$50,224	2.4%	–4.8%	$1.1	–$4.7	–$4.7
2032	$10,384	$50,219	2.4%	–4.8%	$1.2	–$4.7	–$4.7
2033	$10,389	$50,219	2.4%	–4.8%	$1.2	–$4.8	–$4.8
2034	$10,385	$50,216	2.4%	–4.8%	$1.2	–$4.8	–$4.8
2035	$10,389	$50,215	2.4%	–4.8%	$1.2	–$4.9	–$4.9
2036	$10,383	$50,212	2.4%	–4.8%	$1.2	–$4.9	–$4.9
2037	$10,385	$50,209	2.4%	–4.8%	$1.2	–$4.9	–$5.0
2038	$10,387	$50,209	2.4%	–4.8%	$1.2	–$5.0	–$5.0
2039	$10,387	$50,205	2.4%	–4.8%	$1.2	–$5.0	–$5.0
2040	$10,387	$50,208	2.4%	–4.8%	$1.2	–$5.1	–$5.1
NPV at 3%					$20.0	–$65.7	–$65.7
NPV at 7%					$9.9	–$30.7	–$30.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-5. Impact on C2 Fishing Vessel Market: >2000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0	$0.0
2008	$0	–$613	0.0%	0.0%	$0.0	$0.0	Loss less than $0.1
2009	$0	–$807	0.0%	–0.1%	$0.0	$0.0	Loss less than $0.1
2010	$0	–$1,002	0.0%	–0.1%	$0.0	$0.0	Loss less than $0.1
2011	$0	–$1,196	–0.1%	–0.1%	$0.0	$0.0	Loss less than $0.1
2012	$0	–$1,643	–0.1%	–0.1%	$0.0	$0.0	Loss less than $0.1
2013	$0	–$1,759	–0.1%	–0.1%	$0.0	$0.0	Loss less than $0.1
2014	$0	–$1,731	–0.1%	–0.1%	$0.0	$0.0	Loss less than $0.1
2015	$0	–$1,335	–0.1%	–0.1%	$0.5	–$0.5	–$0.6
2016	$12,398	$237,339	11.3%	–0.2%	$0.4	–$0.3	–$0.3
2017	$12,379	$237,000	11.3%	–0.2%	$0.3	–$0.2	–$0.2
2018	$10,360	$181,220	8.6%	–0.2%	$0.3	–$0.2	–$0.2
2019	$10,358	$180,801	8.6%	–0.2%	$0.3	–$0.2	–$0.2
2020	$10,355	$180,373	8.6%	–0.3%	$0.3	–$0.2	–$0.2
2021	$10,351	$179,939	8.6%	–0.3%	$0.3	–$0.2	–$0.2
2022	$10,346	$179,518	8.5%	–0.3%	$0.3	–$0.2	–$0.2
2023	$10,428	$179,203	8.5%	–0.4%	$0.3	–$0.2	–$0.2
2024	$10,421	$178,796	8.5%	–0.4%	$0.3	–$0.2	–$0.2
2025	$10,413	$178,410	8.5%	–0.4%	$0.3	–$0.2	–$0.2
2026	$10,405	$178,031	8.5%	–0.5%	$0.3	–$0.2	–$0.2
2027	$10,396	$177,662	8.5%	–0.5%	$0.3	–$0.2	–$0.2
2028	$10,386	$177,316	8.4%	–0.5%	$0.3	–$0.2	–$0.2
2029	$10,376	$176,996	8.4%	–0.5%	$0.1	–$0.1	–$0.1
2030	$10,365	$176,723	8.4%	–0.5%	$0.1	–$0.1	–$0.1
2031	$10,354	$176,490	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2032	$10,422	$176,359	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2033	$10,408	$176,162	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2034	$10,394	$175,980	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2035	$10,379	$175,807	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2036	$10,364	$175,650	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2037	$10,348	$175,486	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2038	$10,408	$175,410	8.4%	–0.6%	$0.1	–$0.1	–$0.1
2039	$10,390	$175,271	8.3%	–0.7%	$0.1	–$0.1	–$0.1
2040	$10,372	$175,184	8.3%	–0.7%	$0.1	–$0.1	–$0.1
NPV at 3%					$3.3	–$2.3	–$2.3
NPV at 7%					$1.7	–$1.3	–$1.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-6. Impact on C1 Tow/Tug/Push Vessel Market: 800–2000 hp (Average Price per Vessel = $1,550,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$306	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$404	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$501	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$598	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$821	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$879	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$865	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$667	0.0%	–0.1%	$0.6	–$0.6
2016	$6,604	$33,409	2.2%	–0.2%	$0.5	–$0.3
2017	$6,585	$33,232	2.1%	–0.2%	$0.3	–$0.2
2018	$5,498	$25,412	1.6%	–0.2%	$0.2	–$0.1
2019	$5,488	$25,195	1.6%	–0.2%	$0.2	–$0.1
2020	$5,516	$25,007	1.6%	–0.3%	$0.2	–$0.1
2021	$5,506	$24,784	1.6%	–0.3%	$0.2	–$0.2
2022	$5,495	$24,566	1.6%	–0.3%	$0.2	–$0.2
2023	$5,521	$24,390	1.6%	–0.4%	$0.2	–$0.2
2024	$5,510	$24,182	1.6%	–0.4%	$0.2	–$0.2
2025	$5,498	$23,980	1.5%	–0.4%	$0.2	–$0.2
2026	$5,485	$23,783	1.5%	–0.5%	$0.2	–$0.2
2027	$5,509	$23,628	1.5%	–0.5%	$0.2	–$0.2
2028	$5,497	$23,445	1.5%	–0.5%	$0.3	–$0.2
2029	$5,519	$23,314	1.5%	–0.5%	$0.2	–$0.1
2030	$5,505	$23,170	1.5%	–0.5%	$0.2	–$0.1
2031	$5,492	$23,045	1.5%	–0.6%	$0.2	–$0.1
2032	$5,512	$22,967	1.5%	–0.6%	$0.2	–$0.1
2033	$5,498	$22,861	1.5%	–0.6%	$0.2	–$0.1
2034	$5,517	$22,796	1.5%	–0.6%	$0.2	–$0.1
2035	$5,502	$22,702	1.5%	–0.6%	$0.2	–$0.1
2036	$5,487	$22,613	1.5%	–0.6%	$0.2	–$0.1
2037	$5,504	$22,559	1.5%	–0.6%	$0.2	–$0.1
2038	$5,488	$22,474	1.4%	–0.6%	$0.2	–$0.1
2039	$5,505	$22,433	1.4%	–0.7%	$0.2	–$0.1
2040	$5,488	$22,377	1.4%	–0.7%	$0.2	–$0.1
NPV at 3%					$3.4	–$2.6
NPV at 7%					$1.8	–$1.4

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-7. Impact on C1 Tow/Tug/Push Vessel Market: >2000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$592	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$780	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$967	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,155	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,587	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,698	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,672	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,289	0.0%	–0.1%	$0.3	–$0.3
2016	$12,321	$54,303	1.8%	–0.2%	$0.3	–$0.1
2017	$12,403	$54,079	1.8%	–0.2%	$0.2	–$0.1
2018	$10,387	$41,362	1.4%	–0.2%	$0.2	–$0.1
2019	$10,388	$40,963	1.4%	–0.2%	$0.2	–$0.1
2020	$10,389	$40,544	1.4%	–0.3%	$0.2	–$0.1
2021	$10,389	$40,135	1.3%	–0.3%	$0.2	–$0.1
2022	$10,389	$39,735	1.3%	–0.3%	$0.2	–$0.1
2023	$10,387	$39,342	1.3%	–0.4%	$0.2	–$0.1
2024	$10,385	$38,961	1.3%	–0.4%	$0.2	–$0.1
2025	$10,382	$38,589	1.3%	–0.4%	$0.2	–$0.1
2026	$10,378	$38,228	1.3%	–0.5%	$0.2	–$0.1
2027	$10,373	$37,879	1.3%	–0.5%	$0.2	–$0.1
2028	$10,368	$37,544	1.3%	–0.5%	$0.2	–$0.1
2029	$10,362	$37,241	1.2%	–0.5%	$0.1	–$0.1
2030	$10,355	$36,982	1.2%	–0.5%	$0.1	–$0.1
2031	$10,347	$36,760	1.2%	–0.6%	$0.1	–$0.1
2032	$10,423	$36,646	1.2%	–0.6%	$0.1	–$0.1
2033	$10,413	$36,460	1.2%	–0.6%	$0.1	–$0.1
2034	$10,403	$36,286	1.2%	–0.6%	$0.1	–$0.1
2035	$10,392	$36,123	1.2%	–0.6%	$0.1	–$0.1
2036	$10,380	$35,969	1.2%	–0.6%	$0.1	–$0.1
2037	$10,368	$35,818	1.2%	–0.6%	$0.1	–$0.1
2038	$10,355	$35,672	1.2%	–0.6%	$0.1	–$0.1
2039	$10,421	$35,627	1.2%	–0.7%	$0.1	–$0.1
2040	$10,406	$35,536	1.2%	–0.7%	$0.1	–$0.1
NPV at 3%					$2.1	–$1.5
NPV at 7%					$1.1	–$0.8

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-8. Impact on C2 Tow/Tug/Push Vessel Market: 800–2000 hp (Average Price per Vessel = $1,550,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$355	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$468	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$581	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$694	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$953	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,020	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,005	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$775	0.0%	–0.1%	$0.1	Loss less than $0.1
2016	$6,469	$83,929	5.4%	–0.2%	$0.1	Loss less than $0.1
2017	$6,411	$83,688	5.4%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,776	$64,356	4.2%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,725	$64,063	4.1%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,674	$63,761	4.1%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,623	$63,464	4.1%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,573	$63,173	4.1%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,523	$62,889	4.1%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,474	$62,612	4.0%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,425	$62,341	4.0%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,377	$62,079	4.0%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,329	$61,824	4.0%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,281	$61,578	4.0%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,758	$61,876	4.0%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,706	$61,673	4.0%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,655	$61,493	4.0%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,605	$61,329	4.0%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,555	$61,173	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,505	$61,025	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,456	$60,885	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,408	$60,751	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,359	$60,619	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,312	$60,491	3.9%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,264	$60,377	3.9%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,691	$60,759	3.9%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.4	–$0.3
NPV at 7%					$0.2	–$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-9. Impact on C2 Tow/Tug/Push Vessel Market: >2000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$788	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$1,038	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$1,288	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,538	–0.1%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$2,113	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$2,261	–0.1%	–0.1%	$0.0	–$0.1
2014	$0	–$2,226	–0.1%	–0.1%	$0.0	–$0.1
2015	$0	–$1,717	–0.1%	–0.1%	$1.6	–$1.6
2016	$12,367	$236,621	7.9%	–0.2%	$1.3	–$0.9
2017	$12,349	$236,192	7.9%	–0.2%	$0.8	–$0.5
2018	$10,391	$180,411	6.0%	–0.2%	$0.8	–$0.5
2019	$10,388	$179,874	6.0%	–0.2%	$0.8	–$0.5
2020	$10,385	$179,322	6.0%	–0.3%	$0.8	–$0.6
2021	$10,381	$178,766	6.0%	–0.3%	$0.8	–$0.6
2022	$10,376	$178,226	5.9%	–0.3%	$0.8	–$0.6
2023	$10,399	$177,737	5.9%	–0.4%	$0.8	–$0.6
2024	$10,392	$177,219	5.9%	–0.4%	$0.8	–$0.6
2025	$10,385	$176,723	5.9%	–0.4%	$0.8	–$0.6
2026	$10,377	$176,240	5.9%	–0.5%	$0.8	–$0.6
2027	$10,396	$175,797	5.9%	–0.5%	$0.8	–$0.7
2028	$10,386	$175,354	5.8%	–0.5%	$0.8	–$0.7
2029	$10,376	$174,945	5.8%	–0.5%	$0.4	–$0.2
2030	$10,392	$174,625	5.8%	–0.5%	$0.4	–$0.3
2031	$10,381	$174,328	5.8%	–0.6%	$0.4	–$0.3
2032	$10,395	$174,087	5.8%	–0.6%	$0.4	–$0.3
2033	$10,382	$173,839	5.8%	–0.6%	$0.4	–$0.3
2034	$10,394	$173,635	5.8%	–0.6%	$0.4	–$0.3
2035	$10,379	$173,417	5.8%	–0.6%	$0.4	–$0.3
2036	$10,390	$173,243	5.8%	–0.6%	$0.4	–$0.3
2037	$10,374	$173,038	5.8%	–0.6%	$0.4	–$0.3
2038	$10,383	$172,872	5.8%	–0.6%	$0.4	–$0.3
2039	$10,390	$172,726	5.8%	–0.7%	$0.4	–$0.3
2040	$10,397	$172,641	5.8%	–0.7%	$0.4	–$0.3
NPV at 3%					$9.9	–$7.9
NPV at 7%					$5.1	–$4.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-10. Impact on C1 Ferries Vessel Market: 800–2000 hp (Average Price per Vessel = $1,550,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$306	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$404	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$501	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$598	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$821	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$879	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$865	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$667	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$6,644	$33,450	2.2%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$6,585	$33,232	2.1%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,438	$25,353	1.6%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,605	$25,313	1.6%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,555	$25,046	1.6%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,506	$24,784	1.6%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,457	$24,528	1.6%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,408	$24,277	1.6%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,566	$24,239	1.6%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,516	$23,998	1.5%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,467	$23,764	1.5%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,418	$23,537	1.5%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,569	$23,517	1.5%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,519	$23,314	1.5%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,470	$23,134	1.5%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,421	$22,975	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,565	$23,020	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,515	$22,878	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,466	$22,744	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,417	$22,617	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,554	$22,681	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,504	$22,559	1.5%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,455	$22,441	1.4%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,587	$22,515	1.5%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,537	$22,426	1.4%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.6	–$0.5
NPV at 7%					$0.3	–$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-11. Impact on C1 Ferries Vessel Market: >2000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$598	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$789	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$979	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,169	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,605	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,718	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,691	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,304	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$12,224	$119,473	4.0%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$12,115	$119,052	4.0%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$10,291	$91,121	3.0%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$10,199	$90,623	3.0%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$10,108	$90,114	3.0%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$10,018	$89,606	3.0%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$10,756	$89,937	3.0%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$10,660	$89,452	3.0%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$10,565	$88,968	3.0%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$10,471	$88,503	3.0%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$10,378	$88,048	2.9%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$10,285	$87,604	2.9%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$10,193	$87,183	2.9%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$10,102	$86,789	2.9%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$10,012	$86,444	2.9%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$10,686	$86,901	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$10,591	$86,612	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$10,497	$86,339	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$10,403	$86,081	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$10,310	$85,834	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$10,218	$85,602	2.9%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$10,127	$85,367	2.8%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$10,037	$85,144	2.8%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$10,658	$85,648	2.9%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$10,563	$85,483	2.8%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.2	–$0.2
NPV at 7%					$0.1	–$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-12. Impact on C2 Ferries Vessel Market: >2,000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$788	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$1,038	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$1,288	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,538	–0.1%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$2,113	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$2,261	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$2,226	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,717	–0.1%	–0.1%	$0.0	Loss less than $0.1
2016	$12,491	$236,744	7.9%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$12,379	$236,223	7.9%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$10,360	$180,381	6.0%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$10,268	$179,754	6.0%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$10,444	$179,381	6.0%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$10,351	$178,737	6.0%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$10,259	$178,109	5.9%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$10,428	$177,766	5.9%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$10,335	$177,161	5.9%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$10,499	$176,837	5.9%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$10,405	$176,268	5.9%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$10,312	$175,713	5.9%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$10,470	$175,437	5.8%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$10,376	$174,945	5.8%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$10,284	$174,516	5.8%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$10,435	$174,382	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$10,342	$174,034	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$10,488	$173,945	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$10,394	$173,635	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$10,301	$173,339	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$10,442	$173,295	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$10,348	$173,013	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$10,484	$172,974	5.8%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$10,390	$172,726	5.8%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$10,298	$172,542	5.8%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$1.1	–$0.9
NPV at 7%					$0.6	–$0.5

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-13. Impact on C1 Supply/Crew Vessel Market: 800–2,000 hp (Average Price per Vessel = $3,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$608	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$801	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$994	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,186	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,630	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,744	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,717	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,324	0.0%	–0.1%	$0.1	Loss less than $0.1
2016	$6,644	$32,266	1.0%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$6,585	$31,892	1.0%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,438	$23,908	0.8%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,605	$23,663	0.8%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,555	$23,183	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,506	$22,713	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,457	$22,252	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,408	$21,803	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,566	$21,571	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,516	$21,143	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,467	$20,728	0.7%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,418	$20,325	0.7%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,569	$20,137	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,519	$19,783	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,470	$19,475	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,421	$19,206	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,565	$19,154	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,515	$18,923	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,466	$18,705	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,417	$18,501	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,554	$18,492	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,504	$18,300	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,455	$18,114	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,587	$18,132	0.6%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,537	$18,004	0.6%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.6	–$0.7
NPV at 7%					$0.3	–$0.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-14. Impact on C1 Supply/Crew Vessel Market: >2,000 hp (Average Price per Vessel = $6,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$1,182	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$1,557	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$1,932	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$2,308	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$3,169	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$3,392	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$3,340	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$2,575	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$12,224	$117,183	2.0%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$12,547	$116,893	1.9%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$10,291	$88,324	1.5%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$10,199	$87,431	1.5%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$10,530	$86,930	1.4%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$10,436	$86,014	1.4%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$10,343	$85,120	1.4%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$10,250	$84,253	1.4%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$10,565	$83,806	1.4%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$10,471	$82,977	1.4%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$10,378	$82,170	1.4%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$10,285	$81,387	1.4%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$10,193	$80,641	1.3%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$10,491	$80,344	1.3%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$10,397	$79,746	1.3%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$10,305	$79,225	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$10,213	$78,752	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$10,497	$78,683	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$10,403	$78,264	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$10,310	$77,867	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$10,218	$77,495	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$10,489	$77,485	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$10,395	$77,127	1.3%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$10,302	$76,808	1.3%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$10,211	$76,572	1.3%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.5	–$0.5
NPV at 7%					$0.2	–$0.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-15. Impact on C2 Supply/Crew Vessel Market: 800–2,000 hp (Average Price per Vessel = $3,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$657	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$865	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$1,074	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,283	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,762	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,886	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,856	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,432	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$6,469	$82,746	2.7%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$6,411	$82,348	2.7%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,776	$62,911	2.0%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,725	$62,414	2.0%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,674	$61,898	2.0%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,623	$61,393	2.0%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,573	$60,898	2.0%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,523	$60,415	1.9%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,474	$59,944	1.9%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,425	$59,487	1.9%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,377	$59,042	1.9%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,329	$58,611	1.9%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,281	$58,198	1.9%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,758	$58,345	1.9%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,706	$58,014	1.9%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,655	$57,725	1.9%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,605	$57,463	1.9%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,555	$57,217	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,505	$56,986	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,456	$56,769	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,408	$56,562	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,359	$56,359	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,312	$56,164	1.8%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,264	$55,993	1.8%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,691	$56,336	1.8%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.4	–$0.4
NPV at 7%					$0.2	–$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-16. Impact on C2 Supply/Crew Vessel Market: >2,000 hp (Average Price per Vessel = $6,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$1,279	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$1,685	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$2,092	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$2,498	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$3,431	–0.1%	–0.1%	$0.0	–$0.1
2013	$0	–$3,672	–0.1%	–0.1%	$0.0	–$0.1
2014	$0	–$3,615	–0.1%	–0.1%	$0.0	–$0.1
2015	$0	–$2,788	0.0%	–0.1%	$0.9	–$0.9
2016	$12,380	$219,369	3.7%	–0.2%	$0.7	–$0.6
2017	$12,379	$218,705	3.6%	–0.2%	$0.5	–$0.3
2018	$10,360	$166,274	2.8%	–0.2%	$0.4	–$0.3
2019	$10,376	$165,421	2.8%	–0.2%	$0.4	–$0.4
2020	$10,391	$164,537	2.7%	–0.3%	$0.4	–$0.4
2021	$10,404	$163,660	2.7%	–0.3%	$0.4	–$0.4
2022	$10,364	$162,753	2.7%	–0.3%	$0.4	–$0.4
2023	$10,376	$161,927	2.7%	–0.4%	$0.4	–$0.4
2024	$10,387	$161,112	2.7%	–0.4%	$0.4	–$0.4
2025	$10,396	$160,327	2.7%	–0.4%	$0.4	–$0.5
2026	$10,405	$159,564	2.7%	–0.5%	$0.4	–$0.5
2027	$10,363	$158,773	2.6%	–0.5%	$0.4	–$0.5
2028	$10,370	$158,072	2.6%	–0.5%	$0.5	–$0.5
2029	$10,376	$157,435	2.6%	–0.5%	$0.2	–$0.3
2030	$10,382	$156,894	2.6%	–0.5%	$0.2	–$0.3
2031	$10,386	$156,435	2.6%	–0.6%	$0.2	–$0.3
2032	$10,390	$156,026	2.6%	–0.6%	$0.2	–$0.3
2033	$10,392	$155,647	2.6%	–0.6%	$0.2	–$0.3
2034	$10,394	$155,296	2.6%	–0.6%	$0.2	–$0.3
2035	$10,395	$154,968	2.6%	–0.6%	$0.2	–$0.3
2036	$10,395	$154,665	2.6%	–0.6%	$0.2	–$0.3
2037	$10,394	$154,361	2.6%	–0.6%	$0.2	–$0.4
2038	$10,393	$154,073	2.6%	–0.6%	$0.2	–$0.4
2039	$10,390	$153,825	2.6%	–0.7%	$0.2	–$0.4
2040	$10,387	$153,666	2.6%	–0.7%	$0.2	–$0.4
NPV at 3%					$5.5	–$6.0
NPV at 7%					$2.8	–$3.0

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[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-17. Impact on C1 Cargo Vessel Market: 800–2,000 hp (Average Price per Vessel = $3,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$608	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$801	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$994	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,186	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,630	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,744	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,717	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,324	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$6,201	$31,823	1.0%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$7,024	$32,331	1.0%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,221	$23,690	0.8%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,174	$23,232	0.7%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,128	$22,756	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,082	$22,289	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,876	$22,672	0.7%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,824	$22,219	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,772	$21,777	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,721	$21,348	0.7%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,670	$20,930	0.7%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,619	$20,526	0.7%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,569	$20,137	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,519	$19,783	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,470	$19,475	0.6%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,421	$19,206	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,373	$18,962	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,325	$18,733	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,277	$18,517	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,230	$18,314	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,184	$18,122	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,137	$17,933	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,819	$18,478	0.6%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,767	$18,312	0.6%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,716	$18,182	0.6%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.2	–$0.2
NPV at 7%					$0.1	–$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-18. Impact on C2 Cargo Vessel Market: >2,000 hp (Average Price per Vessel = $6,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$1,371	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$1,806	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$2,242	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$2,677	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$3,677	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$3,935	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$3,874	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$2,988	0.0%	–0.1%	$0.2	–$0.3
2016	$12,283	$234,245	3.9%	–0.2%	$0.2	–$0.2
2017	$12,379	$233,630	3.9%	–0.2%	$0.1	–$0.1
2018	$10,429	$177,652	3.0%	–0.2%	$0.1	–$0.1
2019	$10,336	$176,629	2.9%	–0.2%	$0.1	–$0.1
2020	$10,444	$175,776	2.9%	–0.3%	$0.1	–$0.1
2021	$10,351	$174,728	2.9%	–0.3%	$0.1	–$0.1
2022	$10,456	$173,903	2.9%	–0.3%	$0.1	–$0.1
2023	$10,363	$172,913	2.9%	–0.4%	$0.1	–$0.1
2024	$10,464	$172,128	2.9%	–0.4%	$0.1	–$0.1
2025	$10,371	$171,184	2.9%	–0.4%	$0.1	–$0.1
2026	$10,469	$170,454	2.8%	–0.5%	$0.1	–$0.1
2027	$10,375	$169,559	2.8%	–0.5%	$0.1	–$0.1
2028	$10,470	$168,895	2.8%	–0.5%	$0.1	–$0.1
2029	$10,376	$168,111	2.8%	–0.5%	$0.1	–$0.1
2030	$10,467	$167,617	2.8%	–0.5%	$0.1	–$0.1
2031	$10,374	$167,027	2.8%	–0.6%	$0.1	–$0.1
2032	$10,462	$166,672	2.8%	–0.6%	$0.1	–$0.1
2033	$10,368	$166,170	2.8%	–0.6%	$0.1	–$0.1
2034	$10,453	$165,877	2.8%	–0.6%	$0.1	–$0.1
2035	$10,360	$165,431	2.8%	–0.6%	$0.1	–$0.1
2036	$10,442	$165,188	2.8%	–0.6%	$0.1	–$0.1
2037	$10,348	$164,769	2.7%	–0.6%	$0.1	–$0.1
2038	$10,427	$164,542	2.7%	–0.6%	$0.1	–$0.1
2039	$10,334	$164,185	2.7%	–0.7%	$0.1	–$0.1
2040	$10,410	$164,094	2.7%	–0.7%	$0.1	–$0.1
NPV at 3%					$1.5	–$1.6
NPV at 7%					$0.8	–$0.8

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-19. Impact on C1 Other Commercial Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,085,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$216	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$284	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$353	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$421	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$579	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$620	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$610	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$470	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$6,496	$33,657	3.1%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$6,731	$33,780	3.1%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$5,511	$25,859	2.4%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$5,462	$25,664	2.4%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$5,413	$25,462	2.3%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$5,365	$25,264	2.3%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$5,597	$25,350	2.3%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$5,547	$25,158	2.3%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$5,497	$24,970	2.3%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$5,448	$24,787	2.3%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$5,400	$24,608	2.3%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$5,619	$24,702	2.3%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$5,569	$24,531	2.3%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$5,519	$24,373	2.2%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$5,470	$24,232	2.2%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$5,421	$24,105	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$5,629	$24,243	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$5,578	$24,129	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$5,529	$24,019	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$5,479	$23,915	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$5,430	$23,814	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$5,382	$23,715	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$5,576	$23,861	2.2%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$5,527	$23,770	2.2%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$5,477	$23,693	2.2%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.5	–$0.3
NPV at 7%					$0.2	–$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-20. Impact on C1 Other Commercial Vessel Market: >2,000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$423	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$558	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$692	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$827	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,136	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,216	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,197	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$923	0.0%	–0.1%	$0.0	Loss less than $0.1
2016	$12,224	$120,160	5.7%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$12,115	$119,830	5.7%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$10,291	$91,960	4.4%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$10,199	$91,580	4.4%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$10,108	$91,196	4.3%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$10,018	$90,808	4.3%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$10,756	$91,258	4.3%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$10,660	$90,889	4.3%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$10,565	$90,517	4.3%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$10,471	$90,161	4.3%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$10,378	$89,811	4.3%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$10,285	$89,469	4.3%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$10,193	$89,146	4.2%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$10,102	$88,840	4.2%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$10,012	$88,569	4.2%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$10,686	$89,090	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$10,591	$88,857	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$10,497	$88,636	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$10,403	$88,427	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$10,310	$88,224	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$10,218	$88,034	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$10,127	$87,840	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$10,037	$87,657	4.2%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$10,658	$88,193	4.2%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$10,563	$88,051	4.2%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.2	–$0.1
NPV at 7%					$0.1	–$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-21. Impact on C2 Other Commercial Vessel Market: >2,000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	–$521	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	–$686	0.0%	–0.1%	$0.0	Loss less than $0.1
2010	$0	–$852	0.0%	–0.1%	$0.0	Loss less than $0.1
2011	$0	–$1,017	0.0%	–0.1%	$0.0	Loss less than $0.1
2012	$0	–$1,397	–0.1%	–0.1%	$0.0	Loss less than $0.1
2013	$0	–$1,496	–0.1%	–0.1%	$0.0	Loss less than $0.1
2014	$0	–$1,472	–0.1%	–0.1%	$0.0	Loss less than $0.1
2015	$0	–$1,135	–0.1%	–0.1%	$0.1	Loss less than $0.1
2016	$12,491	$222,458	10.6%	–0.2%	Less than $0.1	Loss less than $0.1
2017	$12,379	$222,075	10.6%	–0.2%	Less than $0.1	Loss less than $0.1
2018	$10,633	$170,182	8.1%	–0.2%	Less than $0.1	Loss less than $0.1
2019	$10,538	$169,733	8.1%	–0.2%	Less than $0.1	Loss less than $0.1
2020	$10,444	$169,278	8.1%	–0.3%	Less than $0.1	Loss less than $0.1
2021	$10,351	$168,819	8.0%	–0.3%	Less than $0.1	Loss less than $0.1
2022	$10,259	$168,373	8.0%	–0.3%	Less than $0.1	Loss less than $0.1
2023	$10,167	$167,944	8.0%	–0.4%	Less than $0.1	Loss less than $0.1
2024	$10,076	$167,513	8.0%	–0.4%	Less than $0.1	Loss less than $0.1
2025	$10,755	$167,869	8.0%	–0.4%	Less than $0.1	Loss less than $0.1
2026	$10,659	$167,458	8.0%	–0.5%	Less than $0.1	Loss less than $0.1
2027	$10,564	$167,057	8.0%	–0.5%	Less than $0.1	Loss less than $0.1
2028	$10,470	$166,677	7.9%	–0.5%	Less than $0.1	Loss less than $0.1
2029	$10,376	$166,319	7.9%	–0.5%	Less than $0.1	Loss less than $0.1
2030	$10,284	$166,004	7.9%	–0.5%	Less than $0.1	Loss less than $0.1
2031	$10,192	$165,724	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2032	$10,101	$165,464	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2033	$10,726	$165,934	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2034	$10,630	$165,695	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2035	$10,535	$165,466	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2036	$10,442	$165,251	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2037	$10,348	$165,032	7.9%	–0.6%	Less than $0.1	Loss less than $0.1
2038	$10,256	$164,824	7.8%	–0.6%	Less than $0.1	Loss less than $0.1
2039	$10,165	$164,629	7.8%	–0.7%	Less than $0.1	Loss less than $0.1
2040	$10,074	$164,480	7.8%	–0.7%	Less than $0.1	Loss less than $0.1
NPV at 3%					$0.4	–$0.3
NPV at 7%					$0.2	–$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7C: Impacts on Transportation Service Markets

This appendix provides the time series of impacts from 2007 through 2040 for two transportation service markets (railroad and marine).[T] Table 7C-1 through Table 7C-2 provide the time series of impacts and include the following:

- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in service user surplus
- changes in service provider surplus
- changes in total surplus

All costs and surplus changes are presented in 2005 dollars and real service prices are assumed to be constant during the period of analysis. Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 and 2040 time period.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[T] The engineering costs we used in the EIA are an earlier version of the estimated compliance costs developed for this rule; see Section 7.3.2 for an explanation of the difference. This difference is not expected to have an impact on the results of the market analysis or on the expected distribution of social costs among stakeholders.

Table 7C-1. Impact on Railroad Services Market

Year	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Service Consumer Surplus (million $)	Change in Service Provider Surplus (million $)	Change in Total Surplus (million $)
2007	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2008	0.0%	0.0%	$25.8	–$19.5	–$6.1	–$25.7
2009	0.1%	0.0%	$32.3	–$24.5	–$7.7	–$32.2
2010	0.1%	0.0%	$58.2	–$44.1	–$13.8	–$57.9
2011	0.2%	–0.1%	$110.1	–$83.5	–$26.1	–$109.6
2012	0.1%	–0.1%	$90.3	–$68.4	–$21.4	–$89.8
2013	0.1%	–0.1%	$82.3	–$62.4	–$19.5	–$81.8
2014	0.1%	0.0%	$61.0	–$46.3	–$14.5	–$60.7
2015	0.2%	–0.1%	$65.2	–$102.5	–$32.0	–$134.6
2016	0.3%	–0.1%	$110.0	–$138.9	–$43.4	–$182.3
2017	0.3%	–0.1%	$111.6	–$129.6	–$40.5	–$170.1
2018	0.3%	–0.1%	$130.0	–$144.4	–$45.1	–$189.5
2019	0.3%	–0.2%	$140.5	–$153.3	–$47.9	–$201.2
2020	0.3%	–0.1%	$132.3	–$148.6	–$46.4	–$195.0
2021	0.3%	–0.2%	$150.0	–$163.5	–$51.1	–$214.6
2022	0.4%	–0.2%	$189.6	–$194.8	–$60.9	–$255.7
2023	0.5%	–0.2%	$254.1	–$245.9	–$76.8	–$322.7
2024	0.5%	–0.2%	$260.5	–$251.7	–$78.7	–$330.4
2025	0.5%	–0.3%	$284.0	–$271.2	–$84.7	–$355.9
2026	0.5%	–0.3%	$288.8	–$275.9	–$86.2	–$362.1
2027	0.5%	–0.3%	$308.4	–$292.0	–$91.3	–$383.3
2028	0.6%	–0.3%	$342.6	–$318.8	–$99.6	–$418.4
2029	0.6%	–0.3%	$362.6	–$334.8	–$104.6	–$439.4
2030	0.6%	–0.3%	$380.5	–$348.9	–$109.0	–$458.0
2031	0.6%	–0.3%	$399.4	–$364.2	–$113.8	–$478.0
2032	0.7%	–0.3%	$408.4	–$372.0	–$116.2	–$488.2
2033	0.8%	–0.4%	$485.6	–$431.1	–$134.7	–$565.9
2034	0.8%	–0.4%	$513.5	–$453.0	–$141.6	–$594.5
2035	0.8%	–0.4%	$539.9	–$473.2	–$147.9	–$621.1
2036	0.8%	–0.4%	$550.9	–$479.9	–$150.0	–$629.8
2037	0.8%	–0.4%	$571.1	–$493.9	–$154.3	–$648.2
2038	0.8%	–0.4%	$590.7	–$507.3	–$158.5	–$665.8
2039	0.9%	–0.4%	$610.2	–$520.3	–$162.6	–$682.9
2040	0.9%	–0.4%	$629.2	–$533.0	–$166.6	–$699.6
NPV at 3%			$4,499.2	–$4,168.7	–$1,302.7	–$5,471.4
NPV at 7%			$1,941.2	–$1,819.5	–$568.6	–$2,388.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7C-2. Impact on Marine Services Market

Year	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Service Consumer Surplus (million $)	Change in Service Provider Surplus (million $)	Change in Total Surplus (million $)
2007	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2008	0.1%	0.0%	$18.1	–$13.7	–$4.3	–$18.0
2009	0.1%	–0.1%	$24.1	–$18.2	–$5.7	–$23.9
2010	0.1%	–0.1%	$30.2	–$22.8	–$7.1	–$30.0
2011	0.2%	–0.1%	$36.4	–$27.5	–$8.6	–$36.1
2012	0.2%	–0.1%	$50.4	–$38.1	–$11.9	–$50.1
2013	0.3%	–0.1%	$54.4	–$41.2	–$12.9	–$54.1
2014	0.3%	–0.1%	$54.1	–$40.9	–$12.8	–$53.7
2015	0.2%	–0.1%	$42.1	–$31.8	–$9.9	–$41.8
2016	0.4%	–0.2%	$46.5	–$57.9	–$18.1	–$75.9
2017	0.4%	–0.2%	$57.1	–$66.1	–$20.6	–$86.7
2018	0.4%	–0.2%	$71.6	–$71.9	–$22.5	–$94.4
2019	0.5%	–0.2%	$85.7	–$82.8	–$25.9	–$108.7
2020	0.6%	–0.3%	$100.8	–$94.4	–$29.5	–$123.8
2021	0.6%	–0.3%	$115.8	–$105.9	–$33.1	–$138.9
2022	0.7%	–0.3%	$130.8	–$117.3	–$36.7	–$154.0
2023	0.7%	–0.4%	$145.6	–$128.7	–$40.2	–$168.9
2024	0.8%	–0.4%	$160.3	–$140.0	–$43.7	–$183.7
2025	0.8%	–0.4%	$174.9	–$151.1	–$47.2	–$198.4
2026	0.9%	–0.5%	$189.4	–$162.2	–$50.7	–$212.9
2027	1.0%	–0.5%	$203.6	–$173.1	–$54.1	–$227.2
2028	1.0%	–0.5%	$217.5	–$183.7	–$57.4	–$241.2
2029	1.0%	–0.5%	$230.4	–$193.7	–$60.5	–$254.2
2030	1.1%	–0.5%	$241.9	–$202.5	–$63.3	–$265.8
2031	1.1%	–0.6%	$252.2	–$210.4	–$65.7	–$276.1
2032	1.1%	–0.6%	$261.6	–$217.7	–$68.0	–$285.8
2033	1.2%	–0.6%	$270.8	–$224.8	–$70.2	–$295.0
2034	1.2%	–0.6%	$279.5	–$231.6	–$72.4	–$303.9
2035	1.2%	–0.6%	$288.0	–$238.1	–$74.4	–$312.5
2036	1.2%	–0.6%	$296.1	–$244.5	–$76.4	–$320.9
2037	1.3%	–0.6%	$304.3	–$250.8	–$78.4	–$329.2
2038	1.3%	–0.6%	$312.4	–$257.1	–$80.3	–$337.4
2039	1.3%	–0.7%	$319.7	–$262.8	–$82.1	–$344.9
2040	1.3%	–0.7%	$325.7	–$267.5	–$83.6	–$351.1
NPV at 3%			$2,644.6	–$2,254.7	–$704.6	–$2,959.3
NPV at 7%			$1,151.2	–$986.9	–$308.4	–$1,295.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7D: Time Series of Social Costs

This appendix provides a time series of the rule's estimated social costs from 2007 through 2040.[U] Costs are presented in 2005 dollars. In addition, this appendix includes the net present values by stakeholder for 2006 using social discount rates of 3% and 7% over the 2007 and 2040 time period. As a result, it illustrates how the choice of discount rate determines the present value of the total social costs of the program.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[U] The engineering costs we used in the EIA are an earlier version of the estimated compliance costs developed for this rule; see Section 7.3.2 for an explanation of the difference. This difference is not expected to have an impact on the results of the market analysis or on the expected distribution of social costs among stakeholders.

Table 7D-1. Time Series of Social Costs: 2007 to 2040 ($2005, $million)[a,b]

Stakeholder Groups	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Rail Sector												
Locomotive Producers	–$8.6	–$8.7	–$8.7	–$38.7	–$42.4	–$35.1	–$35.1	–$40.7	–$5.5	–$8.3	–$0.9	–$1.0
Line–Haul	–$6.0	–$6.1	–$6.1	–$33.7	–$35.5	–$27.8	–$27.8	–$30.9	–$0.6	–$0.9	–$0.8	–$1.0
Switcher/Passenger	–$2.6	–$2.6	–$2.6	–$5.0	–$7.0	–$7.2	–$7.2	–$9.8	–$4.9	–$7.4	–$0.1	–$0.1
Rail Transportation Service Providers	$0.0	–$6.1	–$7.7	–$13.8	–$26.1	–$21.4	–$19.5	–$14.5	–$32.0	–$43.4	–$40.5	–$45.1
Rail Transportation Service Consumers	$0.0	–$19.5	–$24.5	–$44.1	–$83.5	–$68.4	–$62.4	–$46.3	–$102.5	–$138.9	–$129.6	–$144.4
Total Locomotive Sector	–$8.6	–$34.3	–$40.9	–$96.6	–$152.0	–$124.9	–$116.9	–$101.4	–$140.1	–$190.6	–$171.0	–$190.5
Marine Sector												
Marine Engine Producers	–$17.3	–$17.3	–$17.3	–$17.3	–$76.2	–$45.8	–$45.8	–$45.8	–$63.1	–$2.1	–$2.1	–$1.7
Auxiliary >800 hp	–$2.6	–$2.6	–$2.6	–$2.6	–$20.2	–$16.0	–$16.0	–$16.0	–$22.3	–$0.5	–$0.5	–$0.4
C1 >800 hp	–$1.9	–$1.9	–$1.9	–$1.9	–$21.4	–$19.0	–$19.0	–$19.0	–$25.7	–$1.6	–$1.6	–$1.2
C2 >800 hp	–$2.0	–$2.0	–$2.0	–$2.0	–$14.1	–$10.7	–$10.7	–$10.7	–$15.1	$0.0	$0.0	$0.0
Other Marine	–$10.8	–$10.8	–$10.8	–$10.8	–$20.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine Vessel Producers	$0.0	–$0.1	–$0.1	–$0.2	–$0.2	–$0.3	–$0.3	–$0.3	–$13.3	–$15.8	–$12.9	–$10.0
C1 >800 hp	$0.0	$0.0	$0.0	$0.0	$0.0	–$0.1	–$0.1	–$0.1	–$9.4	–$13.5	–$11.6	–$8.7
C2 >800 hp	$0.0	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.2	–$0.1	–$3.8	–$2.2	–$1.2	–$1.3
Other Marine	$0.0	$0.0	$0.0	$0.0	$0.0	–$0.1	–$0.1	–$0.1	$0.0	–$0.1	–$0.1	–$0.1
Recreation and Fishing Vessel Consumers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine Transportation Service Providers	$0.0	–$4.3	–$5.7	–$7.1	–$8.6	–$11.9	–$12.9	–$12.8	–$9.9	–$18.1	–$20.6	–$22.5
Marine Transportation Service Consumers	$0.0	–$13.7	–$18.2	–$22.8	–$27.5	–$38.1	–$41.2	–$40.9	–$31.8	–$57.9	–$66.1	–$71.9
Auxiliary Engines < 800 hp[c]	–$7.6	–$7.6	–$7.6	–$7.6	–$15.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total Marine Sector	–$25.0	–$43.1	–$49.1	–$55.1	–$127.6	–$96.1	–$100.1	–$99.7	–$118.2	–$93.8	–$101.8	–$106.1
Total Program	–$33.5	–$77.4	–$89.9	–$151.7	–$279.5	–$221.0	–$217.0	–$201.1	–$258.3	–$284.4	–$272.8	–$296.6

(continued)

Table 7D-1. Time Series of Social Costs: 2007 to 2040 ($2005, $million)[a,b] (continued)

Stakeholder Groups	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Rail Sector												
Locomotive Producers	–$1.1	–$1.1	–$1.2	–$1.5	–$2.0	–$2.1	–$2.3	–$2.3	–$2.5	–$2.8	–$2.9	–$3.1
Line–Haul	–$1.0	–$1.0	–$1.2	–$1.4	–$1.8	–$1.9	–$2.0	–$2.1	–$2.2	–$2.5	–$2.6	–$2.7
Switcher/Passenger	–$0.1	–$0.1	–$0.1	–$0.1	–$0.2	–$0.2	–$0.2	–$0.3	–$0.3	–$0.3	–$0.4	–$0.4
Rail Transportation Service Providers	–$47.9	–$46.4	–$51.1	–$60.9	–$76.8	–$78.7	–$84.7	–$86.2	–$91.3	–$99.6	–$104.6	–$109.0
Rail Transportation Service Consumers	–$153.3	–$148.6	–$163.5	–$194.8	–$245.9	–$251.7	–$271.2	–$275.9	–$292.0	–$318.8	–$334.8	–$348.9
Total Locomotive Sector	–$202.3	–$196.1	–$215.8	–$257.2	–$324.7	–$332.5	–$358.2	–$364.4	–$385.8	–$421.2	–$442.3	–$461.1
Marine Sector												
Marine Engine Producers	–$1.7	–$1.8	–$1.8	–$1.8	–$1.8	–$1.9	–$1.9	–$1.9	–$2.0	–$2.0	–$2.0	–$2.0
Auxiliary >800 hp	–$0.4	–$0.4	–$0.4	–$0.4	–$0.4	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5
C1 >800 hp	–$1.2	–$1.3	–$1.3	–$1.3	–$1.3	–$1.3	–$1.3	–$1.3	–$1.4	–$1.4	–$1.4	–$1.4
C2 >800 hp	$0.0	$0.0	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1
Other Marine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine Vessel Producers	–$10.2	–$10.3	–$10.5	–$10.6	–$10.8	–$10.9	–$11.0	–$11.2	–$11.3	–$11.5	–$9.1	–$9.2
C1 >800 hp	–$8.7	–$8.8	–$8.9	–$9.0	–$9.1	–$9.2	–$9.2	–$9.3	–$9.4	–$9.5	–$8.1	–$8.2
C2 >800 hp	–$1.3	–$1.3	–$1.4	–$1.4	–$1.5	–$1.5	–$1.6	–$1.6	–$1.6	–$1.7	–$0.7	–$0.7
Other Marine	–$0.1	–$0.1	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.3	–$0.3	–$0.3	–$0.3	–$0.3
Recreation and Fishing Vessel Consumers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine Transportation Service Providers	–$25.9	–$29.5	–$33.1	–$36.7	–$40.2	–$43.7	–$47.2	–$50.7	–$54.1	–$57.4	–$60.5	–$63.3
Marine Transportation Service Consumers	–$82.8	–$94.4	–$105.9	–$117.3	–$128.7	–$140.0	–$151.1	–$162.2	–$173.1	–$183.7	–$193.7	–$202.5
Auxiliary Engines < 800 hp[c]	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total Marine Sector	–$120.6	–$135.9	–$151.2	–$166.4	–$181.5	–$196.4	–$211.3	–$226.0	–$240.4	–$254.6	–$265.3	–$277.0
Total Program	–$322.9	–$332.0	–$367.0	–$423.5	–$506.1	–$528.9	–$569.5	–$590.4	–$626.2	–$675.8	–$707.6	–$738.1

(continued)

Table 7D-1. Time Series of Social Costs: 2007 to 2040 ($2005, $million)[a,b] (continued)

Stakeholder Groups	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV (3%)	NPV (7%)
Rail Sector												
Locomotive Producers	–$3.3	–$3.4	–$3.9	–$4.1	–$4.3	–$4.2	–$4.2	–$4.2	–$4.1	–$4.0	–$221.1	–$160.4
Line–Haul	–$2.8	–$2.9	–$3.4	–$3.6	–$3.7	–$3.6	–$3.6	–$3.6	–$3.6	–$3.5	–$172.2	–$124.5
Switcher/Passenger	–$0.4	–$0.5	–$0.5	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$48.9	–$35.9
Rail Transportation Service Providers	–$113.8	–$116.2	–$134.7	–$141.6	–$147.9	–$150.0	–$154.3	–$158.5	–$162.6	–$166.6	–$1,302.7	–$568.6
Rail Transportation Service Consumers	–$364.2	–$372.0	–$431.1	–$453.0	–$473.2	–$479.9	–$493.9	–$507.3	–$520.3	–$533.0	–$4,168.7	–$1,819.5
Total Locomotive Sector	–$481.2	–$491.6	–$569.8	–$598.7	–$625.4	–$634.0	–$652.4	–$670.0	–$687.1	–$703.6	–$5,692.6	–$2,548.5
Marine Sector												
Marine Engine Producers	–$2.1	–$2.1	–$2.1	–$2.1	–$2.2	–$2.2	–$2.2	–$2.2	–$2.3	–$2.3	–$307.5	–$229.4
Auxiliary >800 hp	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5	–$0.5	–$0.6	–$0.6	–$0.6	–$87.3	–$64.0
C1 >800 hp	–$1.4	–$1.4	–$1.4	–$1.4	–$1.5	–$1.5	–$1.5	–$1.5	–$1.5	–$1.5	–$106.8	–$74.6
C2 >800 hp	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$56.8	–$42.6
Other Marine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$56.7	–$48.1
Marine Vessel Producers	–$9.3	–$9.5	–$9.6	–$9.7	–$9.8	–$9.9	–$10.1	–$10.2	–$10.3	–$10.4	–$150.0	–$72.5
C1 >800 hp	–$8.2	–$8.3	–$8.4	–$8.5	–$8.6	–$8.7	–$8.7	–$8.8	–$8.9	–$9.0	–$126.8	–$60.8
C2 >800 hp	–$0.8	–$0.8	–$0.8	–$0.8	–$0.9	–$0.9	–$0.9	–$0.9	–$1.0	–$1.0	–$19.7	–$10.2
Other Marine	–$0.3	–$0.3	–$0.4	–$0.4	–$0.4	–$0.4	–$0.4	–$0.4	–$0.4	–$0.4	–$3.5	–$1.5
Recreation and Fishing Vessel Consumers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.2	$0.1
Marine Transportation Service Providers	–$65.7	–$68.0	–$70.2	–$72.4	–$74.4	–$76.4	–$78.4	–$80.3	–$82.1	–$83.6	–$704.6	–$308.4
Marine Transportation Service Consumers	–$210.4	–$217.7	–$224.8	–$231.6	–$238.1	–$244.5	–$250.8	–$257.1	–$262.8	–$267.5	–$2,254.7	–$986.9
Auxiliary Engines < 800 hp[c]	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$40.2	–$34.2
Total Marine Sector	–$287.5	–$297.3	–$306.7	–$315.8	–$324.5	–$333.0	–$341.4	–$349.8	–$357.4	–$363.7	–$3,456.7	–$1,631.3
Total Program	–$768.7	–$788.9	–$876.5	–$914.4	–$949.9	–$967.0	–$993.8	–$1,019.8	–$1,044.5	–$1,067.3	–$9,149.2	–$4,179.8

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

[c] Marine auxiliary engines <800 hp are not subject to Tier 4 standards, and there are no variable costs associated with the Tier 3 standards. Consequently, there would be no direct compliance impacts for producers or users of these engines. Social costs are limited to fixed costs associated with tooling and certification for Tier 3 standards (those costs occur 2007-2011).

Appendix 7E: Model Equations

To develop the economic impact model, we use a set of nonlinear supply and demand equations for the affected markets and transform them into a set of linear supply and demand equations. These resulting equations describe stakeholder production and consumption responses to policy-induced cost and price changes in each market. They are also used to specify the conditions for a new with-policy equilibrium. We describe these equations in more detail below.

7E.1 Economic Model Equations

7E.1.1 Supply Equations

First, we consider the formal definition of the elasticity of supply with respect to changes in own price:

$$\varepsilon_s = \frac{dQ_s / Q_s}{dp / p} . \qquad \text{(7E.1)}$$

Next, we can use "hat" notation to transform Eq. (7E.1) to proportional changes and rearrange terms:

$$\hat{Q}_s = \varepsilon_s \hat{p} \qquad \text{(7E.1a)}$$

where

$\hat{Q}_s$ = percentage change in the quantity of market supply,

γ_s = market elasticity of supply, and

$\hat{p}$ = percentage change in market price.

As Fullerton and Metcalf note, this approach takes the elasticity definition and turns it into a linear *behavioral* equation for each market.[31]

To introduce the direct impact of the regulatory program, we assume the direct per-unit compliance cost (c) leads to a proportional shift in the marginal cost of production. Under the assumption of perfect competition (price equals marginal cost), we can approximate this shift at the initial equilibrium point as follows:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o} . \qquad \text{(7E.1b)}$$

The with-regulation supply response to price and cost changes can now be written as:

$$\hat{Q}_S = \varepsilon_S \, (\hat{p} - \hat{MC}) \qquad (7E.1c)$$

For equipment producers, the supply response also simultaneously accounts for changes in equilibrium input prices (engines). To do this, we modify Eq. (7E.1b) as follows:

$$\hat{MC} = \frac{c + \alpha(\Delta p_{eng})}{MC_o} = \frac{c + \alpha(\Delta p_{eng})}{p_o} \qquad (7E.1d)$$

where Δp_{engine} is the equilibrium change in the engine price and α is the ratio of engines used per unit of equipment. For example, if one piece of equipment uses only one engine, then α = 1. This equation can accommodate other input-output ratios by multiplying Δp_{eng} by the appropriate input-to-output ratio (α).

For transportation service providers, the supply response also simultaneously accounts for changes in equilibrium input prices (equipment). To do this, we use an equation similar to Eq. (7E.1.d):

$$\hat{MC} = \frac{c + \alpha(\Delta p_{equip})}{MC_o} = \frac{c + \alpha(\Delta p_{equip})}{p_o} \qquad (7E.1e)$$

where Δp_{equip} is the equilibrium change in the equipment price and α is the ratio of equipment used per unit of transportation services.

7E.1.2 Demand Equations

Similar to supply, we can characterize services and selected equipment[V] demand responses to price changes as:

$$\hat{Q}_d = \eta_d \, \hat{p} \qquad (7E.2)$$

where

$\hat{Q}_d$ = percentage change in the quantity of market demand,

η^d = market elasticity of demand, and

$\hat{p}$ = percentage change in market price.

[V] The equipment markets are recreational vessels and fishing vessels. The remaining vessel and locomotive demand curves are derived from the supply decisions of the appropriate downstream transportation service markets.

In contrast the demand for engines and selected equipment markets is a derived demand and is related to equipment or service supply decisions. In order to maintain a constant input-to-output ratio, the derived demand for inputs is specified as:

$$\hat{Q}_{input} = \hat{Q}_{output} . \qquad (7E.3)$$

7E.1.3 Market Equilibrium Conditions

In response to the exogenous increase production costs, stakeholder responses are completely characterized by represented in Eq. (7E.1.c)(service, equipment and engine supply), Eq. (7E.2) (service and selected equipment demand), Eq. (7E.3) (derived demand for selected equipment and engine). Next, we specify the relationship that must hold for markets to "clear", that is, supply in each market equals demand. Given the equations specified above, the new equilibrium satisfies the condition that for each market, the proportional change in supply equals the proportional change in demand:

$$\hat{Q}_s = \hat{Q}_d . \qquad (7E.4)$$

7E.2 Computing With-Regulation Equilibrium Conditions within the Spreadsheet

The French economist Léon Walras proposed one early model of market price adjustment by using the following thought experiment. Suppose there is a hypothetical agent that facilitates market adjustment by playing the role of an "auctioneer." He announces prices, collects information about supply and demand responses (without transactions actually taking place), and continues this process until market equilibrium is achieved.

For example, consider the with-regulation supply and demand conditions at the without-regulation equilibrium price (P) (see Figure 7E-1). The auctioneer determines that the quantity demanded (A) exceeds the quantity supplied (B) at this price and calls out a new (higher) price (P′) based on the amount of excess demand. Consumers and producers make new consumption and production choices at this new price (i.e., they move along their respective demand and supply functions), and the auctioneer checks again to see if excess demand or supply exists. This process continues until P = P* (point C in Figure 7E-1) is reached (i.e., excess demand is zero in the market). A similar analysis takes place when excess supply exists. The auctioneer calls out lower prices when the price is higher than the equilibrium price.

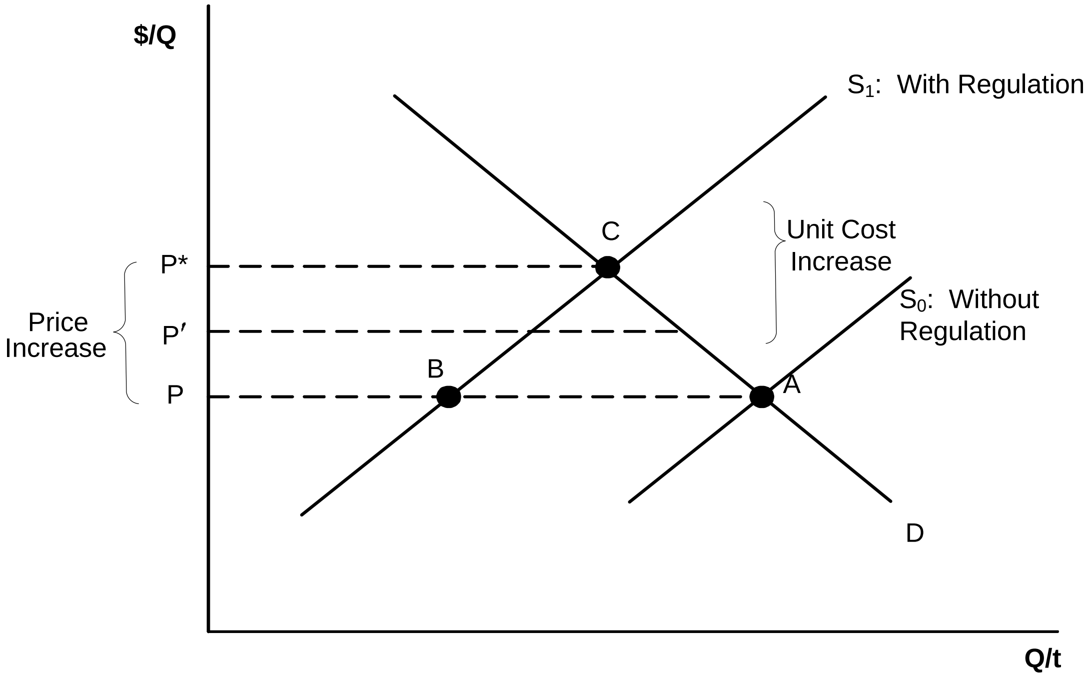


Figure 7E-1. Computing With-Regulation Equilibrium

The economic model uses a similar type of algorithm for determining with-regulation equilibria, and the process can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.

2. Recalculate the market supply in each market. Excess demand currently exists.

3. Determine the new prices via a price revision rule. We use a rule similar to the factor price revision rule described by Kimbell and Harrison.[32] P_i is the market price at iteration i, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and the speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s}\right)^z \qquad (7E.5)$$

4. Recalculate market supply with new prices.

5. Compute market demand in each market.

6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one). When the ratio is appropriately close to one, the market-clearing condition of supply equals demand is satisfied.

7E.3 Social Costs: Consumer and Producer Economic Welfare Calculations

The change in consumer surplus in the affected markets can be estimated using the following linear approximation method:

$$\Delta CS = -[Q_1 \times \Delta p] + [0.5 \times \Delta Q \times \Delta p]. \qquad (7E.6)$$

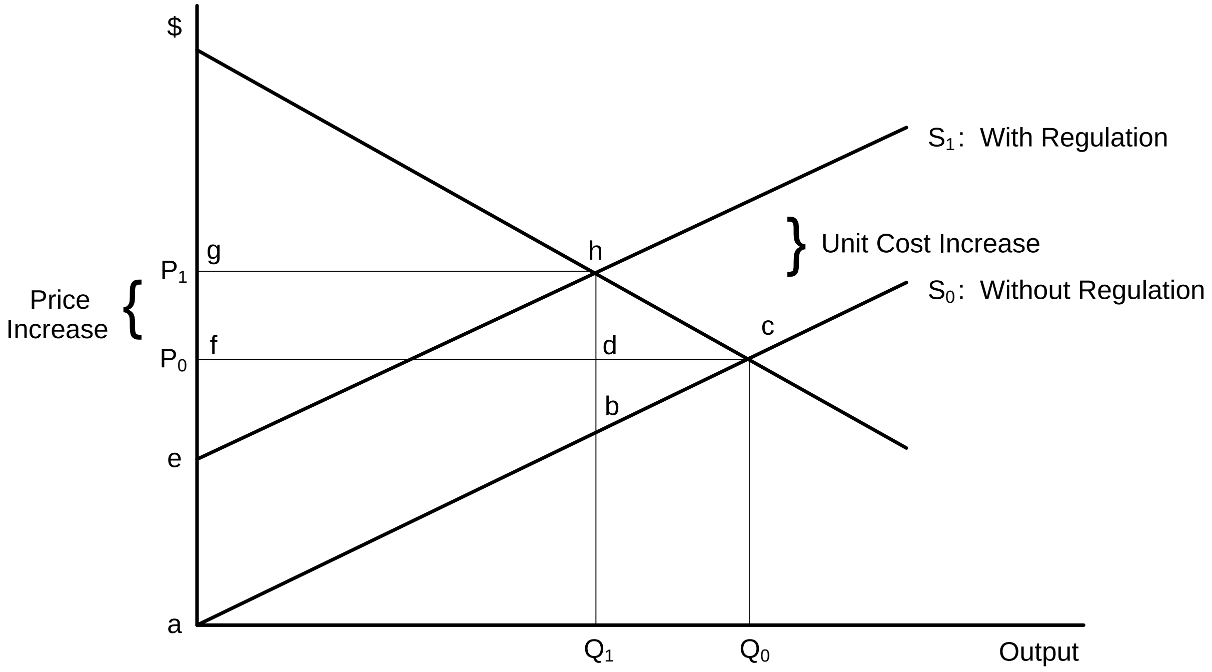
As shown, higher market prices and reduced consumption lead to welfare losses for consumers. A geometric representation of this calculation is illustrated in Figure 7E-2.

For affected supply, the change in producer surplus can be estimated with the following equation:

$$\Delta PS = [Q_1 \times \Delta p] - [Q_1 \times \Delta MC] - [0.5 \times \Delta Q \times (\Delta p - \Delta MC)]. \qquad (7E.7)$$

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change (Δp – ΔMC) is negative. However, these losses are mitigated, to some degree, as a result of higher market prices. A geometric representation of this calculation is also illustrated in Figure 7E-2.

Throughout this report, changes in surplus reflect the *social costs* of the emission control program. These calculations exclude any environmental benefits associated with the rule.



) consumer surplus = –[fghd + dhc]

) producer surplus = [fghd – aehb] – bdc

) total surplus = –[aehb + dhc + bdc]

Figure 7E-2. Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus

Appendix 7F: Elasticity Parameters for Economic Impact Modeling

Elasticities were obtained from peer-reviewed literature or were obtained from other EPA rule that estimated these parameters using empirical methods (i.e. econometrically). Table 7F-1 and Table 7F-2 summarize the price elasticities of supply and demand used in this analysis. The methodologies for estimating the supply and demand elasticities are described in the documents identified in the data source column. The unknown parameters for the analysis were the locomotive and commercial marine vessel supply elasticities. This appendix describes the methods and data used to identify these two supply elasticites used in the economic impact analysis.

It should be noted that the methods we used to estimate the price elasticites have certain limitations. The production function approach that was previously used to estimate the supply elasticity or the approach described in this appendix was limited in available data. Specifically, firm level or plant level data was unavailable for the companies that operate in the affected sectors. As a result, the supply elasticities were estimated with industry level aggregate data. However, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To address these concerns, EPA intends to investigate estimates for the price elasticity of supply for the affected industries for which published estimates are not available, using alternative methods and data inputs. This research program will use the cross-sectional data model at either the firm-level or plant level from the U.S. Census Bureau to estimate these elasticities. We plan to use the results of this research provided the results are robust and that they are available in time for the analysis for the final rule.

Table 7F-1. Summary of Market Demand Elasticities Used in EIM

Market	Estimate	Source	Method	Data Source
Rail				
Rail Transp. Svcs	-0.5	Literature estimate	Literature review	Boyer, K.D. 1997. *Principles of Transportation Economics*. Reading, MA: Addison-Wesley.
Locomotives	Derived			
Marine				

Marine Transp. Svcs	-0.5	Literature estimate	Assumed value	Uses the same elasticity as the locomotive transportation services sector.
Vessels—Commercial Fishing (>800 hp)	Derived			
Vessels—Fishing (<800 hp)	-2.0	Econometric estimate	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	-2.0	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2007. *Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment Draft Regulatory Impact Analysis*. EPA420-D-07-004. Available at <http://www.epa.gov/otaq/regs/nonroad/marinesi-equipld/420d07004.pdf>.
Engines	Derived			

Table 7F-2. Summary of Supply Elasticities Used in EIM

Market	Estimate	Source	Method	Input Data Source
Rail				
Rail Transp. Svcs	1.6	Literature estimate	Method based on cost elasticities reported in Ivaldi and McCollough (2001)	Ivaldi, M. and McCullough, G. 2001. "Density and Integration Effects on Class I U.S. Freight Railroads." Journal of Regulatory Economics 19:161-162.
Locomotives	2.7	EPA estimate	Calibration method	U.S. Bureau of the Census. 2004a. “Railroad Rolling Stock Manufacturing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004” Annual Survey of Manufacturers. M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Marine				
Marine Transp. Svcs	1.6	Assumed value; uses the same elasticity as the rail transportation services sector		

Vessels—Commercial and large fishing	2.3	EPA estimate	Calibration method	U.S. Bureau of the Census. 2004b. "Ship Building and Repairing: 2002." *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. "Statistics for Industry Groups and Industries: 2004" Annual Survey of Manufacturers. M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Vessels—Recreational and small fishing	2.3	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2007. *Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment Draft Regulatory Impact Analysis*. EPA420-D-07-004. Available at <http://www.epa.gov/otaq/regs/nonroad/marinesi-equipld/420d07004.pdf>.
Engines	3.8	Econometric estimate	Previous EPA economic analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.

The technique we used to quantify the locomotive and commercial marine vessel industry supply elasticity is described as "calibration approach" in Handbook of of Econometrics, Volume 5.[33] This approach involves specifying an economic model of supply, treating some of the parameters of the model as fixed using secondary data, and solving for unknown parameters that replicate a benchmark data set.[W] The specific procedure uses an analytical expression for a short-to-intermediate run supply elasticity derived by Rutherford and recent benchmark data sets from Economic Census data between 1997 and 2004.[34]

As described by Rutherford, the procedure specifies that the functional form of the production function is the constant elasticity of substitution (CES). It also assumes there is a fixed capital input that makes it consistent with the intermediate-run time frame of the analysis. As Rutherford shows, the price elasticity of supply can be expressed as

$$\varepsilon = (1 - \theta) \times \sigma / \theta,$$

where θ represents the value share of capital and σ represents the elasticity of substitution between inputs. For this analysis, we assume an elasticity of substitution of one ($\sigma = 1$), which yields a Cobb-Douglas production technology that is a special case of the CES production

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[W] A complete discussion of the meaning, merits and criticism, and best practices of these types of techniques can be found in Dawkins, Christina & T. N. Srinivasan, & John Whalley, (2001). "Calibration" in Handbook of Econometrics, Volume 5, ed. J. J. Heckman & E. E. Leamer, (Amsterdam: Elsevier).

function. The Cobb-Douglas production function is one of the most commonly used production functions in economics studies.

We collected the latest Economic Census data for NAICS 336510 (Railroad Rolling Stock Manufacturing) that provides an estimate of the value share of capital θ for locomotives. To compute this value share, we subtracted reported payroll costs from the reported industry value added and divided by the total value of shipments (see Table 7F-3). Using the elasticity formula, σ = 1, and annual value share data reported in Table 7F-3, we computed an average supply elasticity value of 2.7 for this industry. Accounting for variability of the value share parameter across 1997 to 2004, we computed a 95% confidence interval for the elasticity value that ranges from 1.9 to 3.4.

Similarly, we estimated the value share of capital θ for commercial marine vessels from latest Economic Census data for NAICS 336611 (Ship Building and Repairing Manufacturing). Using the elasticity formula, σ = 1, and annual value share data reported in Table 7F-4, we computed an average supply elasticity value of 2.3 for this industry. By the value share parameter across 1997 to 2004, we computed a 95% confidence interval for the elasticity value that ranges from 1.3 to 3.2.

The parameter estimates suggest both locomotive and commercial marine vessel supplies are elastic and firms can change production levels in response to changes in market prices. Two factors support an elastic supply estimate for this sector. First, industries that are less capital intensive typically have more flexibility to adjust variable inputs (e.g. labor and/or materials) and can change production levels in response to variations in market prices. The Census data for locomotive and ship building manufacturing are consistent with this observation and suggest the capital share of production costs in the locomotive or ship building industry is small relative to other inputs. The value share of capital is ranging from 20% to 30% for locomotives and from 25% to 38% for ship building and repairing. Second, industries with excess production capacity also have more flexibility to change output levels in response to price changes. Data from the Census also suggest the locomotive manufacturing industry's capacity utilization rates have been low, implying excess capacity exists. Data for the fourth quarters of 2000 to 2004 show utilization rates ranging from 45% to 69%. For ship building and repairing industry, the production capacity utilization ratio for the fourth quarters of 2000 to 2004 is ranging around 50% to 80% according to U.S. Bureau of the Census data.

Table 7F-3. Benchmark Supply Elasticities for NAICS 336510 (Railroad Rolling Stock Manufacturing): 1997–2004 ($1,000)

Year	Value of Shipments	Value Added	Payroll Costs	Value Share of Capital (θ)[a]	Supply Elasticity $\varepsilon = (1 - \theta) \times \sigma / \theta$ σ=1 (Cobb-Douglas)
2004	$7,566,129	$3,216,704	$1,123,054	28%	2.6
2003	$7,404,763	$2,909,834	$1,156,084	24%	3.2
2002	$7,793,382	$3,741,703	$1,195,073	33%	2.1
2001	$8,578,053	$3,824,449	$1,449,784	28%	2.6
2000	$9,722,424	$4,360,089	$1,480,181	30%	2.4
1999	$10,352,310	$4,460,735	$1,532,969	28%	2.5
1998	$9,256,810	$3,848,408	$1,440,110	26%	2.8
1997	$8,263,395	$3,345,283	$1,319,135	25%	3.1
Parameter Statistics					
Average					2.7
Standard deviation					0.4
Upper bound (95% confidence interval)					3.4
Lower bound (95% confidence interval)					1.9

[a] The value share of capital is computed by subtracting payroll costs from reported value added and dividing by the total value of shipments.

Sources: U.S. Bureau of the Census. 2004. “Railroad Rolling Stock Manufacturing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1.

U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004.” *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.

Table 7F-4. Benchmark Supply Elasticities for NAICS 336611 (Ship Building & Repairing): 1997–2004 ($1,000)

Year	Value of Shipments	Value Added	Payroll Costs	Value Share of Capital (θ)[a]	Supply Elasticity $\varepsilon = (1 - \theta) \times \sigma / \theta$ σ=1 (Cobb-Douglas)
2004	$13,705,958	$8,573,286	$3,772,590	35%	1.9
2003	$13,485,503	$8,679,730	$3,692,026	37%	1.7
2002	$12,814,574	$8,449,010	$3,628,382	38%	1.7
2001	$11,792,832	$6,968,749	$3,439,474	30%	2.3
2000	$11,380,112	$6,324,192	$3,435,806	25%	2.9
1999	$11,070,960	$6,328,784	$3,336,632	27%	2.7
1998	$11,143,246	$6,728,975	$3,347,525	30%	2.3
1997	$10,542,961	$6,202,797	$3,353,414	27%	2.7
Parameter Statistics					
Average					2.3
Standard Deviation					0.5
Upper Bound (95% Confidence Interval)					3.2
Lower Bound (95% Confidence Interval)					1.3

[a] The value share of capital is computed by subtracting payroll costs from reported value added and dividing by the total value of shipments.

Sources: U.S. Bureau of the Census. 2004b. “Ship Building and Repairing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1.

U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004.” *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.

Appendix 7G: Initial Market Equilibrium - Price Forecasts

The EIM analysis begins with current market conditions: equilibrium supply and demand. To estimate the economic impact of a regulation, standard practice uses projected market equilibrium (time series of prices and quantities) as the baseline and evaluates market changes from this projected baseline. Consequently, it is necessary to forecast equilibrium prices and quantities for future years.

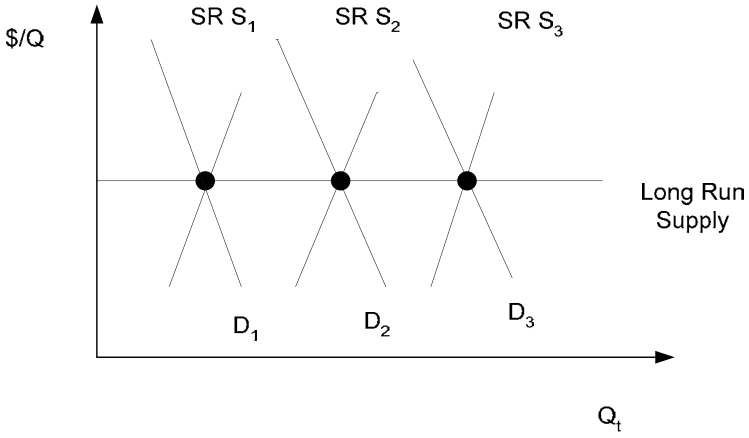

Figure 7G-1. Prices and Quantities in Long Run Market Equilibrium

Equilibrium price forecasts typically use one of two approaches.[35] The first assumes a constant (real) price of goods and services over time. The second models a specific time series where prices may change over time due to exogenous factors.

In the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time. As shown in Figure 7G-1, demand grows over time, in the long run, capacity will also grow as existing firms expand or new firms enter the market and eliminate any excess profits. This produces a flat long run supply curve. Note that in the short to medium run time frame the supply curve has a positive slope due to limitations in how quickly firms can react.

If capacity is constrained (preventing the outward shift of the baseline supply curve) or if the price of production inputs increase (shifting the baseline supply curve upward over time), then prices may trend upward reflecting that either the growth in demand is exceeding supply or the commodity is becoming more expensive to produce.

It is very difficult to develop forecasts events (such as those mentioned above) that influence long run prices. As a result, the approach used in this analysis is to use a constant 2005 observed price.

Appendix 7H: Sensitivity Analysis

The economic impact analysis presented in this Chapter is based on an economic impact model developed specifically for this analysis. The EIM reflects specific assumptions about behavioral responses (represented the price elasaticities of supply and demand) and how the engineering compliance costs are included in the market supply function shift (supply affected by variable costs only, in accordance with the underlying assumption of perfect competition). This appendix examines the sensitivity of the market and social welfare impacts estimated by the model to the values used for these key parameters. Alternative values for these parameters are selected and the results are compared to the results of the primary analysis described in Section 7.1. Four model components are examined:[X]

- Scenario 1: alternative market supply and demand elasticity parameters for all markets
- Scenario 2: alternative ways to treat the market supply shifts (variable and fixed costs)
- Scenario 3: alternative supply elasticity parameter for equipment markets, based on supply elasticities estimated using an alternative methodology
- Scenario 4: alternative way to treat compliance costs for auxiliary engines above 800 hp

The results of these four sensitivity analysis scenarios are presented below. Although estimates of market impacts and total economic welfare changes for the different scenarios are similar for to the primary case, the different assumptions highlight the role the assumptions play in determining the distribution of welfare changes among stakeholders.

[X] An additional sensitivity analysis was included in the draft RIA prepared for the NPRM in which we examined an alternative methodology of allocating operating costs (fuel costs associated with Tier 4 and marine remanufacture costs). In the primary case for the draft EIA, all marine operating costs were allocated to the marine transportation service providers; in the sensitivity analysis we explored a scenario that allocated operating costs to fishing and recreational vessels as well. This scenario is not relevant for the final rule for two reasons. First, recreational engines are not subject to the Tier 4 standards in the final rule, and recreational engines above 800 hp are not expected to come under the marine remanufacture program due to their operational characteristics. Second, fishing vessels below 800 hp are not subject to the Tier 4 standards or marine remanufacture requirements, and fishing vessels above 800 hp are now modeled as being directly consumed in the transportation services market (see 7.1.3.2).

7H.1 Model Elasticity Parameters

Key model parameters include estimates of the price elasticity of supply and demand used by the model to characterize behavioral responses of producers and consumers in each market in response to a change in price.

Consumer demand and producer supply responsiveness to changes in the commodity prices are referred to by economists as “elasticity.” The measure is typically expressed as the percentage change in quantity (demanded or supplied) brought about by a percent change in own price. A detailed discussion regarding the estimation and selection of the supply and demand elasticities used in the EIM are discussed in Appendix 10F. This component of the sensitivity analysis examines the impact of changes in selected elasticity values, holding other parameters constant. The goal is to determine whether alternative elasticity values significantly alter conclusions in this report.

There are at least two ways to examine the sensitivity of the EIA results to assumptions about the price elasticity of supply or demand. The first is to choose upper and lower bounds for these variables based on the ranges of values reported in the literature or based on sensitivity analysis constructed around estimated values. This method was not available for this study because, as described in Appendix F, many of these parameters were obtained from secondary sources and information was not readily available to compute confidence intervals for them. Therefore, an alternative approach was used in which the supply or demand elasticity parameters were increased/decreased by about 25 percent while holding all other model parameters (including the other elasticities) constant. Table 7H-1 reports the upper- and lower-bound demand and supply elasticity estimates used in this analysis.

Parameter	Elasticity Source	Lower Bound	Base Case	Upper Bound
DEMAND ELASTICITIES				
Rail and marine transportation services	Literature estimate	-0.4	-0.5	-0.6
Locomotive	Derived		N/A	
Commercial vessels	Derived		N/A	
Recreational and fishing vessels	Econometric Estimate	-1.5	-2.0	-2.5
Marine engines	Derived		N/A	
SUPPLY ELASTICITIES				
Rail and marine transportation services	Literature estimate	1.2	1.6	2.0
Locomotives	Calibration Estimate	2.0	2.7	3.4
Commercial marine vessels	Calibration Estimate	1.7	2.3	2.9

Recreational and fishing vessels	Econometric Estimate	1.7	2.3	2.9
Marine engines	Econometric Estimate	2.9	3.8	4.8

The results of this analysis for 2020 are presented in Tables 7H-2 and 7H-3. Varying the model's elasticity parameters does not significantly change the estimated impacts on total economic welfare. However, varying the model parameters has an impact on how the regulatory program costs are distributed across stakeholders. The elasticity parameters play an important role in determining the economic incidence of the regulatory program.

In scenarios in which the supply side of the service markets is more responsive to price changes (more elastic) users of services would bear more of the burden of the regulatory program. Thus, when the elasticity of supply is more elastic (producers are more sensitive to a change in price) and demand is held constant, the expected surplus loss to users of transportation services increases from 28 percent to 30 percent for marine and from 45 percent to 47 percent for rail, respectively (see Table 7H-2). Similarly, when the elasticity of demand is less elastic (consumers are less sensitive to a change in price) and the supply elasticity is held constant, the expected surplus loss to users of transportation services increases from 28 percent to 31 percent for marine and from 45 percent to 48 percent for rail, respectively (see Table 7H-3).

In contrast, when the supply side of the service market is less responsive to price changes (the elasticity of supply is less elastic) or the demand side of the service is more sensitive to price changes (the elasticity of demand is more elastic), service providers would bear more of the burden of the regulatory program. Here, when the elasticity of supply is decreased but the elasticity of demand is held constant, the expected surplus loss to providers of transportation services increases from 9 percent to 11 percent for marine and from 14 percent to 17 percent for rail, respectively (see Table 7H-2). When the elasticity of demand is more elastic (consumers are more sensitive to a change in price) and the supply elasticity is held constant, the expected surplus loss to providers of transportation services increases from 9 percent to 10 percent for marine and from 14 percent to 17 percent for rail, respectively (see Table 7H-3).

With regard to locomotive, marine vessel, and marine diesel engine suppliers, their share of the surplus loss increases when the price elasticity of supply is less elastic (they are less sensitive to prices changes) or when the price elasticity of demand is more elastic (consumers are more sensitive to price changes).

With regard to market effects, price increases and quantity decreases are somewhat higher when the price elasticity of supply is more elastic or the price elasticity of demand is less elastic and somewhat lower when the price elasticity of supply is less elastic or the price elasticity of demand is more elastic.

Table 7H-2. Sensitivity Analysis for Supply Elasticity Parameters: 2020[a]

Market–Level Impacts	Variable Engineering Cost Per Unit	Primary Case				Supply Upper				Supply Lower			
		Change in Price		Change in Quantity		Change in Price		Change in Quantity		Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Rail Sector													
Locomotives													
Line Haul	$65,343	$64,261	3.2%	-1	–0.1%	$64,433	3.2%	-1	–0.2%	$64,009	3.2%	-1	–0.1%
Switcher/Passenger	$21,139	$20,436	1.6%	0	–0.1%	$20,548	1.6%	0	–0.2%	$20,271	1.6%	0	–0.1%
Transportation services	NA	NA	0.3%	NA	–0.1%	NA	0.3%	NA	–0.2%	NA	0.3%	NA	–0.1%
Marine Sector													
Engines													
Auxiliary >800 hp	$28,363	$27,129	13.1%	–9	–2.7%	$27,267	13.1%	–10	–3.0%	$26,950	13.0%	–8	–2.3%
C1 >800 hp	$14,131	$12,497	6.5%	–12	–2.9%	$12,676	6.6%	–13	–3.2%	$12,267	6.4%	–10	–2.4%
C2 >800 hp	$54,893	$54,573	12.4%	0	–0.3%	$54,621	12.4%	0	–0.3%	$54,502	12.4%	0	–0.3%
Other marine	$0	-$1	0.0%	0	0.0%	$0	0.0%	0	0.0%	–$1	0.0%	0	0.0%
Equipment													
C1 >800 hp	$6,936	$26,158	1.6%	–11	–2.9%	$28,705	1.8%	–12	–3.2%	$22,890	1.4%	–10	–2.4%
C2 >800 hp	$10,174	$170,164	5.3%	0	–0.3%	$171,103	5.3%	0	–0.3%	$168,818	5.2%	0	–0.3%
Other marine	$0	–$6	0.0%	–2	0.0%	–$5	0.0%	–2	0.0%	–$8	0.0%	–2	0.0%
Transportation services	NA	NA	0.6%	NA	–0.3%	NA	0.6%	NA	–0.3%	NA	0.5%	NA	–0.3%
Welfare Impacts (Million $)		**Surplus Change**		**Share**		**Surplus Change**		**Share**		**Surplus Change**		**Share**	
Locomotives													
Locomotive producers		–$1.1		0.3%		–$0.9		0.3%		–$1.3		0.4%	
Line Haul		–$1.0		0.3%		–$0.9		0.3%		–$1.3		0.4%	
Switcher/Passenger		–$0.1		0.0%		–$0.1		0.0%		–$0.1		0.0%	
Rail transport. service providers		–$46.4		14.0%		–$39.0		11.8%		–$57.3		17.3%	
Users of rail transport. services		–$148.6		44.8%		–$156.1		47.0%		–$137.5		41.4%	
Total locomotive sector		–$196.1		59.1%		–$196.1		59.1%		–$196.1		59.1%	
Marine													
Marine engine producers		–$1.8		0.5%		–$1.6		0.5%		–$2.0		0.6%	
Auxiliary >800 hp		–$0.4		0.1%		–$0.4				–$0.5			
C1 >800 hp		–$1.3		0.4%		–$1.1		0.3%		–$1.4		0.4%	
C2 >800 hp		$0.0		0.0%		$0.0		0.0%		–$0.1		0.0%	
Other marine		$0.0		0.0%		$0.0		0.0%		$0.0		0.0%	
Marine vessel producers		–$10.3		3.1%		–$9.4		2.8%		–$11.5		3.5%	
C1 >800 hp		–$8.8		2.7%		–$8.0		2.4%		–$9.9		3.0%	
C2 >800 hp		–$1.3		0.4%		–$1.3		0.4%		–$1.4		0.4%	
Other marine		–$0.1		0.0%		–$0.1		0.0%		–$0.2		0.1%	
Recreat'l and small /fishing vessel		$0.0		0.0%		$0.0		0.0%		$0.0		0.0%	
Marine transport. service providers		–$29.5		8.9%		–$25.0		7.5%		–$36.0		10.8%	
Users of marine transport. services		–$94.4		28.4%		–$99.9		30.1%		–$86.4		26.0%	
Fixed engineering costs (engines <800 hp)		$0.0		0.0%		$0.0		0.0%		$0.0		0.0%	
Total marine sector		–$135.9		40.9%		–135.9		40.9%		–$135.9		40.9%	
Total program		–$332.0		100.0%		–$332.0		100.0%		–$332.0		100.0%	

[a] Figures are in 2005 dollars.

Table 7H-3. Sensitivity Analysis for Demand Elasticity Parameters: 2020[a]

Market–Level Impacts	Variable Engineering Cost Per Unit	Primary Case				Demand Upper Bound				Demand Lower Bound			
		Change in Price		Change in Quantity		Change in Price		Change in Quantity		Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Locomotives													
Line Haul	$65,343	$64,261	3.21%	–1	–0.15%	$64,068	3.20%	–2	–0.17%	$64,479	3.22%	–1	–0.12%
Switcher/Passenger	$21,139	$20,436	1.57%	0	–0.15%	$20,310	1.56%	0	–0.17%	$20,577	1.58%	0	–0.12%
Transportation services	NA	NA	0.29%	NA	–0.15%	NA	0.28%	NA	–0.17%	NA	0.31%	NA	–0.12%
Marine													
Engines													
Auxiliary>800 hp	$28,363	$27,129	13.07%	–9	–2.69%	$26,990	12.99%	–10	–2.98%	$27,306	13.17%	–8	–2.31%
C1 >800 hp	$14,131	$12,497	6.52%	–12	–2.86%	$12,318	6.44%	–13	–3.17%	$12,727	6.62%	–10	–2.45%
C2 >800 hp	$54,893	$54,573	12.42%	0	–0.28%	$54,518	12.41%	0	–0.32%	$54,634	12.43%	0	–0.22%
Other marine	$0	–$1	0.00%	0	–0.01%	–$1	0.00%	0	–0.01%	$0	0.00%	0	–0.01%
Equipment													
C1 >800 hp	$6,936	$26,158	1.63%	–11	–2.86%	$23,616	1.47%	–12	–3.17%	$29,434	1.85%	–10	–2.45%
C2 >800 hp	$10,174	$170,164	5.28%	0	–0.28%	$169,132	5.25%	0	–0.32%	$171,356	5.31%	0	–0.22%
Other marine	$0	–$6	0.00%	–2	–0.01%	–$7	0.00%	–2	–0.01%	–$5	0.00%	–1	–0.01%
Transportation services	NA	NA	0.55%	NA	–0.28%	NA	0.52%	NA	–0.32%	NA	0.59%	NA	–0.22%
Welfare Impacts (Million $)													
Locomotives		**Surplus Change**	**Share**		**Surplus Change**	**Share**		**Surplus Change**	**Share**				
Locomotive producers		–$1.1	0.3%			–$1.3	0.4%			–$0.9	0.3%		
Line Haul		–$1.0	0.3%			–$1.2	0.4%			–$0.8	0.2%		
Switcher/Passenger		–$0.1	0.0%			–$0.1	0.0%			–$0.1	0.0%		
Rail transport. service providers		–$46.4	14.0%			–$54.7	16.5%			–$37.1	11.2%		
Users of rail transport.services		–$148.6	44.8%			–$140.1	42.2%			–$158.2	47.6%		
Total locomotive sector		–$196.1	59.1%			–$196.1	59.1%			–$196.1	59.1%		
Marine													
Marine engine producers		–$1.8	0.5%			–$1.9	0.6%			–$1.5	0.5%		
Auxiliary >800 hp		–$0.4				–$0.5				–$0.4			
C1 >800 hp		–$1.3	0.4%			–$1.4	0.4%			–$1.1	0.3%		
C2 >800 hp		$0.0	0.0%			–$0.1	0.0%			$0.0	0.0%		
Other marine		$0.0	0.0%			$0.0	0.0%			$0.0	0.0%		
Marine vessel producers		–$10.3	3.1%			–$11.2	3.4%			–$9.2	2.8%		
C1 >800 hp		–$8.8	2.7%			–$9.6	2.9%			–$7.8	2.4%		
C2 >800 hp		–$1.3	0.4%			–$1.4	0.4%			–$1.3	0.4%		
Other marine		–$0.1	0.0%			–$0.2	0.1%			–$0.1	0.0%		
Rec/fishing vessel consumers		$0.0	0.0%			$0.0	0.0%			$0.0	0.0%		
Marine transport. service providers		–$29.5	8.9%			–$34.5	10.4%			–$23.8	7.2%		
Users of marine transport services		–$94.4	28.4%			–$88.2	26.6%			–$101.5	30.6%		
Fixed Engineering Costs (all engines <800 hp)		$0.0	0.0%			$0.0	0.0%			$0.0	0.0%		
Total marine sector		–$135.9	40.9%			–135.8	40.9%			–$136.0	40.9%		
Total program		–$332.0	100.0%			–$331.9	100.0%			–$332.1	100.0%		

[a] Figures are in 2005 dollars.

7H.2 Fixed Cost Shift Scenario

As discussed in 7.2.3.4, in the primary economic analysis only the variable costs are used to shift the supply curve in the engine and equipment markets. This is because in a competitive market the industry supply curve is generally based on the market's marginal cost curve and fixed costs do not influence production decisions on the margin.

In this scenario, the supply shift for engine and equipment producers includes fixed as well as variable costs that are incurred in 2014. The year 2014 was chosen because engine and equipment manufacturers will be incurring R&D and other fixed costs associated with the Tier 4 standards, but not the one-time certification costs that will be incurred in 2015. The analysis also includes the Tier 3 variable costs that will continue until the Tier 4 engines and equipment become available.

Results are provided for all locomotive markets. For the marine sector, only propulsion marine diesel engines above 800 hp are included. There are two reasons for this. First, the Economic Impact Model (EIM) does not permit adding marine diesel engines below 800 hp for this sensitivity analysis. Because the smaller marine engines are not subject to the Tier 4 standards, and there are no variable costs associated with the Tier 3 standards, those markets were omitted from the EIM to simplify model development. Therefore it is not possible to include them. Second, as explained in 7.3.2.3, the primary analysis uses one compliance cost, based on the weighted average compliance costs, for both auxiliary marine engine markets (800-2,000 hp and above 2,000 hp). This results in an over-estimate of the market impacts for auxiliary engines 800-2,000 hp and an under-estimate of the market impacts for auxiliary engines above 2,000 hp, and also affects the impacts on the vessel markets to which these auxiliary engines were allocated. These effects would be even more exaggerated if a weighted average of the fixed costs were used. Therefore, the analysis omits the large auxiliary engines and considers only marine propulsion engines above 800 hp. The results of this sensitivity analysis are compared with an adjusted primary case that includes locomotives and marine propulsion engines above 800 hp.

The results of this analysis are presented in Table 7H-4.

In 2014, the changes in the results are considerable. In the rail sector, the expected price change for line haul locomotives increases from $355 to $38,688 (a 1.9 pecent increase instead a small price decrease). The expected price change for switcher/passenger locomotives increases from -$231 to $104,544 for switcher/passenger locomotives (a 8.0 percent price increase instead of a small price decrease. With regard to the social welfare costs, the burden of the program shifts from locomotive manufacturers to trail transportation service providers and consumers, as the locomotive manufacturers pass their costs to downstream consumers. The share of the social costs burden for locomotive manufacturers drops from 15 percent and 5 percent for line haul and switcher/passenger locomotives, respectively, to nearly zero. The share of the burden for transportation service providers and consumers increases from 7.2 percent and 23 percent to 12 percent and 38 percent, respectively.

The results are similar for the marine sector. In this case, engine and vessel prices change from a slight drop in prices (less than $150 for engines and less than $2,500 for vessels) to a price increase of 13 to 17 percent for engines ($23,800 and $73,275) and 2 to 5 percent for vessels ($28,388 and $143,674), depending on engine size. With regard to the social welfare costs, there is also a shift to equipment and the marine transportation sectors similar to that in the locomotive sector. However, in the marine case equipment manufacturers are not able to pass along the entire amount of the fixed costs to the transportation markets, and therefore bear a larger share of the burden. Specifically, the share of the burden of the program for engine manufacturers drops from 15 percent ($30M) to less than 1 percent ($1M), while the share of the burden for vessel manufacturers increases from 0.1 percent ($200,000) to 3.6 percent ($7.2M). The burden for marine transportation providers increases from 6 percent to 9 percent ($12.8M to $17.9M); the burden for marine transportation service consumers increases from 20 percent to 29 percent ($41 to $57.2M).

Even with these cost and welfare shifts, the overall production of locomotives and marine diesel engines and vessels is not expected to decrease significantly, and prices of rail and marine transportation services are not expected to increase significantly. Locomotive sales would decrease by about 1 locomotive, and marine engines and vessels would decrease by about 16 engines and 13 vessels. The impact on rail and marine transportation service prices would be negligible, and both are below 0.5 percent even when fixed costs are included. This is because rail and marine transportation services are production inputs for other goods and services, and an increase in their prices would be a relatively small increase to the total production costs of goods and services using these inputs.

Table 7H-4. Sensitivity Analysis for Supply Shifts (Fixed and Variable Costs): 2014[a]

	Variable Cost Only Supply Shift				Fixed and Variable Cost Supply Shift Scenario			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Line Haul	-$355	0.0%	0	0.0%	$38,688	1.9%	-1	-0.1%
Switcher/Passenger	-$231	0.0%	0	0.0%	$104,544	8.0%	0	-0.1%
Transportation services	NA	0.1%	NA	0.0%	NA	0.2%	NA	-0.1%
Marine								
Engines								
Auxiliary>800 hp	Excluded from analysis; see text				Excluded from analysis; see text			
C1 >800 hp	-$9	0.0%	0	0.0%	$23.842	13.2%	–16	–3.5%
C2 >800 hp	-$147	0.0%	0	-0.1%	$73,275	17.0%	0	–0.2%
Other marine	$0	0.0%	0	0.0%	$0	0.0%	0	0.0%
Equipment								
C1 >800 hp	-$181	0.0%	0	0.0%	$28,388	2.1%	–13	–3.5%
C2 >800 hp	-$2,354	-0.1%	0	-0.1%	$143,674	4.5%	0	–0.2%
Other marine	$0	0.0%	0	0.0%	$0	0.0%	0	0.0%
Transportation services	NA	0.3%	NA	-0.1%	NA	0.4%	NA	–0.2%
Welfare Impacts (Million $)		**Surplus Change**	**Share**			**Surplus Change**	**Share**	
Locomotives								
Locomotive producers		–$40.7	20.2%			–$0.5	0.2%	
Line Haul		–$30.9	15.4%			–$0.5	0.2%	
Switcher/Passenger		–$9.8	4.9%			$0.0	0.0%	
Rail transport. service providers		–$14.5	7.2%			–$24.0	12.0%	
Users of rail transport.services		–$46.3	23.0%			–$76.9	38.3%	
Total locomotive sector		–$101.4	50.4%			–$101.4	50.5%	
Marine								
Marine engine producers		–$29.7	14.8%			–$1.2	0.6%	
Auxiliary >800 hp	Excluded from analysis; see text				Excluded from analysis; see text			
C1 >800 hp		–$19.0	9.4%			–$1.2	0.6%	
C2 >800 hp		–$10.7	5.3%			$0.0	0.0%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		–$0.2	0.1%			–$7.2	3.6%	
C1 >800 hp		–$0.1	0.0%			–$7.0	3.5%	
C2 >800 hp		–$0.2	0.1%			–$0.2	0.1%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Rec/fishing vessel consumers		$0.0	0.0%			$0.0	0.0%	
Marine transport. service providers		–$12.8	6.4%			–$17.9	8.9%	
Users of marine transport services		–$41.0	20.4%			–$57.2	28.5%	
Auxiliary marine >800 hp[b]		–$16.0	8.0%			–$16.0	8.0%	
Total marine sector		–$99.7	49.6%			–$99.5	49.5%	
Total program		–$201.1	100.0%			–$200.9	100.0%	

[a] Figures are in 2005 dollars.

[b] Auxiliary engines above 800 were excluded from the model for this sensitivity analysis; this is a line item entry that reflects the engineering costs for these markets.

7H.3 Alternative Equipment Supply Elasticity Scenario

In the third sensitivity scenario, we use alternative estimates for the price elasticity of supply for the locomotive and marine vessel markets.

The supply elasticities used in the primary analysis were estimated using a calibration approach as described in Appendix F, and aggregate industry data over the years 1997 through 2004 for NAICS 336510 (railroad rolling stock manufacturing) and NAICS 336611 (ship building and repairing). This method was chosen because of limitations with the available data: we were not able to obtain firm-level or plant-level production data for companies that operate in the affected sectors. However, as we noted in the proposal for this rule, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To address these concerns, we investigated estimates for the price elasticity of supply for the affected industries for which published estimates are not available using alternative methods and data inputs.[36] This analysis used a cross-sectional data model and establishment-level data from the U.S. Census Bureau to estimate these supply elasticities. It should be noted that this analysis is still in draft form and the estimated supply elasticities have not yet been peer-reviewed. Therefore, we are providing them as a sensitivity analysis and not incorporating them into the primary analysis.

Supply elasticities were estimated for 3 markets: NAICS 336611: Ship Building and Repairing (for commercial marine vessels); NAICS industry 336612: Boat Building (for recreational marine vessels); and NAICS industry 366510: Railroad Rolling Stock Manufacturing (for locomotives). We used a panel data set comprised of confidential establishment-level data from the 1972, 1977, 1982, 1992, 1997 and 2002 Census of Manufacturers (COM).

It should be noted that while the use of data at the establishment addresses uncertainty introduced in the analysis by using data aggregated on a yearly basis, it does not resolve uncertainty due to the variety of establishments included in each NAICS category. Each of the NAICS categories includes firms engaged in activities that are not affected by the new standards. In addition, the production processes and thus production function of the non-affected firms may be very different from those firms that are affected by the rule.

For example, NAICS 336611 includes repair yards as well as yards that produce new vessels. Repair yards, as well as yards that engaged in specialized services such as scaling, may not have the same production function as yards that produce new vessels. In addition, the production function of a yard that engages in all of these activities may be different from a yard that engages solely in new vessel construction. In addition, NAICS 336611includes all shipyards, ranging from yards that make very large ocean-going vessels, to military vessels, to medium and small commercial craft such as tugs, fishing boats, supply boats, and passenger vessels, as well as non-self-propelled barges. This large variety of commercial vessels reflects a range of production processes, not all of which can be expected to be the same as those used to produce the vessels that will be affected by the rule. For example, the production processes used to make OGV and military vessels are likely to be different from those used to make non-self-propelled barges and these are likely to be different from those used to make commercial self-propelled vessels. In addition, commercial self-propelled vessels that use engines are likely to have different production processes from smaller commercial vessels. Large commercial vessels are more likely to be unique designs produced for a specific customer while small commercial vessels may be serially produced with minimal customization or even built with fiberglass hulls.

With regard to NAICS 336612, that category includes all boat building, for gasoline as well as diesel powered vessels. The vast majority of recreational vessels are gasoline powered and therefore are not affected by this rule. In addition, gasoline-powered vessels are primarily fiberglass hull vessels. This construction process is very different from aluminum or wooden hulls used in higher end vessels that are more likely to have diesel engines.

Finally, with regard to NAICS industry 366510: Railroad Rolling Stock Manufacturing, this category is comprised of roughly 100 establishments primarily involved in one or more of the following manufacturing activities: manufacturing and/or rebuilding locomotives, locomotive frames and parts; manufacturing railroad, street, and rapid transit cars and car equipment for operation on rails for freight and passenger service; and manufacturing rail layers, ballast distributors, rail tamping equipment and other railway track maintenance equipment. Many of these establishments are not engaged in locomotive manufacturing, such as track or rail manufacturing and maintenance, ancillary equipment and maintenance – these products may involve different technologies or production processes/functions by using different total labor or materials input from the locomotive manufacturing. In addition, for the emerging switcher market, we don’t know what their production process is. We assume they have the same production function as the line haul locomotive manufacturers. But, in fact, the production function of the switcher manufacturers may be different because they are expected to purchase the “merchant engine” from other non-road engine manufacturers.

The alternative supply elasticities are set out in Table 7H-6. These supply elasticities are all more elastic than those used in the primary analysis, suggesting that manufacturers of locomotives and marine vessels are more sensitive to price changes (a one percent change in price leads to more than a 1 percent change in quantity supplied).

Table 7H-6. Alternative Supply Elasticities

NAICS	Primary Case	Sensitivity Analysis
NAICS 336510 (locomotives)	2.7	5.9
NAICS 336611 (commercial marine)	2.3	7.1
NAICS 336612 (recreational marine)	2.3	4.2

The results of the sensitivity analysis for 2020 are set out in Table 7H-7. Despite the significant change in the locomotive and marine vessel supply elasticities, the results of the analysis are not affected by very much. This suggests that the main driver of the market response to this regulatory program is the inelastic price elasticity of demand in the affected transportation service markets. There are small increases in the expected market results, but the price and quantity changes are very small. The price change for locomotives increases from $64,261 to $64,843 for line haul and from $20,436 to $20,814 for switcher/passenger locomotives, with no change in the quantity produced. The price change for marine engines above 800 hp decreases, from $12,497 to $11,842 for C1 engines, and from $54,573 to $54,563 for C2 engines, with a small change in the quantity produced (less than 20). For vessels, the price change increases from $26,158 to $34,917 for vessels C1 engines and $170,164 to $172,803 for vessels with C2 engines.

These small impacts occur because the only change in the analysis is to the supply elasticities for the equipment markets (locomotives and marine vessels). Notably, the supply and demand elasticities for the rail and marine transportation sectors as well as the supply elasticities for marine engines remain the same. The more elastic supply elasticities for the equipment markets means suppliers can pass on more of the direct compliance costs to consumers (in this case, the transportation services market) in the form of higher prices relative to the primary case. These higher prices lead to a larger decrease in the quantity of equipment demanded than in the primary case. In the case of marine vessels, the drop in demand is high enough to slightly offset the price increase associated with the direct compliance costs, resulting in a smaller increase in prices when compared to the primary case.

There is also a change in the way the social costs are distributed among stakeholders, although these changes are small. In the rail sector, the share allocated to the transportation services market consumers increases from 44.8 percent to 44.9 percent, while the share for locomotive producers decreases from 0.3 percent to 0.2 percent. In the marine sector, the share of social costs attributed to marine service providers and consumers increases from 8.9 percent to 9.1 percent, and 28.4 percent to 29.3 percent, respectively. The share attributed to engine manufacturers increases somewhat, from 0.5 percent to 0.7 percent, while the share attributed to vessel producers decreases from 3.1 percent to 1.8 percent.

Table 7H-7. Sensitivity Analysis for Alternative Equipment Supply Elasticities: 2020[a]

	Primary Case Elasticities				Alternative Locomotive and Vessel Supply Elasticities			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Rail Sector								
Locomotives								
Line Haul	$64,261	3.2%	-1	-0.1%	$64,843	3.2%	-1	-0.1%
Switcher/Passenger	$20,436	1.6%	0	-0.1%	$20.814	1.6%	0	-0.1%
Transportation services	N/A	0.3%	N/A	-0.1%	N/A	0.3%	N/A	-0.1%
Marine Sector								
Engines								
Auxiliary >800 hp	$27,129	13.1%	-9	-2.7%	$26,677	12.8%	-13	-3.7%
C1 >800 hp	$12,497	6.5%	-12	-2.9%	$11,842	6.2%	-17	-4.0%
C2 >800 hp	$54,573	12.4%	0	-0.3%	$54,563	12.4%	0	-0.3%
Other Marine	-$1	0.0%	0	0.0%	-$1	0.0%	0	0.0%
Equipment								
C1 >800 hp	$26,158	1.6%	-11	-2.9%	$34,917	2.2%	-16	-4.0%
C2 >800 hp	$170,164	5.3%	0	-0.3%	$172,803	5.3%	0	-0.3%
Other marine	-$6	0.0%	-2	0.0%	-$3	0.0%	-2	0.0%
Transportation services	N/A	0.6%	N/A	-0.3%	N/A	0.6%	N/A	-0.3%
Welfare Impacts (Million $)		**Surplus Change**	**Share**			**Surplus Change**	**Share**	
Locomotives								
Locomotive Producers		$1.1	0.3%			-$0.5	0.2%	
Line Haul		-$1.0	0.3%			-$0.5	0.1%	
Switcher/Passenger		-$0.1	0.0%			$0.0	0.0%	
Rail transportation service providers		-$46.4	14.0%			-$46.6	14.0%	
Users of rail transportation service		-$148.6	44.8%			-$149.0	44.9%	
Total locomotive sector		-$196.1	59.1%			-$196.1	59.1%	
Marine								
Marine engine producers		-$1.8	0.5%			-$2.4	0.7%	
Auxiliary >800 hp		-$0.4	0.1%			-$0.6	0.2%	
C1 >800 hp		-$1.3	0.4%			-$1.8	0.5%	
C2 >800 hp		$0.0	0.0%			-$0.1	0.0%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		-$10.3	3.1%			-$6.0	1.8%	
C1 >800 hp		-$8.8	2.7%			-$4.8	1.4%	
C2 >800 hp		-$1.3	0.4%			-$1.1	0.3%	
Other marine		-$0.1	0.0%			$0.0	0.0%	
Rec/fishing vessel consumers		$0.0	0.0%			$0.0	0.0%	
Marine transportation svc providers		-$29.5	8.9%			-$30.4	9.1%	
Users of marine transportation service		-$94.4	28.4%			-$97.2	29.3%	
Total marine sector		-$135.9	40.9%			-$135.9	40.9%	
Total program		-$332.0				-$322.0		

[a] Figures are in 2005 dollars

7H.4 Alternative Auxiliary Engine Compliance Cost Scenario

In the fourth sensitivity scenario, we use alternative compliance costs for marine auxiliary engines above 800 hp.

As explained in section 7.3.2.2, the compliance costs for marine auxiliary engines above 800 hp are a weighted average of all compliance costs for those engines. This weighted average is applied to both categories of auxiliary marine engines examined in this anlaysis: those 800-2,000 hp and those above 2,000 hp. This means that the supply shift is the same for both of the auxiliary engine markets even though the actual program impacts are different for them. The weighted average compliance costs were obtained by dividing the total compliance costs for engines above 800 hp by the number of engines above 800 hp. This results in estimated compliance costs of $37,097 in 2016, the first year of the Tier 4 program.

In this analysis, we apply separate compliance costs to each of the two auxiliary marine engine markets, using the compliance costs set out in Table 7H-8. We performed the analysis for 2016 and 2030. The results are reported in Tables 7H-9 and 7H-10.

Table 7H-7. Sensitivity Analysis for Alternative Compliance Costs: Marine Auxiliary Markets

Engine Category	Primary Case	Sensitivity Analysis	
		2016	2030
Aux. Marine 800-2,000	$37,097	$19,073	$67,255
Aux Marine >2,000 hp	$28,359	$14,582	$51,414

As expected, the market results for this analysis are different for marine auxiliary engines. In 2016, the expected price impacts for engines 800 to 2,000 hp is lower than the primary case (10.4 percent price increase instead of 20.9 percent) and the expected price impacts for engines above 2,000 hp being higher (18.3 percent price increase instead of 9.6 percent). There is only a small change in quantity produced, however, with a slightly smaller decrease for auxiliary engines 800 to 2,000 hp and no change for the larger engines. These results are similar for a 2030.

The social welfare impacts change only negligibly for the marine markets (less than 0.5 percent change), with marine engine and vessel producers bearing slightly less of the total social welfare costs and marine transportation service providers and users bearing slightly more. Specifically, in 2016 the share for engine manufacturers decreases to 0.6 percent from 0.7, while vessel manufacturers would see their share decrease from 5.8 percent to 5.1 percent. Marine transportation service providers would see their share increase from 6.4 percent to 6.5 percent, and marine transportation service users would see their share increase from 20.3 percent to 20.7 percent. We expect that actual social welfare impacts would be less that these estimated impacts, however. By allocating all of the auxiliary engines above 800 hp to the vessels that will be affected by this program, this analysis over-estimates the vessel impacts of the program. In fact, not all of the very large auxiliary engines are actually used on the commercial vessels that are subject to this program; some will be installed on vessels with Category 3 marine diesel engines. While it is appropriate to consider these costs in the economic impact analysis for this program, it is clear that not all of these social costs will be passed on to the producers and users of vessels directly affected by this program.

In conclusion, the simplifying method of using weighted average compliance costs for auxiliary engines above 800 hp does not change the results of the analysis.

Table 7H-9. Sensitivity Analysis for Auxiliary Engine Compliance Costs: 2016[a]

	Primary Scenario				**Sensitivity Scenario**			
	Change in Price		**Change in Quantity**		**Change in Price**		**Change in Quantity**	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Line Haul	$84,227	4.2%	-1	-0.1%	$84,227	4.2%	-1	-0.1%
Switcher/Passenger	$13,494	1.0%	0	-0.1%	$13,494	1.0%	0	-0.1%
Transportation services	NA	0.3%	NA	-0.1%	NA	0.3%	NA	-0.1%
Marine								
Engines								
Aux 800 to 2000 hp	$34,894	20.9%	-11	-5.0%	$17,417	10.4%	-8	-3.8%
Aux > 2000 hp	$36,919	9.6%	0	-0.2%	$67,084	18.3%	0	-0.2%
C1 >800 hp	$16,384	8.5%	-15	-3.7%	$16,696	8.6%	-14	-3.3%
C2 >800 hp	$71,602	16.3%	0	-0.2%	$71,600	16.3%	0	-0.2%
Other marine	$0	0.0%	0	0.0%	$0	0.0%	0	0.0%
Equipment								
C1 >800 hp	$34,043	2.1%	-14	-3.7%	$29,574	1.9%	-12	-3.3%
C2 >800 hp	$225,143	7.0%	0	-0.2%	$262,231	8.4%	0	-0.2%
Other marine	-$4	0.0%	-1	0.0%	-$4	0.0%	-1	0.0%
Transportation services	NA	0.4%	NA	-0.2%	NA	0.4%	NA	-0.2%
Welfare Impacts (Million $)		**Surplus Change**	**Share**			**Surplus Change**	**Share**	
Locomotives								
Locomotive producers		–$8.3	2.9%			–$8.3	2.9%	
Line Haul		–$0.9	0.3%			–$0.9	0.3%	
Switcher/Passenger		–$7.4	2.6%			–$7.4	2.6%	
Rail transport. service providers		–$43.4	15.3%			–$43.4	15.3%	
Users of rail transport.services		–$138.9	48.8%			–$138.9	48.8%	
Total locomotive sector		–$190.6	67.0%			–$190.6	67.0%	
Marine								
Marine engine producers		–$2.1	0.7%			–$1.8	0..6%	
Aux 800 to 2000 hp		–$0.4	0.1%			–$0.3	0.1%	
Aux > 2000 hp		–$0.1	0.0%			–$0.1	0.0%	
C1 >800 hp		–$1.6	0.5%			–$1.3	0.5%	
C2 >800 hp		$0.0	0.0%			–$0.0	0.0%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		–$15.8	5.6%			–$14.5	5.1%	
C1 >800 hp		–$13.5	4.7%			–$12.2	4.3%	

C2 >800 hp		–$2.2	0.8%			–$2.2	0.8%	
Other marine		–$0.1	0.0%			$0.1	0.0%	
Rec/fishing vessel consumers		$0.0	0.0%			$0.0	0.0%	
Marine transport. service providers		–$18.1	6.4%			–$18.3	6.5%	
Users of marine transport services		–$57.9	20.3%			–$58.7	20.7%	
Total marine sector		–$93.8	33.0 %			–$93.3	32.9%	
Total program		–$284.4	100.0%			–$283.8	100.0%	

[a] Figures are in 2005 dollars

Table 7H-10. Sensitivity Analysis for Auxiliary Engine Compliance Costs: 2030[a]

	Primary Scenario				Sensitivity Scenario			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Line Haul	$63,019	3.2%	-4	-0.3%	$63,019	3.2%	-4	-0.3%
Switcher/Passenger	$19,628	1.5%	-1	-0.3%	$19,628	1.5%	-1	-0.3%
Transportation services	NA	0.6%	NA	-0.3%	NA	0.6%	NA	-0.3%
Marine								
Engines								
Aux 800 to 2000 hp	$26,626	15.9%	-10	-3.9%	$13,267	7.9%	-8	-3.0%
Aux > 2000 hp	$27,809	7.2%	-1	-0.5%	$50,890	13.9%	-1	-0.5%
C1 >800 hp	$12,479	6.5%	-13	-2.9%	$12,718	6.6%	-12	-2.6%
C2 >800 hp	$54,264	12.3%	-1	-0.5%	$54,262	12.3%	-1	-0.5%
Other marine	-$1	0.0%	0	0.0%	-$1	0.0%	0	0.0%
Equipment								
C1 >800 hp	$25,768	1.6%	-12	-2.9%	$22,352	1.5%	-11	-2.6%
C2 >800 hp	$164,774	5.1%	0	-0.5%	$193,158	6.2%	0	-0.5%
Other marine	-$12	0.0%	-4	0.0%	-$12	0.0%	-4	0.0%
Transportation services	NA	1.1%	NA	-0.5%	NA	1.0%	NA	-0.5%
Welfare Impacts (Million $)		**Surplus Change**	**Share**			**Surplus Change**	**Share**	
Locomotives								
Locomotive producers		–$3.1	0.4%			–$3.1	0.4%	
Line Haul		–$2.7	0.4%			–$2.7	0.4%	
Switcher/Passenger		–$0.4	0.1%			–$0.4	0.1%	
Rail transport. service providers		–$109.0	14.8%			–$109.0	14.8%	
Users of rail transport.services		–$348.9	47.3%			–$348.9	47.3%	
Total locomotive sector		–$461.1	62.5%			–$461.1	62.5%	
Marine								
Marine engine producers		–$2.0	0..3%			–$1.7	0.2%	
Aux 800 to 2000 hp		–$0.4	0.1%			–$0.3	0.1%	
Aux > 2000 hp		–$0.1	0.0%			–$0.1	0.0%	
C1 >800 hp		–$1.4	0.2%			–$1.2	0.2%	
C2 >800 hp		–$0.1	0.0%			–$0.1	0.0%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		–$9.2	1.2%			–$8.1	1.1%	
C1 >800 hp		–$8.2	1.1%			–$7.0	1.0%	
C2 >800 hp		–$0.7	0.1%			–$0.7	0.1%	
Other marine		$0.3	0.0%			$0.3	0.0%	
Rec/fishing vessel consumers		$0.0	0.0%			$0.0	0.0%	
Marine transport. service providers		–$63.3	8.6%			–$63.5	8.6%	
Users of marine transport services		–$202.5	27.4%			–$203.2	27.5%	
Total marine sector		–$277.0	37.5%			–$276.5	37.5%	
Total program		–$738.1	100.0%			–$737.5	100.0%	

[a] Figures are in 2005 dollars

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CHAPTER 8: Regulatory Alternatives

The program we are finalizing today represents a broad and comprehensive approach to reducing emissions from locomotive and marine diesel engines. As we developed this final rule, we considered a number of alternatives with regard to the scope and timing of the standards. After carefully evaluating these alternatives, we believe that our new program provides the best opportunity for achieving timely and substantial emission reductions from locomotive and marine diesel engines. Our final program balances a number of key factors: (1) achieving very significant emissions reductions as early as possible, (2) providing appropriate lead time to develop and apply advanced control technologies, and (3) coordinating requirements in this final rule with existing highway and nonroad diesel engine programs. The alternative scenarios described here were constructed to further evaluate each individual aspect of our program, and have enabled us to achieve the appropriate balance between these key factors. This chapter presents a detailed explanation of our analysis, including a year by year breakout of expected costs and emission reductions.

8.1 Alternatives Considered

Our final rule consists of a comprehensive three-part program to address emissions from diesel locomotive engines and marine diesel engines below 30 liters per cylinder displacement. First, we are adopting stringent emission standards for existing locomotives and standards for existing commercial marine diesel engines above 600 kW. These standards apply when an engine is remanufactured. Second, we are adopting a set of near-term emission standards, referred to as Tier 3, for newly-built locomotives and marine engines that reflect the application of technologies to reduce engine-out PM and NO_x. Third, we are adopting longer-term standards, referred to as Tier 4, for newly-built locomotives and marine engines that utilize high-efficiency catalytic aftertreatment technology enabled by the availability of Ultra-Low Sulfur Diesel (ULSD). We are also adopting standards to eliminate emissions from unnecessary locomotive idling. As we developed this final rule, we evaluated alternative scenarios that looked at the impact of varying the timing and scope of our final standards.

Table 8-1 gives a brief summary of the alternatives we considered. The first alternative compares our proposed program to our final program. Alternatives 1 and 2 look at the effects of eliminating both the remanufacturing programs and the Tier 3 near-term standards that our final rule includes. Finally, Alternative 4 examines the effects of moving Tier 4 ahead to 2013 and eliminating both the remanufacturing programs and the Tier 3 near-term standards.

Table 8-1 Summary of Alternatives and Standards

Final Rule	• Locomotive Remanufacturing • Marine Remanufacturing, • Tier 3 Near-term program, • Tier 4 Long-term standards
Alternative 1: Proposed Program from the Notice of Proposed Rulemaking	• Proposed Locomotive Remanufacturing program, • Proposed Tier 3 Near-term program, • Proposed Tier 4 Long-term standards
Alternative 2: Exclusion of Remanufacturing Standards	• Tier 3 Near-term program, • Tier 4 Long-term standards
Alternative 3: Elimination of Tier 3	• Locomotive Remanufacturing, • Marine Remanufacturing, • Tier 4 Long-term standards
Alternative 4: Tier 4 Exclusively in 2013	• Tier 4 Long-term standards only in *2013*

8.1.1 Alternative 1: Proposed Program from the Notice of Proposed Rulemaking

Alternative 1 examines the differences between the program we proposed and the program we are finalizing in this rulemaking. The final rule makes a number of important changes to the program originally set out in the proposal which we believe will yield greater overall NO_x and PM reductions, especially in the critical early years of the program. In particular, the adoption of standards for remanufactured marine engines and a 2-year pull-ahead of the Tier 4 NO_x requirements for line-haul locomotives and for 2000-3700 kW marine engines provide greater near-term reductions than the proposal. The final rule also expands the remanufactured locomotive program to include Class II railroads. The analysis of this alternative illustrates the additional benefits gained through the development process which resulted in our final program.

8.1.2 Alternative 2: Exclusion of Remanufacturing Standards

Alternative 2 examines the potential impacts of the locomotive and marine remanufacturing programs by excluding them from the analysis (see sections III.B.(1)(a)(*i*), III.B.(1)(b), and III.B.(2)(b) of our Preamble for more details on the remanufacturing standards). Alternative 2 is identical to the final program with the exception of the removal of both the locomotive and marine remanufacturing standards, as the timing and scope of Tier 3 and Tier 4 standards remain unchanged in this alternative. These results can be compared with the results of the primary program to estimate the benefits that would be lost if we did not finalize either the locomotive or marine remanufacturing standards.

8.1.3 Alternative 3: Elimination of Tier 3

Alternative 3 eliminates the Tier 3 standards, while retaining the Tier 4 standards and the combined locomotive and marine remanufacturing requirements. The timing and scope of both the Tier 4 and the locomotive and marine remanufacturing programs would remain unchanged. These results can be compared with the results of the final program to estimate the benefits that would be foregone if the near-term standards were not finalized.

8.1.4 Alternative 4: Tier 4 Exclusively in 2013

Alternative 4 most closely reflects the program described in our Advanced Notice of Proposed Rulemaking (ANPRM), whereby we would set new aftertreatment based emission standards as soon as possible. In this case, we believe the earliest that such standards could logically be started is in 2013 (three months after the introduction of 15 ppm ULSD in this sector). This alternative would eliminate the Tier 3 standards and both the locomotive and marine remanufacturing standards, while pulling the Tier 4 standards ahead to 2013 for all portions of the Tier 4 program. These results show the benefits of the comprehensive program we are finalizing today compared to the aggressive but narrow approach outlined in our ANPRM.

8.2 Emission Inventory Impacts

8.2.1 Methodology

8.2.1.1 Inventory Impacts

Based on our primary case, we estimated inventory impacts using a methodology based on engine population, hours of use, average engine loads, and in-use emissions factors for each alternative. (Refer to Chapter 3 of this RIA for a more complete discussion of how the primary control inventories were generated). The results are shown in Table 8-2.

8.2.1.2 Costs

We have estimated the costs associated with each alternative using the same methods employed for the final rule. The cost estimates for the locomotive remanufacturing program include adjustments for costs associated with hardware requirements. The cost estimates for the marine remanufacturing program were generated in a similar manner as those generated for the locomotive remanufacturing program. We have estimated the cost per remanufactured marine engine as equal to that for a remanufactured locomotive engine because we would expect a similar or identical remanufacture kit to be used. At this time, for alternative 4 we are unable to make an accurate estimate of the cost for pulling ahead Tier 4 technologies, since we do not believe it to be feasible at this time. However, we have reported costs in the summary table reflecting the same cost estimation aaproach we have used for our final program and have denoted unestimated additional costs as ‘C’. These additional unestimated costs would include costs for additional engine test cells, engineering staff, and engineering facilities necessary to accelerate the development of Tier 4. The details of our estimated remanufacturing program costs can be found in Chapter 5 of this RIA. The results are shown in Table 8-2.

8.2.1.3 Benefits

To estimate the PM-related monetized benefits for each of the alternative scenarios, we used a benefits transfer approach to scale the PM benefits from the final Locomotive and Marine Engine control scenario. The PM benefits scaling approach is similar to the scaling approach conducted for the Clean Air Nonroad Diesel (CAND) Rule (see Chapter 9 of the CAND RIA). For the estimate of benefits generated for the final rule, we ran a sophisticated photochemical air quality model, the Community Multiscale Air Quality model (CMAQ), to estimate baseline and post-control ambient concentrations of PM for 2030. Benefits for the final standards were then generated using the inputs and methods described in Chapter 6 of the RIA for this rule. We then scaled these PM benefits to reflect the magnitude of the $PM_{2.5}$ precursor emissions changes estimated to occur as a result of the alternative control scenarios. The results are shown in Table 8-2.

8.2.2 Analysis

Table 8-2 includes the expected yearly emission reductions associated with each alternative, including: the estimated PM and NO_x reductions for years 2006-2040 expressed as a net present value (NPV) using discounting rates of 3% and 7%. The yearly estimated costs are also expressed in this table at both 3% and 7% NPV. The benefit analysis from 2020 and the analysis from 2030 are also included on this table. For further analysis, Table 8-3 and Table 8-4 summarize the PM and NO_x emission reductions and costs for each alternative through 2040; and Table 8-5 and Table 8-6 summarize the emission reductions, costs and benefits for the year 2020 and the year 2030. Figure 8.2-1 and Figure 8.2-2 illustrate the inventory impacts of each alternative from 2006-2040 for comparison.

Table 8-2 Inventory, Cost, and Benefits year from 2006-2040

	Final Program					**Alternative 1: Proposed Program from Notice of Proposed Rulemaking**				
Calendar Year	$PM_{2.5}$ Emissions **Reductions** (tons)	NO_x Emissions **Reductions** (tons)	Total Costs (Millions)	PM-only Benefits[a,b] (Billions)		$PM_{2.5}$ Emissions **Reductions** (tons)	NO_x Emissions **Reductions** (tons)	Total Costs (Millions)	PM-only Benefits[a,b] (Billions)	
				3%	7%				3%	7%
2006	0	0	$0	---	---	0	0	$0	---	---
2007	0	0	$30	---	---	0	0	$30	---	---
2008	320	14,000	$110	---	---	60	5,100	$90	---	---
2009	930	24,000	$90	---	---	390	7,300	$70	---	---
2010	1,700	44,000	$150	---	---	840	20,000	$110	---	---
2011	2,800	70,000	$280	---	---	1,700	39,000	$230	---	---
2012	4,200	87,000	$220	---	---	2,700	51,000	$170	---	---
2013	5,200	110,000	$210	---	---	3,300	65,000	$160	---	---
2014	6,300	130,000	$200	---	---	4,300	82,000	$160	---	---
2015	7,300	160,000	$270	---	---	5,300	95,000	$200	---	---
2016	8,900	210,000	$290	---	---	6,900	120,000	$220	---	---
2017	11,000	250,000	$290	---	---	8,600	180,000	$240	---	---
2018	12,000	290,000	$310	---	---	10,000	220,000	$270	---	---
2019	13,000	330,000	$340	---	---	11,000	260,000	$290	---	---
2020	14,000	370,000	$350	$3.9	$3.6	13,000	310,000	$300	$3.3	$3.0
2021	16,000	410,000	$380	---	---	14,000	350,000	$330	---	---
2022	17,000	450,000	$440	---	---	15,000	390,000	$390	---	---
2023	18,000	490,000	$520	---	---	17,000	460,000	$470	---	---
2024	19,000	540,000	$550	---	---	18,000	520,000	$500	---	---
2025	21,000	580,000	$590	---	---	20,000	570,000	$570	---	---
2026	22,000	620,000	$610	---	---	21,000	610,000	$590	---	---
2027	23,000	670,000	$640	---	---	22,000	660,000	$630	---	---
2028	24,000	710,000	$690	---	---	23,000	700,000	$680	---	---
2029	25,000	750,000	$730	---	---	25,000	740,000	$710	---	---
2030	27,000	790,000	$760	$9.2	$8.4	26,000	780,000	$750	$8.8	$8.0
2031	28,000	830,000	$790	---	---	27,000	820,000	$780	---	---
2032	29,000	870,000	$810	---	---	28,000	860,000	$800	---	---
2033	30,000	910,000	$900	---	---	29,000	900,000	$890	---	---
2034	31,000	950,000	$930	---	---	31,000	940,000	$930	---	---
2035	32,000	990,000	$970	---	---	32,000	980,000	$960	---	---
2036	33,000	1,000,000	$990	---	---	33,000	1,000,000	$980	---	---
2037	34,000	1,100,000	$1,000	---	---	34,000	1,100,000	$1,000	---	---
2038	35,000	1,100,000	$1,000	---	---	35,000	1,100,000	$1,000	---	---
2039	36,000	1,100,000	$1,100	---	---	36,000	1,100,000	$1,100	---	---
2040	37,000	1,100,000	$1,100	---	---	36,000	1,100,000	$1,100	---	---
NPV 3%	308,000	8,760,000	$9,410	---		286,000	8,140,000	$8,760	---	
NPV 7%	134,000	3,710,000	$4,310	---		121,000	3,320,000	$3,900	---	

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

	Alternative 2: Exclusion of Remanufacturing Standards					Alternative 3: Elimination of Tier 3				
	PM$_{2.5}$ Emissions **Reductions** (tons)	NO$_x$ Emissions **Reductions** (tons)	Total Costs (Millions)	PM-only Benefits[a,b] (Billions)		PM$_{2.5}$ Emissions **Reductions** (tons)	NO$_x$ Emissions **Reductions** (tons)	Total Costs (Millions)	PM-only Benefits[a,b] (Billions)	
				3%	7%				3%	7%
2006	0	0	$0	---	---	0	0	$0	---	---
2007	0	0	$30	---	---	0	0	$0	---	---
2008	60	600	$30	---	---	320	14,000	$80	---	---
2009	90	2,600	$30	---	---	930	24,000	$50	---	---
2010	110	4,400	$70	---	---	1,700	44,000	$120	---	---
2011	140	6,500	$140	---	---	2,800	70,000	$220	---	---
2012	440	9,800	$80	---	---	3,700	85,000	$220	---	---
2013	840	14,000	$80	---	---	3,600	100,000	$210	---	---
2014	1,500	31,000	$100	---	---	3,500	120,000	$200	---	---
2015	2,400	65,000	$180	---	---	3,800	150,000	$270	---	---
2016	3,500	100,000	$180	---	---	4,800	190,000	$290	---	---
2017	4,800	150,000	$190	---	---	6,000	230,000	$290	---	---
2018	6,100	190,000	$210	---	---	6,900	270,000	$310	---	---
2019	7,500	240,000	$250	---	---	7,700	310,000	$340	---	---
2020	8,800	280,000	$290	$2.5	$2.3	8,800	350,000	$350	$2.8	$2.6
2021	10,000	330,000	$320	---	---	9,900	380,000	$380	---	---
2022	12,000	370,000	$360	---	---	11,000	420,000	$440	---	---
2023	13,000	420,000	$450	---	---	12,000	460,000	$520	---	---
2024	15,000	470,000	$490	---	---	14,000	510,000	$550	---	---
2025	16,000	520,000	$530	---	---	15,000	550,000	$590	---	---
2026	18,000	570,000	$570	---	---	16,000	590,000	$610	---	---
2027	19,000	620,000	$610	---	---	17,000	640,000	$640	---	---
2028	21,000	670,000	$650	---	---	19,000	680,000	$690	---	---
2029	22,000	720,000	$690	---	---	20,000	720,000	$730	---	---
2030	24,000	760,000	$720	$8.2	$7.5	21,000	760,000	$760	$7.8	$7.1
2031	25,000	810,000	$760	---	---	23,000	800,000	$790	---	---
2032	26,000	850,000	$790	---	---	24,000	840,000	$810	---	---
2033	28,000	890,000	$880	---	---	25,000	880,000	$900	---	---
2034	29,000	930,000	$920	---	---	26,000	920,000	$930	---	---
2035	30,000	970,000	$950	---	---	28,000	950,000	$970	---	---
2036	32,000	1,000,000	$980	---	---	29,000	990,000	$990	---	---
2037	33,000	1,000,000	$1,000	---	---	30,000	1,000,000	$1,000	---	---
2038	34,000	1,100,000	$1,000	---	---	31,000	1,100,000	$1,000	---	---
2039	35,000	1,100,000	$1,100	---	---	32,000	1,100,000	$1,100	---	---
2040	36,000	1,100,000	$1,100	---	---	33,000	1,100,000	$1,100	---	---
NPV 3%	240,000	7,640,000	$8,080	---		237,000	8,360,000	$9,240	---	
NPV 7%	96,000	3,030,000	$3,430	---		100,000	3,530,000	$4,160	---	

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

	Alternative 4: Tier 4 Exclusively in 2013				
	$PM_{2.5}$ Emissions **Reductions** (tons)	NO_x Emissions **Reductions** (tons)	Total Costs[a] (Millions)	PM-only Benefits[b,c] (Billions)	
				3%	7%
2006	0	0	$0	---	---
2007	0	0	$0	---	---
2008	60	600	$80	---	---
2009	90	2,600	$80	---	---
2010	120	4,400	$80	---	---
2011	150	6,300	$80	---	---
2012	200	8,700	$120	---	---
2013	1,500	51,000	$140	---	---
2014	2,600	93,000	$170	---	---
2015	3,800	140,000	$180	---	---
2016	5,000	180,000	$210	---	---
2017	6,300	220,000	$250	---	---
2018	7,500	270,000	$280	---	---
2019	8,800	310,000	$320	---	---
2020	10,000	350,000	$360	$3.0	$2.8
2021	11,000	400,000	$450	---	---
2022	13,000	440,000	$490	---	---
2023	14,000	490,000	$530	---	---
2024	16,000	530,000	$570	---	---
2025	17,000	580,000	$610	---	---
2026	18,000	620,000	$640	---	---
2027	20,000	660,000	$680	---	---
2028	21,000	710,000	$710	---	---
2029	22,000	750,000	$750	---	---
2030	24,000	790,000	$780	$8.4	$7.6
2031	25,000	830,000	$810	---	---
2032	26,000	870,000	$850	---	---
2033	28,000	900,000	$940	---	---
2034	29,000	940,000	$970	---	---
2035	30,000	980,000	$1,000	---	---
2036	31,000	1,000,000	$1,000	---	---
2037	32,000	1,000,000	$1,000	---	---
2038	33,000	1,100,000	$1,100	---	---
2039	34,000	1,100,000	$1,100	---	---
2040	34,000	1,100,000	$1,100	---	---
NPV 3%	249,000	8,320,000	$9,070 + C	---	
NPV 7%	101,000	3,420,000	$3,950 + C	---	

[a] The 'C' represents the additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time, such additional engine test cells, engineering staff, and engineering facilites necessary to introduce Tier 4 one year earlier.

[b] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[c] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Table 8-3 Summary of Total Inventory and Costs Through 2040 NPV 3%

Program	PM Emissions Redcutions (tons) 2006-2040 NPV 3%	NO_x Emissions Reductions (tons) 2006-2040 NPV 3%	Total Costs[a] (Millions) 2006-2040 NPV 3%
Final Program	308,000	8,760,000	$9,410
Alternative 1: Proposed Program from Notice of Proposed Rulemaking	286,000	8,140,000	$8,760
Alternative 2: Exclusion of Remanufacturing Standards	240,000	7,640,000	$8,080
Alternative 3: Elimination of Tier 3	237,000	8,360,000	$9,240
Alternative 4: Tier 4 Exclusively in 2013	249,000	8,320,000	$9,070 + C

[a] 'C' represents additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time.

Table 8-4 Summary of Total Inventory and Costs Through 2040 NPV 7%

Program	PM Emissions Redcutions (tons) 2006-2040 NPV 7%	NO_x Emissions Reductions (tons) 2006-2040 NPV 7%	Total Costs[a] (Millions) 2006-2040 NPV 7%
Final Program	134,000	3,710,000	$4,310
Alternative 1: Proposed Program from Notice of Proposed Rulemaking	121,000	3,320,000	$3,900
Alternative 2: Exclusion of Remanufacturing Standards	96,000	3,030,000	$3,430
Alternative 3: Elimination of Tier 3	100,000	3,530,000	$4,160
Alternative 4: Tier 4 Exclusively in 2013	101,000	3,420,000	$3,950 + C

[a] 'C' represents additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time.

Table 8-5 Summary of Inventory, Costs, and Benefits for 2020

Program	2020 PM Emissions Reductions (tons)	2020 NO_x Emissions Reductions (tons)	2020 Total Costs[a] (Millions)	2020 Benefits[bc] (Billions) PM only	
				3%	7%
Final Program	14,000	370,000	$350	$3.9	($3.6)
Alternative 1: Proposed Program from Notice of Proposed Rulemaking	13,000	310,000	$300	$3.3	($3.0)
Alternative 2: Exclusion of Remanufacturing Standards	8,800	280,000	$290	$2.5	($2.3)
Alternative 3: Elimination of Tier 3	8,800	350,000	$350	$2.8	($2.6)
Alternative 4: Tier 4 Exclusively in 2013	10,000	350,000	$360 + C	$3.0	($2.8)

[a] The 'C' represents the additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time, such additional engine test cells, engineering staff, and engineering facilites necessary to introduce Tier 4 one year earlier.
[b] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).
[c] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Table 8-6 Summary of Inventory, Costs, and Benefits for 2030

Program	2030 PM Emissions Reductions (tons)	2030 NO_x Emissions Reductions (tons)	2030 Total Costs[a] (Millions)	2030 Benefits[bc] (Billions) PM only 3% (7%)	
				3%	7%
Final Program	27,000	790,000	$760	$9.2	$8.4
Alternative 1: Proposed Program from Notice of Proposed Rulemaking	26,000	780,000	$750	$8.8	$8.0
Alternative 2: Exclusion of Remanufacturing Standards	24,000	760,000	$720	$8.2	$7.5
Alternative 3: Elimination of Tier 3	21,000	760,000	$760	$7.8	$7.1
Alternative 4: Tier 4 Exclusively in 2013	24,000	790,000	$780 + C	$8.4	$7.6

[a] The 'C' represents the additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time, such additional engine test cells, engineering staff, and engineering facilites necessary to introduce Tier 4 one year earlier.
[b] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).
[c] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Figure 8.2-1 $PM_{2.5}$ Inventories for 2006-2040

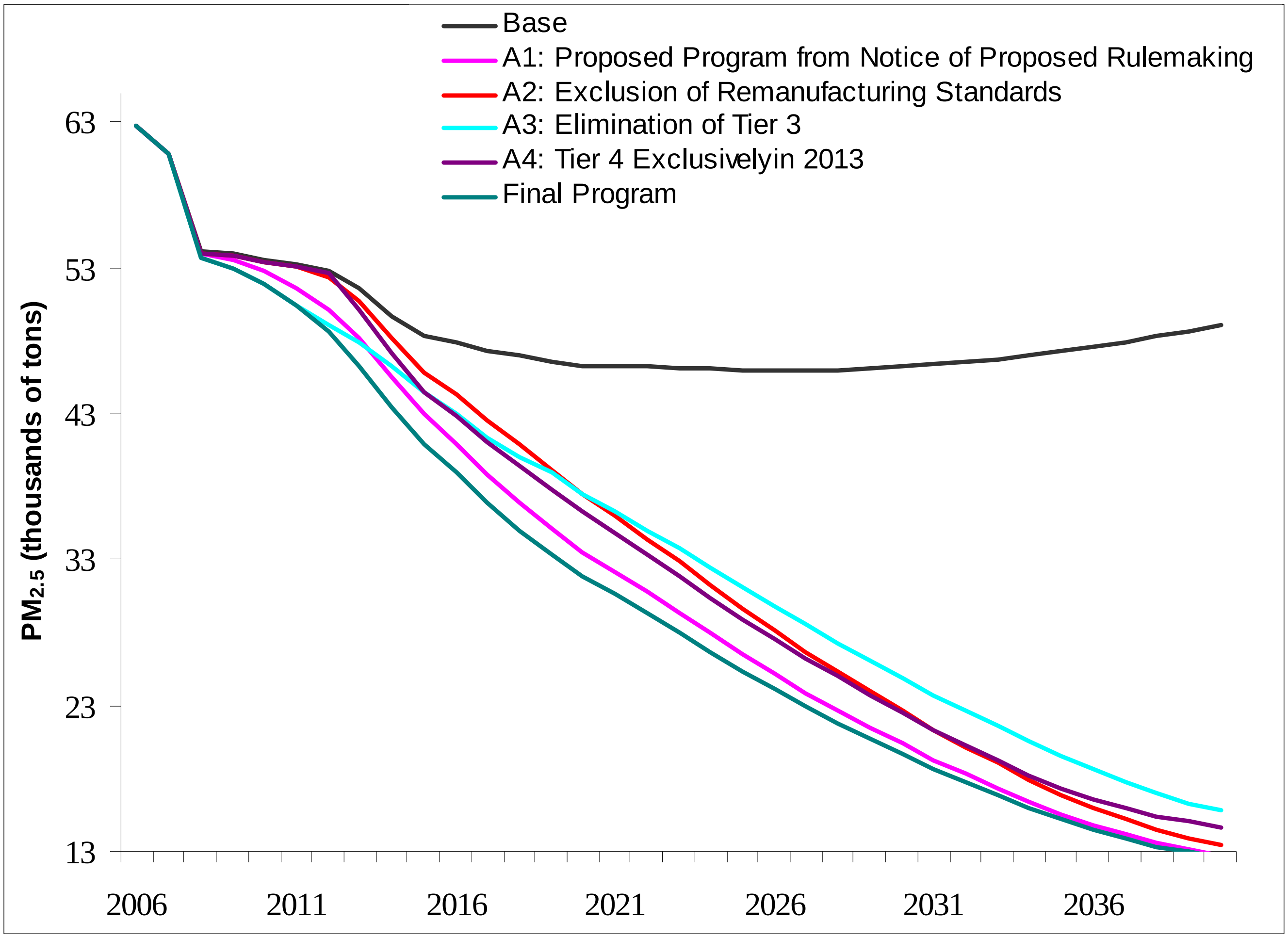
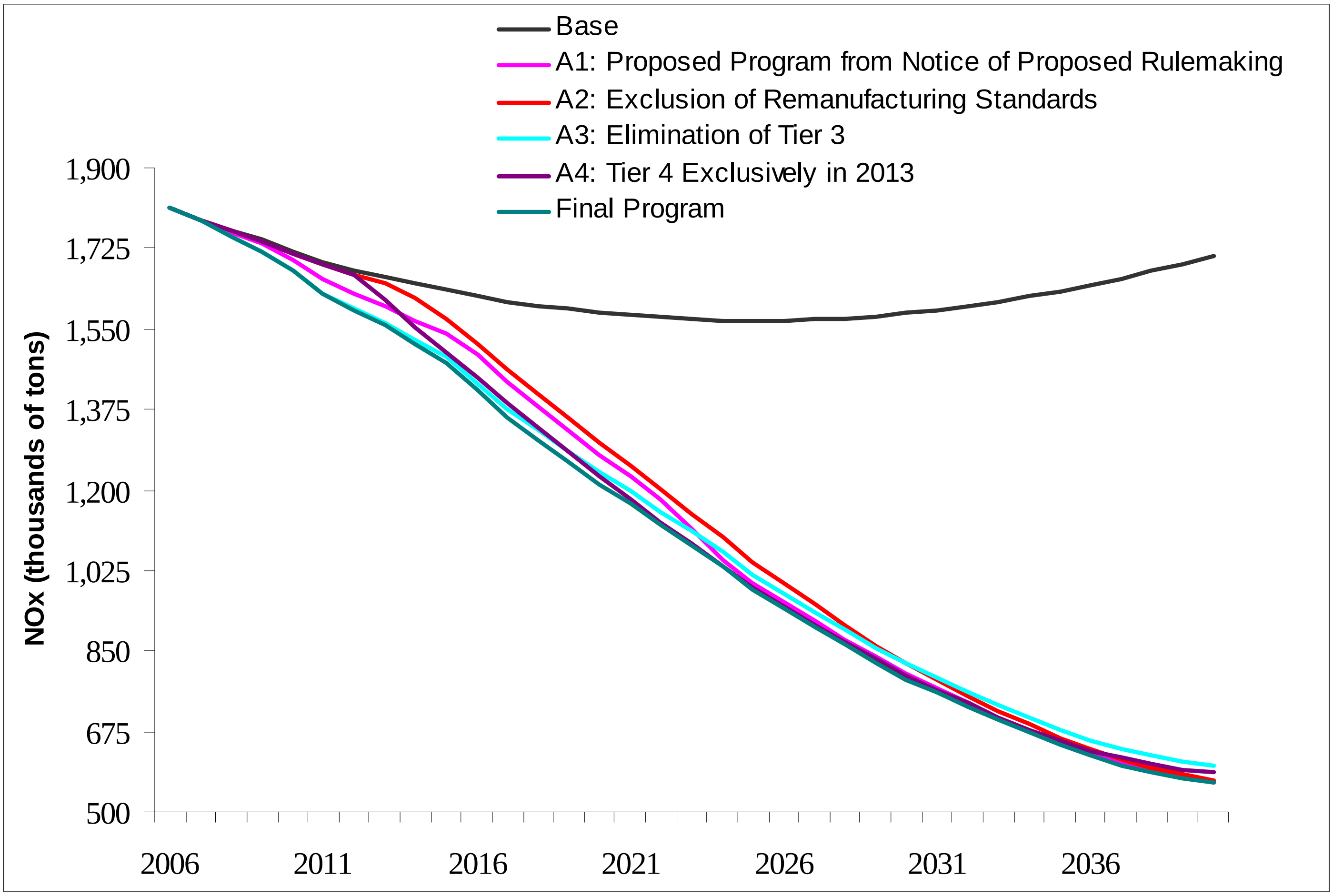


Figure 8.2-2 NO_x Inventories for 2006-2040



8.3 Summary of Results

8.3.1 Alternative 1: Proposed Program from the Notice of Proposed Rulemaking

Table 8-2 shows the changes in inventory that arise from comparing our proposal to our final rulemaking. As a stand-alone program, through the year 2040 Alternative 1 provides $PM_{2.5}$ reductions of 286,000 tons NPV 3%, or 121,000 tons NPV 7%, and NO_x reductions of 8,140,000 tons NPV 3%, or 3,320,000 tons NPV 7%. The cost of this alternative through 2040 is estimated to be $8,760 million NPV 3%, or $3,900 million NPV 7%. In 2020, this alternative provides monetized health and welfare benefits of $3.3 billion at a 3% discount rate, or $3.0 billion at a 7% discount rate, and $8.8 billion in 2030 at a 3% discount rate or $8.0 billion at a 7% discount rate. Through 2040 our final program provides additional $PM_{2.5}$ reductions of 22,000 tons NPV 3%, or 13,000 tons NPV 7%, and additional NO_x reductions of 620,000 tons NPV 3%, or 390,000 tons NPV 7%. Through 2040, the additional costs of our final program will be $650 million NPV 3%, or $410 million NPV 7%. The additional $PM_{2.5}$ monetized health and welfare benefits in 2020 of our final program are $0.6 billion at a 3% discount rate, or $0.6 billion at a 7% discount rate, while in 2030 the additional monetized health and welfare benefits total $0.4 billion at a 3% discount rate, or $0.4 billion at a 7% discount rate. Figures 8.1 and Figure 8.2 show the increase in emission reductions that our final program provides over our proposed program. The decrease in $PM_{2.5}$ inventory of our final program as compared to the proposed program is almost immediate; the decrease in NO_x inventory is also greatest in the near-term as compared to our proposed program. Figure 8.1 and Figure 8.2 demonstrate that the changes made to the proposed program result in a final program that provides greater overall NO_x and PM reductions in the critical early years of the program.

8.3.2 Alternative 2: Exclusion of Remanufacturing Standards

Our analysis of this alternative shows the valuable emission reductions and health and welfare benefits that the locomotive and marine remanufacturing standards provide. The locomotive and marine remanufacturing programs provide inventory impacts and benefits both in the near-term and the long-term. As a stand-alone program, Alternative 2 provides $PM_{2.5}$ reductions of 240,000 tons NPV 3%, or 96,000 tons NPV 7%, and NO_x reductions of 7,640,000 tons NPV 3%, or 3,030,000 tons NPV 7% through the year 2040. The cost of this alternative through 2040 is estimated to be $8,080 million NPV 3%, or $3,430 million NPV 7%. In 2020, this alternative provides monetized health and welfare benefits of $2.5 billion at a 3% discount rate, or $2.3 billion at a 7% discount rate, and $8.2 billion in 2030 at a 3% discount rate, or $7.5 billion at a 7% discount rate. Compared to the final program, our analysis shows that by 2040 eliminating the locomotive and marine remanufacture programs lessen $PM_{2.5}$ emission reductions by 68,000 tons NPV 3%, or 38,000 tons NPV 7%, and NO_x emission reductions by nearly 1,120,000 tons NPV 3% or 680,000 tons NPV 7%. The cost of this alternative, as compared to our final program through 2040, is estimated to be $1,330 million less than our proposal at NPV 3%, or $880 million less at NPV 7%. Compared to our final program, eliminating the locomotive and marine remanufacture programs reduce the monetized health and welfare benefits by $1.4 billion at a 3% discount rate, or $1.3 billion at a 7% discount rate in 2020, and $1.0 billion at a 3% discount rate, or $0.9 billion at a 7% discount rate in 2030. Figure 8.1 shows that the remanufacturing programs provide $PM_{2.5}$

emission reductions throughout the entire length of the program. Eliminating the locomotive and marine remanufacturing programs would also reduce the NO_x emission benefits that our final program provides. Figure 8.2-2 shows the loss of early NO_x benefits that this alternative would result in as compared to our final program. This alternative shows that when our final program includes the locomotive and marine remanufacture programs it provides significant additional emission reductions, and over one-third more health and welfare benefits in 2020 alone.

8.3.3 Alternative 3: Elimination of Tier 3

Alternative 3 eliminates the Tier 3 standards, while retaining Tier 4 and the combined locomotive and marine remanufacturing requirements. This alternative allows us to consider the value of combining the Tier 4 standards with the locomotive and marine remanufacturing standards together as one program, and conversely, allows us to see the additional benefits gained when combining them with the Tier 3 standards. Although the remanufacturing programs provide significant benefits in the near-term, as evidenced by the analysis of Alternative 2, it is clear that Tier 3 also plays an important role in providing both near-term and long-term emission reductions. As a stand-alone program, Alternative 3 provides $PM_{2.5}$ reductions of 237,000 tons NPV 3%, or 100,000 tons NPV 7%, and NO_x reductions of 8,360,000 tons NPV 3%, or 3,530,000 tons NPV 7% through the year 2040. The cost of this alternative through 2040 is estimated to be $9,240 million NPV 3%, or $4,160 million NPV 7%. In 2020, this alternative provides monetized health and welfare benefits of $2.8 billion at a 3% discount rate, or $2.6 billion at a 7% discount rate and $7.8 billion in 2030 at a 3% discount rate, or $7.1 billion at a 7% discount rate. Comparing this alternative to our final program allows us to consider the value of the Tier 3 standards on their own merits. Specifically, this alternative would lessen $PM_{2.5}$ emissions reductions by nearly 71,000 tons NPV 3%, or 34,000 tons NPV 7%, and NO_x emissions by 400,000 tons NPV 3 %, or 180,000 tons NPV 7%. The cost of this alternative, as compared to our final program through 2040, is estimated to be $170 million less at NPV 3%, or $150 million less at NPV 7%. The monetized health and welfare benefits that would be forgone by eliminating Tier 3 are $1.1 billion at a 3% discount rate, or $1.0 billion at a 7% discount rate in 2020, and $1.4 billion at a 3% discount rate, or $1.3 billion at a 7% discount rate in 2030. Figure 8.2-1 shows the decrease in $PM_{2.5}$ emission reductions that this alternative results in. Figure 8.2-2 shows that this alternative also provides decreased long-term NO_x reductions. This alternative shows that by eliminating Tier 3 from our final program, we would lose almost one-quarter of the total PM emissions reductions and over one-quarter of the PM health and welfare benefits in 2020 alone. As these alternatives show, each element of our comprehensive program: the locomotive and marine remanufacturing programs, the Tier 3 emission standards, and the Tier 4 emission standards, represents a valuable emission control program on its own, while the collective program results in the greatest emission reductions we believe to be possible giving consideration to all of the elements described in our final rule.

8.3.4 Alternative 4: Tier 4 Exclusively in 2013

Alternative 4 eliminates the Tier 3 standards along with the locomotive and marine remanufacturing standards, while pulling the Tier 4 standards ahead to 2013 for all portions of the Tier 4 program. As stated in our NPRM, we are concerned that it may not be feasible to introduce Tier 4 technologies on locomotive and marine diesel engines earlier than the proposal specifies. We have used the same cost estimation approach for this alternative as that of our final program, however, we are unable to make an accurate estimate of the cost for such an approach since we do not believe it to be technologically feasible at this time. Therefore, we have denoted the unestimated costs that are necessary to accelerate the development of Tier 4 technologies with a ‘C’ in the summary tables. These additional unestimated costs would include costs for additional engine test cells, engineering staff, and engineering facilities necessary to introduce Tier 4 one year earlier. As a stand-alone program, Alternative 4 provides $PM_{2.5}$ reductions of 249,000 tons NPV 3%, or 101,000 tons NPV 7%, and NO_x reductions of 8,320,000 tons NPV 3%, or 3,420,000 tons NPV 7% through the year 2040. In 2020, this alternative provides monetized health and welfare benefits of \$3.0 billion at a 3% discount rate, or \$2.8 billion at a 7% discount rate, and \$8.4 billion in 2030 at a 3% discount rate, or \$7.6 billion at a 7% discount rate. Through 2040, this alternative, as compared to our final program, would decrease $PM_{2.5}$ reductions by more than 59,000 tons NPV 3%, or 33,000 tons NPV 7%, and NO_x emissions by 440,000 tons NPV 3%, or 290,000 tons NPV 7%. Compared to our final program, the reduction in monetized health and welfare benefits of this alternative are \$0.9 billion at a 3% discount rate or \$0.8 billion at a 7% discount rate in 2020, while in 2030 the reductions in monetized benefits are \$0.8 billion at a 3% discount rate, or \$0.8 billion at a 7% discount rate. This alternative shows that in addition to the technical challenges necessary to introduce Tier 4 technologies, it would actually result in higher $PM_{2.5}$ and NO_x emissions and lower health and welfare benefits than our final program.

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