Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines

United States
Environmental Protection
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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
ABT	Average Banking and Trading
ACS	American Cancer Society
AE	Alaska Southeast Region
AE	Auxiliary Engine
AEO	Annual Energy Outlook (an EIA publication)
AESS	Automatic Engine Stop/Start System
AFC	Average Daily Fuel Consumption
AIM	Aerosol Inorganics Model
AIRS	Aerometric Information Retrieval System
AMVER	Automated Mutual-Assistance Vessel Rescue
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)
ASPEN	Assessment System for Population Exposure Nationwide
ATAC	Average Total Cost
avg	Average
AW	Alaska West Region
BAF	Bunker Adjustment Factor; a surcharge reflecting the fluctuation in fuel cost
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; marine diesel engines up to 7 liters per cylinder displacement
C2	Category 2; marine diesel engines 7 to 30 liters per cylinder
C3	Category 3; marine diesel engines at or above 30 liters per cylinder
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
CMV	Commercial Marine Vessel
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
DM	Distillate Marine Grade
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
DSP	Deep Sea Port
DV	Design Values
DWT	Dead Weight Tonnage
EAC	Early Action Component
EC	East Coast Region
EC	Elemental Carbon
ECA	Emission Control Area
EDHS	Electric Driven Heating System
EEZ	Exclusive Economic Zone
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
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

GC	Gulf Coast Region
GDP	Gross Domestic Product
GEOS	Goddard Earth Observing System
GETS	General Electric Transportation Systems
GI	Global Insight
GIS	Geographic Information System
GL	Great Lakes Region
GRT	Gross Registered Tonnage
GT	Gas Turbine
H_2	Hydrogen Gas
HAD	Diesel Health Assessment Document
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HD	Heavy-Duty
HE	Hawaii East Region
HEI	Health Effects Institute
HEP	Head End Power
HES	Health Effects Subcommittee
HFO	Heavy Fuel Oil
hp	Horsepower
hp-hrs	Horsepower Hours
hrs	Hours
HW	Hawaii West Region
IACS	International Association of Classification Societies
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
ICOADS	International Comprehensive Ocean-Atmospheric Data Set
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRIS	Integrated Risk Information System
ISCST3	Industrial Source Complex Short Term Model
ISO	International Standardization Organization
ISORROPIA	Inorganic Aerosol Thermodynamic Model
ITB	Integrated Tug Barge
JAMA	Journal of the American Medical Association
K	Kelvin
k	Thousand
km	Kilometer
kts	Knots
kW	Kilowatt
kWH	Kilowatt Hour
L	Liter
L/cyl	Liters Per Cylinder
lb	Pound
LCO	Light Cycle Oil
LF	Load Factor
LGC	Large Gas Carrier
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
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
MDO	Marine Diesel Oil
ME	Main Engine
MECA	Manufacturers of Emission Controls Association
mg	Milligram
MGO	Marine Gas Oil
MDO	Marine Diesel Oil
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
MSD	Medium Speed Diesel
MSDS	Material Safety Data Sheet
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
NASSCO	National Steel and Shipbuilding Company
NATA	National Air Toxic Assessment
NBER	National Bureau of Economic Research
NCAR	National Center for Atmospheric 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
NM	Nautical Mile
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
NP	North Pacific Region
NPRM	Notice of Proposed Rulemaking

NPV	Net Present Value
NRC	National Research Council
NRLM	Nonroad, Locomotive and Marine diesel fuel
NRT	Net Registered Tonnage
NRT4	Nonroad Tier 4 Rule
NSTC	National Science and Technology Council
NTE	Not To Exceed
NWN	National Waterway Network
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
OGV	Ocean-Going Vessel
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
POLA/LB	Ports of Los Angeles, Long Beach
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
RM	Residual Marine
rpm	Revolutions per Minute
RPO	Regional Planning Organization
RRF	Relative Reduction Factors
RSZ	Reduced Speed Zone
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
SFC	Specific Fuel Consumption
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
SP	South Pacific Region
SSD	Slow Speed Diesel
ST	Steam Turbine
STB	Surface Transportation Board
STEEM	Waterway Network Ship Traffic, Energy and Environment Model
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
TEU	Twenty-foot Equivalent Unit; basic container measurement used in the shipping industry
THC	Total Hydrocarbon
TSD	Technical Support Document
TVCC	Total Variable Compliance Cost
ULCC	Ultra Large Crude Carrier
ULSD	Ultra Low Sulfur Diesel fuel
URS	Upper Respiratory Symptoms
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
UV	Ultraviolet
UV-b	Ultraviolet-b
VLCC	Very Large Crude Carrier
VLGC	Very Large Gas Carrier
VOC	Volatile Organic Compound
VOF	Volatile Organic Fraction
VOS	Voluntary Observing Ships
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

EPA is proposing emission standards for new Category 3 marine diesel engines (engines with per cylinder displacement at or above 30 liters) installed on U.S. vessels. The proposed standards are part of a coordinated strategy to address emissions from ocean-going vessels (OGV) and are an important step in EPA's ongoing National Clean Diesel Campaign (NCDC).

Emissions from OGV remain at high levels. The Category 3 engines on these vessels use emission control technology that is comparable to that used by nonroad engines in the early 1990s, and use fuel that can have a sulfur content of 30,000 ppm or more. As a result, these engines emit high levels of pollutants that contribute to unhealthy air in many areas of the U.S. As we look into the future, however, emissions from ocean-going vessels are expected to become a dominant inventory source. This will be due to both emission reductions from other mobile sources as new emission controls go into effect and to the anticipated activity growth for ocean transportation.

Our coordinated strategy to control emissions from ocean-going vessels consists of actions at both the national and international levels. It includes: (1) the engine and fuel controls we are proposing in this action under our Clean Air Act authority; (2) the proposal[A] submitted by the United States Government to the International Maritime Organization to amend MARPOL Annex VI to designate U.S. coasts as an Emission Control Area (ECA)[B] in which all vessels, regardless of flag, would be required to meet the most stringent engine and marine fuel sulfur requirements in Annex VI; and (3) the new engine emission and fuel sulfur limits contained in the amendments to Annex VI that are applicable to all vessels regardless of flag and that are implemented in the U.S. through the Act to Prevent Pollution from Ships (APPS)..

We project that by 2030 the coordinated strategy would reduce annual emissions of NO_X and PM by 1.2 million and 143,000 tons, respectively, and the magnitude of these reductions would continue to grow well beyond 2030.[C] The estimated annual monetized health benefits of this coordinated strategy in 2030 would be between $110 and $280 billion,

[A] *Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulphur Oxides and Particulate Matter,* Submitted by the United States and Canada. IMO Document MEPC59/6/5, 27 March, 2009. A copy of this document can be found at http://www.epa.gov/otaq/regs/nonroad/marine/ci/mepc-59-eca-proposal.pdf

[B] For the purpose of this proposal, the term "ECA" refers to both the ECA and internal U.S. waters. Refer to Section VI.B. of the preamble for a discussion of the application of the fuel sulfur and engine emission limits to U.S. internal waters through APPS.

[C] These emission inventory reductions include reductions from ships operating within the 24 nautical mile regulatory zone off the California Coastline, beginning with the effective date of the coordinated strategy program elements. The California regulation contains a provision that would sunset the requirements of the rule if the federal program achieves equivalent emission reductions. See http://www.arb.ca.gov/regact/2008/fuelogv08/fro13.pdf at 13 CCR 2299.2(j)(1).

assuming a 3 percent discount rate (or between $100 and $260 billion assuming a 7 percent discount rate). The annual cost of the overall program in 2030 would be significantly less, at approximately $3.1 billion.

This Regulatory Impact Analysis provides technical, economic, and environmental analyses of the coordinated strategy. Chapter 1 provides industry characterization for the marine industry. Chapter 2 presents air quality modeling results and describes the health and welfare effects associated with NO_X, SO_X, PM, and ozone. Chapter 3 provides our estimates of the current emission inventories and the reductions that can be expected from the coordinated strategy. 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 coordinated strategy. Chapter 7 contains our estimates of the market impacts of the coordinated strategy and the distribution of costs among stakeholders. Finally, Chapter 8 provides the results of our small entity screening analysis for the proposed rule.

1. Coordinated Strategy to Reduce Emissions from Ocean-Going Vessels

The components of the coordinated strategy are summarized below. Readers should refer to the preamble for additional information about these provisions.

Clean Air Act Engine and Fuel Standards

We are proposing new engine standards for Category 3 marine diesel engines under our Clean Air Act authority. The proposed Tier 2 and Tier 3 NO_X limits are set out in Table ES-1 and would apply to engines with per cylinder displacement at or above 30 liters installed on U.S. vessels. In addition to the NO_X emission limits, we are proposing standards for emissions of hydrocarbons (HC) and carbon monoxides (CO) from new Category 3 engines. We are not proposing to set a standard for PM emissions for Category 3 engines. However, significant PM emissions benefits will be achieved through the ECA fuel sulfur requirements, described below, that will apply to ships that operate in areas that affect U.S. air quality. We are also proposing to require engine manufacturers to measure and report PM emissions pursuant to our authority in section 208 of the Act.

Table ES-1 Existing and Proposed NO_X Emission Standards for Category 3 Engines (g/kW-hr)

		LESS THAN 130 RPM	130-2000 RPM[a]	OVER 2000 RPM
Tier 1	2004[b]	17.0	$45.0 \cdot n^{(-0.20)}$	9.8
Tier 2	2011	14.4	$44.0 \cdot n^{(-0.23)}$	7.7
Tier 3	2016	3.4	$9.0 \cdot n^{(-0.20)}$	2.0

Notes:
[a] Applicable standards are calculated from n (maximum in-use engine speed in RPM), rounded to one decimal place.
[b] Tier 1 NO_X standards currently apply for engines originally manufactured after 2004.

With regard to fuels, we are proposing fuel sulfur limits under section 211(c) of the Clean Air Act that match the limits that apply under Annex VI for ECAs (see below). The adoption of such standards would: (1) forbid the production and sale of fuel oil above 1,000 ppm sulfur for use in the waters within the proposed U.S. ECA and internal U.S. waters; and (2) allow for the production and sale of 1,000 ppm sulfur fuel for use in Category 3 marine vessels.

ECA Designation of U.S. Coasts

To realize the benefits from the MARPOL Annex VI Tier III NOx and fuel sulfur controls, areas must be designated as Emission Control Areas. On March 27, 2009, the U.S. and Canadian governments submitted a proposal to amend MARPOL Annex VI to designate North American coastal waters as an ECA (referred to as the "U.S./Canada ECA" or the "North American ECA"). ECA designation would ensure that U.S. and foreign ships that affect U.S. air quality meet stringent NOX and fuel sulfur requirements while operating within 200 nautical miles of U.S. coasts. The area of the U.S./Canada ECA described in the proposed amendment is presented in Figure ES-1. The fuel sulfur limits that apply in ECAs pursuant to Annex VI are contained in Table ES-2. The engine emission limits that apply in

ECAs are the MARPOL Annex VI Tier III limits, which are equivalent to the Tier 3 NOx limits contained in Table ES-1.**Table ES-2 Annex VI Fuel Sulfur Limits**

	GLOBAL		ECA	
Fuel Sulfur	2004	45,000 ppm[a]	2005	15,000 ppm[a]
	2012	35,000 ppm[a]	2010[a]	10,000 ppm[a]
	2020	5,000 ppm[a,b]	2015	1,000 ppm[a]

Notes:
[a] Annex VI standards are in terms of percent sulfur. Global sulfur limits are 4.5%; 3.5%; 0.5%. ECA sulfur limits are 1.5%; 1.0%; 0.1%.
[b] Subject to a feasibility review in 2018; may be delayed to 2025.

Figure ES-1 Proposed U.S./Canada Emission Control Area

The ECA stringent international engine NOx standards and fuel sulfur limits will apply to U.S. and foreign vessels while they operate in the designated area upon adoption of the proposed amendment to Annex VI. If this proposal is not timely adopted by IMO, we intend to take supplemental action to control emissions from vessels, including foreign vessels, that affect U.S. air quality.

MARPOL Annex VI and the Act to Prevention Pollution from Ships

The United States became a party to MARPOL Annex VI by depositing its instrument of ratification with IMO on October 8, 2008. This was preceded by the President signing into law the Maritime Pollution Prevention Act of 2008 (Public Law 110-280) on July 21, 2008, that contains amendments to the Act to Prevent Pollution from Ships (33 USC 1901 et seq.). These APPS amendments require compliance with Annex VI by all persons subject to the engine and vessel requirements of Annex VI. The amendments also authorize the United States Coast Guard and EPA to enforce the provisions of Annex VI against domestic and foreign vessels and to develop implementing regulations, as necessary. In addition, APPS

gives EPA sole authority to certify engines installed on U.S. vessels to the Annex VI requirements. The preamble contains proposed regulations to implement several aspects of the Annex VI engine and fuel regulations, which we are proposing under that APPS authority. Our cost and benefit analyses for the coordinated strategy includes the costs for U.S. vessels of implementing those provisions of the MARPOL Annex VI program that are in addition to the ECA requirements.

2. Projected Inventory and Cost Impacts of the Coordinated Strategy

This RIA presents estimated inventory and cost impacts for the entire coordinated strategy, including the Annex VI Tier II NO_X requirements and the ECA controls that will be mandatory for U.S. and foreign vessels through the Act to Prevent Pollution from Ships (See Chapter 5 for more details). Specifically, the analysis estimates the costs of the proposed Clean Air Act (CAA) Tier 2 and Tier 3 emission standards for U.S.-flagged vessels, operational costs associated with the global Tier II and Tier III standards for foreign-flagged vessels operating in the ECA, and the ECA fuel sulfur requirements. We also include Clean Air Act compliance costs that will apply only to new U.S. vessels for verification testing after engine installation (PLT). The fuel program changes are implementation provisions and do not impose compliance costs, but instead may reduce the costs for fuel distributors of complying with EPA's distillate diesel standards. Similarly, the programmatic changes under consideration for Category 1 and 2 engines (see Section VI.C of the preamble) would not impose compliance costs but instead are intended to facilitate compliance with both Annex VI and our Clean Air Act requirements for those engines.

Inventory Reductions

A discussion of the current and projected inventories for several key air pollutants are contained in Chapter 3. Nationally, in 2009, Category 3 vessels will contribute 10 percent of mobile source NO_X emissions, 24 percent of mobile source diesel $PM_{2.5}$ emissions, and 80 percent of mobile source SO_2 emissions. In 2030, absent the coordinated strategy, these vessels would become a larger portion of the total mobile source emissions inventory constituting 40 percent of mobile source NO_X emissions, 75 percent of mobile source diesel $PM_{2.5}$ emissions, and 95 percent of mobile source SO_2 emissions.

We estimate that the coordinated strategy would reduce annual NO_X emissions by 1.2 million tons, $PM_{2.5}$ emissions by 143,000 tons, and SO_2 emissions by 1.3 million tons in 2030.

Engineering Costs

The total engineering costs associated with the coordinated strategy are the summation of the engine and vessel costs and include both hardware and operating costs. This analysis can be found in Chapter 5. The cost of the coordinated strategy is estimated to be $1.9 billion in 2020 and $3.1 billion in 2030; over 98 percent of these costs are attributable to expected increases in operating costs for U.S. and foreign flag vessels traveling within the ECA. These increased operating costs include changes in fuel consumption rates, increases in fuel costs, and the use of urea for engines equipped with selective catalytic reduction (SCR). The total

cost of the coordinated strategy based on a 3 percent discount rate from 2010 through 2040 is estimated to be $43 billion and $22 billion at a 7 percent discount rate.

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 ES-3 contains the estimated cost per ton of pollutant reduced based on the net present value of the engineering costs and inventory reductions from 2010 through 2040. This estimate captures all of the engineering costs and emissions reductions associated with the coordinated strategy. When attributed by pollutant, at a net present value of 3 percent from 2010 through 2040, the NO_X controls are expected to cost about $510 per ton of NO_X reduced, SO_X controls are expected to cost about $930 per ton of SO_X reduced, and the PM controls are expected to cost about $7,950 per ton of PM reduced ($500, $920, and $7,850 per ton of NO_X, SO_X, and PM respectively, at a net present value of 7 percent over the same period.)

Table ES-3 Program Cost per Ton Estimates

POLLUTANT	2010 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 3%	2010 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 7%
NO_X	$510	$500
SO_X	$930	$920
PM	$7,950	$7,850

3. Estimated Benefits and Economic Impacts of the Coordinated Strategy

We estimated benefits for the entire coordinated strategy, including the Annex VI Tier II NO_X requirements and the ECA controls that will be mandatory for U.S. and foreign vessels through the Act to Prevent Pollution from Ships. Note that the Clean Air Act-specific portions of the coordinated strategy are compliance measures (PLT, distillate fuel program changes) and do not impact the estimated benefits. The benefits analysis is presented in Chapter 6. It 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.

Estimated Benefits

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 other PM and ozone non-mortality related benefits information. These benefits are presented in Table ES-4. These estimates reflect EPA's most current interpretation of the scientific literature on $PM_{2.5}$ and mortality, including our updated benefits methodology (i.e., a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels) compared to estimates in previous RIAs that did not include these changes. Please see Section 6.4.1.3 of the RIA for more discussion of the treatment of thresholds in this analysis.

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-4) to estimates of PM-related premature mortality derived from the epidemiological literature.

Table ES-4 Estimated Monetized PM- and Ozone-Related Health Benefits of Coordinated U.S. Strategy to Control Ship Emissions

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]
Multi-city	Bell et al., 2004	$110 - $280
	Huang et al., 2005	$120 - $280
	Schwartz, 2005	$120 - $280
Meta-analysis	Bell et al., 2005	$120 - $280
	Ito et al., 2005	$120 - $280
	Levy et al., 2005	$120 - $280

Notes:

[a] Total includes premature mortality-related and morbidity-related 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 either the American Cancer Society (ACS) cohort study (Pope et al., 2002) or the Harvard Six-Cities study (Laden et al., 2006).

[b] 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 6-2.

[c] Results reflect the use of a 3 percent discount rate. Using a 7% discount rate, the benefits are approximately 10% less. Monetary results presented in Chapter 6 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 the coordinated strategy will annually prevent between 13,000 and 32,000 PM-related premature deaths (based on the American Cancer Society cohort study and the Harvard Six-Cities study), between 220 and 980 ozone-related premature deaths, 1,500,000 work days lost, and approximately 10,000,000 minor restricted-activity days.

Benefit-Cost Analysis

We estimate that the monetized benefits of the coordinated strategy in 2030 will range between approximately $110 and $280 billion, assuming a 3 percent discount rate. The annual cost of the coordinated strategy in 2030 is estimated to be significantly less, at approximately $3.1 billion. The 2030 benefits outweigh the costs by at least a factor of 32 and could be as much as a factor of 90. Thus, even taking the most conservative benefits assumptions, benefits of the coordinated strategy clearly outweigh the costs.

Economic Impact Analysis

We performed an economic impact analysis to estimate the market-level changes in prices and outputs for affected markets, the social costs of the coordinated strategy, 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 $3.1 billion in 2030.[D] These costs are expected to be borne by purchasers of marine transportation services. Because there are no close transportation alternatives for the vast majority of goods currently moved by ship, these costs are expected to be passed to consumers of marine transportation in the form of higher freight rates. Ultimately, these costs will be incurred by the purchasers of goods transported by ocean-going vessels in the form of higher prices for those goods.

With regard to market-level impacts, the equipment costs of the coordinated strategy are expected to increase the price of a new vessel by 2 percent or less. The impact of the coordinated strategy, including the increase in operating costs due to the ECA fuel and emission requirements, on the price of ocean marine transportation services would vary, depending on the route and the amount of time spent in the proposed U.S. ECA. For example, we estimate that the cost of operating a ship in liner service between Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in the proposed ECA, would increase by about 3 percent. For a container ship, this represents a price increase of about $18 per container, assuming the total increase in operating costs is passed on to the purchaser of marine transportation services. This would be about a 3 percent price increase. The per passenger price of a seven-day Alaska cruise operating entirely within the ECA is expected to increase about $7 per day. For ships that spend less time in the ECA, the expected increase in total operating costs and therefore the impact on freight prices would be smaller.

4. Alternatives

In the course of designing our rulemaking, we investigated several alternative approaches to both the engine and fuel programs. The analysis for those alternatives is contained in the preamble, and is not duplicated in this RIA. The preamble also contains a description of a voluntary program to encourage emission reductions from existing Category 3 marine diesel engines.

[D] All estimates presented in this section are in 2006$.

CHAPTER 1: Industry Characterization

CHAPTER 1: Industry Characterization

1.1 Introduction

Marine transportation is a key component of the U.S. national economy, for both our internal and external trade. According to the U.S. Maritime Administration, the United States saw about 2.3 billion metric tons of goods shipped via waterborne transportation in 2006, of which about 1.4 billion, or nearly 65 percent, was foreign trade (imports and exports to and from the United States).[1] This foreign trade, carried primarily by ocean-going vessels powered by Category 3 marine diesel engines, had a value of about $1.4 trillion.

This chapter provides some basic information about the segment of the marine transportation sector, ocean-going marine that is affected by today's proposal. The material presented below is a brief synopsis of the unique attributes of the maritime industry, derived from two detailed reports prepared for this rulemaking.[2,3] These reports explore in greater detail the various aspects of the marine transportation sector and the marine fuel markets. We encourage readers to review the full reports for further information.

1.2 Marine Transportation Sector

In this report, the marine transportation sector refers to (1) Category 3 marine diesel engines, (2) the vessels that use those engines, and (3) the transportation services that use those vessels. EPA defines Category 3 marine engines as compression-ignition engines with a displacement greater than or equal to 30 liters per cylinder.[A] Category 3 engines can be incredibly large and can have anywhere from four to 20 cylinders with displacements ranging from 30 to 3,000 liters per cylinder. These engines can provide power output from 2,000 kW to over 100,000 kW. The two most common types of Category 3 engines are slow-speed diesel engines (SSD) with engine speeds of 150 rpm or less, and medium-speed diesel engines (MSD) with engine speeds of approximately 300 to 600 rpm, less common are steam or gas turbine engines. EPA adopted an initial level of emission standards for Category 3 (C3) engines on February 28, 2003 (68 FR 9746). This includes all marine diesel engines with per-cylinder displacement above 30 liters. These initial standards are identical to the standards specified in MARPOL Annex VI.

The marine transportation industry relies on a variety of large ocean-going commercial vessel types powered by C3 engines to carry goods and passengers around the world. The EPA typically defines large commercial vessels as vessels engaged in waterborne trade and/or passenger transport that exceed 400 feet in length and/or weigh more than 2,000 GT.[4] Marine

[A] Marine diesel engines with per-cylinder displacement below 30 liters, called Category 1 and Category 2 engines (C1 and C2, respectively), became regulated under an initial U. S. Environmental Protection Agency (EPA) rulemaking in 1999 (64 FR 73300, December 29, 1999). EPA adopted more stringent standards for these engines as part of the Clean Diesel Locomotive and Marine Rule, which is a three-phased program and will ensure that all locomotives and C1 and C2 marine diesel engines will produce less pollution (73 FR 37096, June 30, 2008).

vessel owners and operators include U.S. and foreign entities that provide ocean marine transportation services to many industries including: consumer goods, chemical, agricultural, petroleum, personal transportation, etc. The statistics presented in this report were compiled in 2008 using Lloyd's Register of Ships Sea-Web service.[5] Sea-Web provides detailed information on the vessels that make up the global fleet including details on the installed engines, the vessels themselves, and the owners and operators of these vessels. Engine details available include: engine designer, builder, model, type, and propulsion power rating. Vessel details include: ship type, year built, gross tonnage (GT), flag state, and actual build details (e.g., hull type). The analyses presented here are based only on vessels built in or after 1990, with at least 5,000 kW, are at least 2,000 GT, and are in-service; only vessels with complete records were included; for the purposes of this report these vessels will be referred to as the "global fleet."

Table 1-1 Characteristics of the "Global Fleet"

	AVERAGE YEAR BUILT	AVERAGE GT	NUMBER OF 2-STROKES	NUMBER OF 4-STROKES	NUMBER OF GAS TURBINES	NUMBER OF STEAM TURBINES	AVERAGE ENGINE POWER (KW)
Auto Carrier	2002	49,000	386	18	0	0	13000
Bulk Cargo	2000	37,000	4127	281	0	0	9400
Container	2001	34,000	2977	492	0	0	27000
Misc	2000	18,000	19	157	0	2	7500
Passenger	1999	42,000	7	402	16	1	10000
Reefer	1995	9,300	224	21	0	0	9700
RoRo	2000	20,000	47	137	8	0	11000
Tanker	2002	57,000	3464	191	4	182	13000

The coordinated strategy for emission controls of C3 marine engines is slightly different than previous EPA rules in that, in addition to the Clean Air Act (CAA) authority, the U.S. Government has petitioned the International Maritime Organization (IMO) to create an Emission Control Area (ECA) around most of the U.S. coastline. The regulations for C3 marine diesel engine emissions could directly impact several 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, (5) vessel operators who own existing marine diesel engines with engine displacement at or greater than 30 liters per cylinder (L/cyl), (6) marine fuel manufacturers, (7) marine fuel distributors/brokers, and (8) U.S. ports.

1.2.1 Engine Types

1.2.1.1 Two-Stroke Engines

Two-stroke engines are usually SSD connected to a direct drive propulsion system. These engines have large displacements of up to 3,000 L/cylinder. SSD are used for propulsion on bulk carriers, container ships, larger tankers, general cargo and roll-on/roll-of (RoRo) ships. They are typically turbo-charged with aftercooling and have four exhaust valves per cylinder. Scavenge air enters the cylinder through a series of intake ports arranged around the bottom of the cylinder. Intake is controlled by the piston as it uncovers or covers the intake ports. Fuel injection is typically mechanical with three injectors per cylinder.

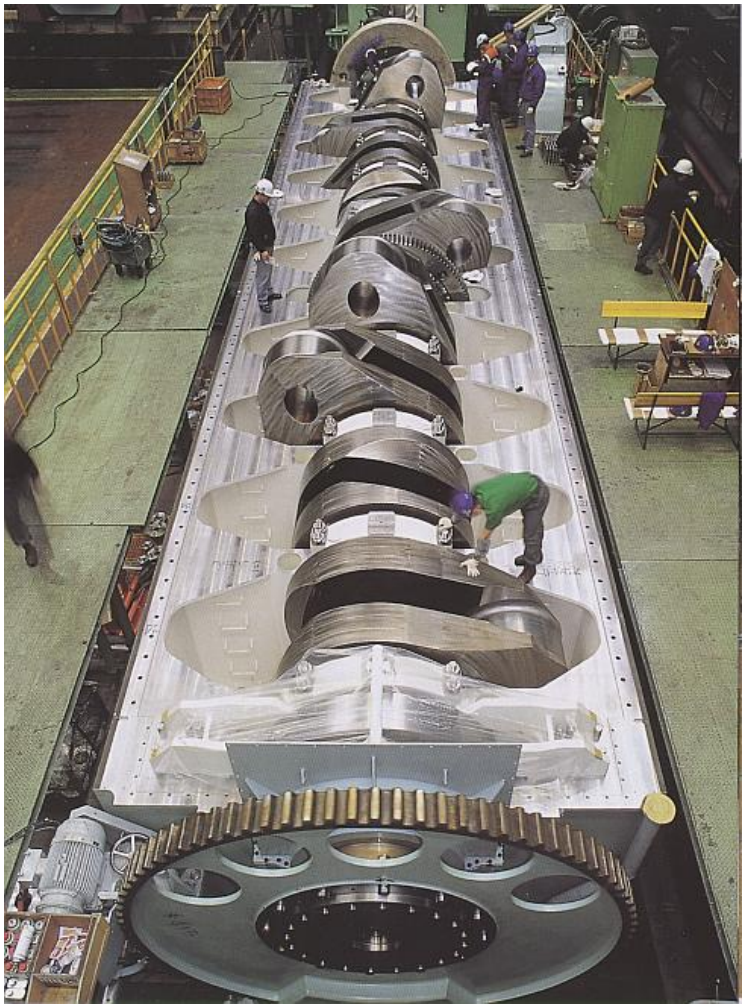
The top three two-stroke engine designers of the global fleet on a per-vessel basis are MAN which represents over 71 percent of that total, Wärtsila which produced nearly 18 percent, and Mitsubishi which captured just over 10 percent. MAN is headquartered in Munich, Germany and is a supplier of diesel engines, turbo machinery, special gear systems, trucks and buses. In 2008, MAN employed over 51,000 people and generated revenue of approximately $23 billion.[6] Wartsila is headquartered in Helsinki, Finland and is a provider of ship design, engines, generator sets, gears and other propulsion equipment. They employ nearly 19,000 people and have locations in close to 70 countries.[7] Mitsubishi Power Systems, Inc. (MPS) headquartered in Lake Mary, FL is a subsidiary company of Mitsubishi Heavy Industries, Ltd. (MHI) which employs more than 40,000 people worldwide generating more than $25 billion in annual revenues.[8] MPS produces gas and steam turbines in addition to medium speed engines up to nearly 15,000 kW, and low speed engines over 67,000 kW. MHI also builds and repairs ships, marine engines and equipment.

Table 1-2 Number of Engines Built per Year by Manufacturer

YEAR BUILT[A]	MAN	WARTSILA[B]	MITSUBISHI	OTHER	TOTAL
1990	170	86	41	0	297
1991	178	91	34	0	303
1992	171	107	46	0	324
1993	193	92	55	0	340
1994	260	108	46	0	414
1995	302	96	59	0	457
1996	352	125	67	0	544
1997	369	147	92	0	608
1998	377	136	82	0	595
1999	368	106	69	0	543
2000	331	155	62	0	548
2001	442	122	44	1	609
2002	474	80	53	0	607
2003	497	92	60	0	649
2004	579	87	80	0	746
2005	703	116	81	0	900
2006	764	115	68	0	947
2007	833	100	92	0	1025
2008	673	60	59	3	795
Total	8036	2021	1190	4	11251
Percent	71%	18%	10%	0.04%	

Notes:
[a] Assumes that the engine was built the same year the vessel was reported as being built.
[b] Wartsila count includes Sulzer engines.

Wartsila manufactures the world's most powerful diesel engine, the 14-cylinder Wärtsilä RT-flex96C marine engine has a maximum continuous power output of 84,000 kW (113,000 bhp) at 102 rpm. This engine is nearly 90 feet long, and over 44 feet tall and weighs over five million pounds, see Figure 1-1.[9,10]



Source:http://www.aucklandshipbrokers.com/index.php?option=com_content&task=view&id=100&Itemid=68

Figure 1-1 Wartsila RT-flex96C 84,000 kW SSD Engine

1.2.1.2 Four-Stroke Engines

Four-stroke engines are usually MSD engines with significantly smaller cylinder displacements (30 to 200 L/cylinder) than SSD, and typically have six to 18 cylinders. These engines are commonly connected to an electric drive propulsion system which is actually a large generator that can be used to generate auxiliary power as well as drive the propulsion systems. They are typically used as propulsion engines on smaller tankers, general cargo, RoRo, ferries, cruise ships, and as auxiliary engines on large ships for power generation or refrigeration. They are generally turbo-charged and aftercooled, have two intake and two exhaust valves per cylinder and are mechanically fuel injected with one injector per cylinder.

The top three four-stroke engine designers of the global fleet on a per-vessel basis are Wartsila which represents over 36 percent of that total, MAN which produced nearly 32 percent, and MAK which captured approximately 29 percent. MAK is owned by Caterpillar which

produces medium and high speed engines of up to 16,000 kW for main propulsion, and nearly 7,700 kW for marine generator sets and is headquartered in Hamburg, Germany.[11]

Table 1-3 Number of Engines Built per Year by Manufacturer

YEAR BUILT[A]	WARTSILA[B]	MAN[C]	MAK	OTHER	TOTAL
1990	10	17	9	3	39
1991	14	19	4	1	38
1992	12	21	11	1	45
1993	22	22	11	1	56
1994	22	13	10	1	46
1995	30	19	12	1	62
1996	20	33	13	2	68
1997	34	33	9	2	78
1998	51	35	5	3	94
1999	59	34	6	5	104
2000	55	24	21	3	103
2001	49	12	21	2	84
2002	41	23	28	2	94
2003	31	34	43	2	110
2004	36	12	46	1	95
2005	22	28	44	2	96
2006	24	55	57	3	139
2007	51	60	89	7	207
2008	38	48	51	4	141
Total	621	542	490	46	1699

Notes:
[a] Assumes that the engine was built the same year the vessel was reported as being built.
[b] Wartsila count includes Sulzer engines.
[c] MAN count includes Pielstick engines.

1.2.2 Other Engine Types

Turbine powered vessels accounted for less than two percent of the global fleet, and of those 13 percent are gas turbines, while the remaining 87 percent are steam turbines. The top three turbine engine designers include General Electric (GE), Kawasaki, and Mitsubishi and together account for over 91 percent of installed turbine engines. GE sold gas turbine engines exclusively to the global fleet representing 11 percent of the turbine powered fleet, while both Kawasaki and Mitsubishi only have steam turbine engines in the global fleet, accounting for 40 and 39 percent of the turbine powered fleet respectively. Steam turbines have traditionally been the choice of Liquid Natural Gas carriers primarily because any boil-off gas could be sent through the turbine and burned.

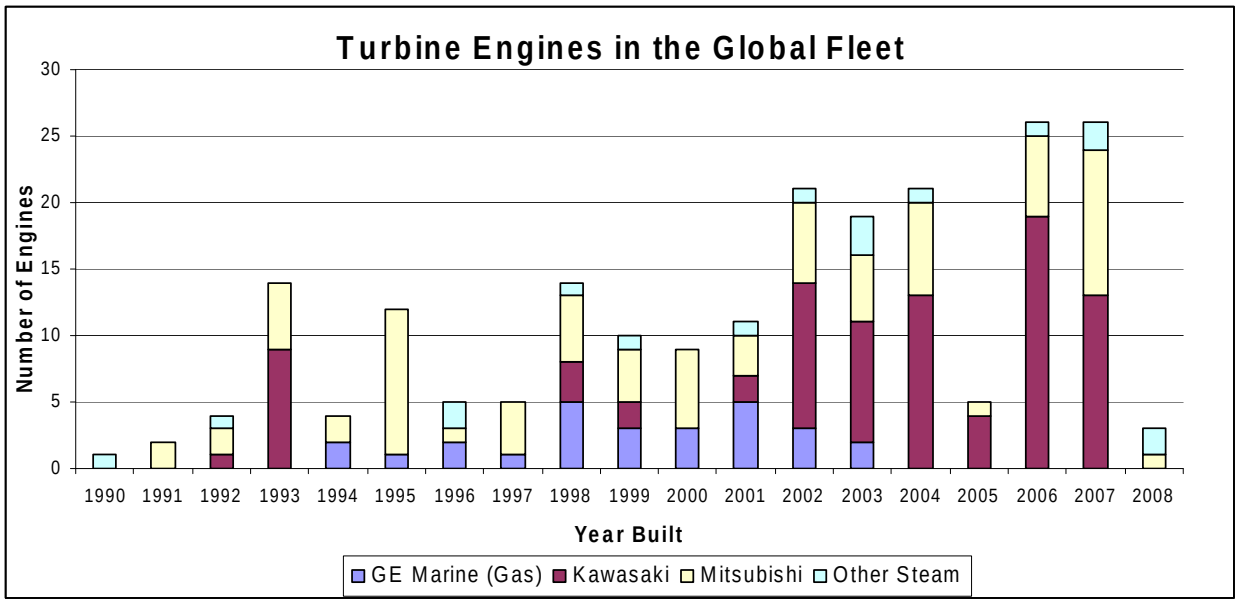


Figure 1-2 Steam and Gas Turbines in the Current Global Fleet

1.2.2.1 Auxiliary Engines

Category 3 engines can also be used for auxiliary engines as well as Category 2. They are used to generate electrical power for navigation equipment, maneuvering equipment, and crew services. The engines used to generate electrical power are typically, however, Category 2 diesel engines. Some vessels, such as refrigerated cargo vessels, may require Category 3 engines to meet electric power requirements. Cruise ships often employ diesel-electric engines that provide both propulsion and power generation. In addition to propulsion and electric power engines, an auxiliary engine is typically installed for emergency use. In 2007, over 10,000 auxiliary engines were ordered, totally 11,600 megawatts.[12,13]

1.2.2.2 Main Engines in the Global Fleet

Category 3 engines are not typically mass-produced. They are built in different configurations with varying numbers of cylinders, engine displacement, power output, and engine speed. Because of the variety of configurations and applications, the selection of the main engine is a major consideration in the overall design of a vessel. As a result, the engine selected for a specific vessel is often a unique design or configuration that is built specifically for that vessel. In many cases, C3 engines designed by these manufacturers are built under license by other companies in Europe and Asia. It can take up to two or three years to receive delivery of components such as crankshafts and engine blocks, Wartsila notes that it is not engine assembly that slows production, but delivery of these larger components from sub-suppliers.[14]

1.3 Marine Vessels

The marine transport industry relies on a variety of vessel types to carry goods and passengers around the world. These vessels are typically categorized by the type of cargo the vessel is designed to transport and by the vessel size, in terms of carrying capacity and hull

dimensions. Table 1-3 outlines the vessel categories that constitute the majority of the current OGV world fleet.

Table 1-4 Vessel type, category, and size range for the majority of the OGV world fleet.

Vessel Type	Vessel Size Category	Average Size Range (DWT)
Bulk Carrier	Coastal	1,253 – 9,994 (5,576)
	Handy	10,095 – 39,990 (27,593)
	Handymax	40,009 – 54,881 (47,616)
	Panamax	55,000 – 78,932 (69,691)
	Capesize	80,000 – 364,767 (157,804)
Container	Feeder	1,000-13,966 (9,053)
	Intermediate	14,003-36,937 (24,775)
	Panamax	37,042-54,700 (45,104)
	Post Panamax	55,238-84,900 (67,216)
	Suezmax	85,250-120,892 (101,099)
Liquid Gas Carrier (Liquid Petroleum Gas (LPG) / Liquid Natural Gas (LNG))	Midsize	1,001-34,800 (7,048)
	Large Gas Carrier (LGC)	35,760-59,421 (50,796)
	Very Large Gas Carrier (VLGC)	62,510-122,079 (77,898)
General Cargo	Coastal Small	1,000-9,999 (3,789)
	Coastal Large	10,000-24,912 (15,673)
	Handy	25,082-37,865 (29,869)
	Panamax	41,600-49,370 (44,511)
Cruise / Passenger	All	1,000–19,189 (6,010)
Refrigerated (Reefer)	All	1,000–19,126 (6,561)
Roll-on / Roll-off (Ro-Ro)	All	1,000–19,126 (7,819)
Tanker	Coastal	1,000-23,853 (7,118)
	Handymax	25,000-39,999 (34,422)
	Panamax	40,000-75,992 (52,300)
	AFRAmax	76,000-117,153 (103,112)
	Suezmax	121,109-167,294 (153,445)
	Very Large Crude Carrier (VLCC)	180,377-319,994 (294,475)
	Ultra Large Crude Carrier (ULCC)	320,051-441,893 (364,896)

1.3.1 Vessel Design and Construction

Ship builders typically design their vessels based on the type of freight they intend to haul as the type of cargo transported necessitates specific design characteristics, for example, container vessels require a different structure than a vessel that hauls bulk freight. Six ship builders are responsible for the majority of commercial vessels constructed in the United States, including Bath Iron Works, Electric Boat Company, the National Steel and Shipbuilding Company (NASSCO), Avondale Operations, Ingalls Operations, and Newport News Shipbuilding. There is a much larger number of ship builders outside the United States. Since 2000, U.S. ship builders have produced 20 to 40 vessels per year, while foreign ship builders have produced 60 to 120 vessels per year.[15]

Vessel design is an iterative process that typically includes three stages: concept design, preliminary design, and contract design. The concept design stage considers the vessel's general objectives, adjusting key vessel parameters and specifications based on the owner's stated technical and economic criteria. The preliminary design stage further refines the concept design by analyzing expected performance and profitability of various alternatives for key design elements (e.g., proportions, lines, hydrostatics, layout, power). Upon completion, the preliminary design yields the final vessel attributes, including dimensions, displacement, stability, propulsive performance, and structural details.[12]

1.3.2 Vessel Building Classification Societies

Ships must be built in accordance with shipbuilding standards in the country where they are flagged or in accordance with standards imposed by the International Association of Classification Societies (IACS). The classification societies implement many of the national or international requirements that apply to marine vessels, including the various requirements under MARPOL Annex VI. Classification societies include, among others, American Bureau of Shipping, Det Norske Veritas, and Germanischer Lloyd. In the United States, the U.S. Coast Guard works closely with the American Bureau of Shipping to implement and enforce applicable requirements. It is important to note that EPA implements and enforces requirements related to exhaust emission standards cooperatively with the U.S. Coast Guard, but without the involvement of classification societies.

The global shipping industry comprises a large number of diverse firms. Vessel owners and operators provide marine transportation services in support of international trade and commodity flows over water. Every ship in the world's shipping fleet is designated by the flag of registry. The flag of registry is a useful way of characterizing the shipping industry. However, in many cases, the flag of registry has no correlation with the location of the parent company that owns/operates a vessel. This confusion results partly because "open registries" allow owners/operators to register ships in countries outside of their country of domicile (owner/operator country). The five countries with the most flagged ships in the "Global Fleet" in order are Singapore, the Marshall Islands, China, Liberia, and Panama. Table 1-5 presents these values, and shows the ships under the U.S. flag as well.

The U.S. fleet of privately owned ocean-going vessels primarily includes bulk carriers, containerships, gas carriers, general cargo vessels, passenger vessels, refrigerated container

vessels, roll-on/roll-off vessels, and tankers. Containerships comprise the largest number of vessels in the U.S. commercial fleet with a total of approximately 75 ships (~45% of the total), while there are around 50 tankers (~33%). The average age of U.S.-flagged commercial ocean-going vessel is approximately 20 years.

Table 1-5 Ship Type by Country of Flag

SHIP TYPE	SINGAPORE	MARSHALL ISLANDS	CHINA[a]	LIBERIA	PANAMA	UNITED STATES OF AMERICA
Auto Carrier	22	1	2	6	173	16
Bulk Cargo	161	253	608	284	1337	11
Container	236	164	234	676	577	37
Misc	4	4	12	3	6	7
Passenger	0	0	9	0	32	2
Reefer	1	3	0	67	64	0
RoRo	0	1	2	0	11	14
Tanker	279	313	213	500	528	32
Grand Total	703	739	1080	1536	2728	119

Note:

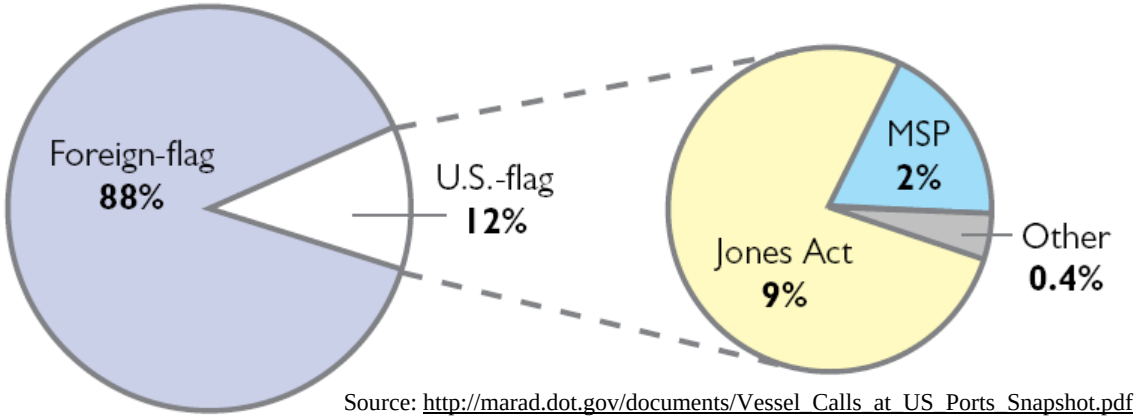
[a] This includes the People's Republic of China, Republic of (Taiwan), and Hong Kong.

Section 27 of the Merchant Marine Act of 1920, more commonly known as the Jones Act, was enacted with the goal of maintaining a domestic merchant fleet of U.S.-owned and U.S.-crewed vessels that is sufficient to carry the majority of U.S. waterborne commerce and also to assist the military in times of war. The Jones Act fleet is a subset of the total U.S. fleet and accounts for 52% of U.S.-flagged ships. The Maritime Administration (MARAD) is the U.S. Department of Transportation agency responsible for monitoring and maintaining the domestic merchant fleet, including the Jones Act fleet.

1.4 The Marine Transportation Sector

Over 95 percent of foreign trade was moved by ship in 2006.[16] Fifty ports in the U.S. handle approximately 84 percent of all waterborne domestic and international cargo; ten ports handle 85 percent of all containerized cargo and have seen a 54 percent increase in container movements between 2001 and 2006.[10] The U.S. ranks second in container traffic after China; one in nine containers is either bound for or originated from the U.S.[17] It is expected that this trade will continue to grow.

In 2007, the number of vessels calling on U.S. ports increased nearly 13 percent when looking over the past five years; of these calls 34 percent were tankers, 31 percent containerships, 17 percent dry-bulk vessels, 10 percent roll-on roll-off, and 6 percent by general cargo ships.[18] The size of vessels visiting U.S. ports has also increased, and in 2007, 54 percent of the calls to U.S. ports were by vessels less than 10 years old, up 47 percent over the previous five years.[12] Figure 1-3 shows the vessel calls by flag to U.S. Ports in 2007.[15]



Source: http://marad.dot.gov/documents/Vessel_Calls_at_US_Ports_Snapshot.pdf

Figure 1-3 2007 Vessel Calls by Flag to U.S. Ports

1.5 Marine Fuels

All marine fuel used today is created from the same basic distillation process that creates other liquid hydrocarbons such as motor gasoline, heating oil and kerosene. Distillate marine fuels are comparable to other forms of distillate hydrocarbon liquids, such as nonroad diesel fuel or No. 2 fuel oil, in that they have similar chemical properties and specification limits. Residual marine fuels, also called Intermediate Fuel Oils (IFO) or Heavy Fuel Oils (HFO), are composed of heavy, residuum hydrocarbons which are created as a by-product during petroleum refining, and can contain various contaminants such as heavy metals, water, and high sulfur levels. These contaminants can harm engines and fuel distribution lines and equipment, therefore residual fuel is typically treated and 'cleaned' of a large amount of these contaminants prior to combustion in the marine engine.

Both residual and distillate marine fuels are required to meet international fuel specifications established in the International Organization for Standardization (ISO) specification 8217 Petroleum products—Fuels (class F)—Specifications of Marine Fuels.[19] Each category of fuel is discussed below.

Marine distillate fuel is divided into four distinct fuel types: DMX, DMA, DMB, and DMC; however, only two of these fuels are commonly used in the marine transportation industry. DMX is a very low sulfur middle distillate hydrocarbon, and is therefore rather expensive when compared to other distillate fuels. This distillate type is mainly used onboard marine vessels for emergencies. The next two types of distillate fuel, DMA & DMB, are also called Marine Gas Oil (MGO) and Marine Diesel Oil (MDO) respectively. These two distillate fuels comprise the majority of marine distillate fuels sold. Lastly, DMC, is a higher sulfur fuel and is normally created by contaminating DMB fuel.

Marine residual fuel is created through traditional petroleum refining as a 'waste' product of the refining process. Typically, this fuel is rather dense and viscous, and it tends to contain heavy metals and other contaminants normally contained within crude oil. Residual fuel oil is categorized by the viscosity of the fuel at a set reference temperature and there are several

categories of this fuel type; however, the most commonly used fuel in the marine transportation industry is Intermediate Fuel Oil (IFO) 180 and 380.

1.5.1 Marine Gas Oil (MGO)

MGO is a light distillate product that is clear and bright, typically amber in color, and can be manufactured by blending light cycle oil (LCO) with other light distillate oils. MGO is a relatively light and clean gas oil, compared to other marine fuels. MGO also has a relatively high cetane value and density, making it a fuel that is best suited for higher rpm engines. Typically, MGO is used for propulsion in small- to medium-sized marine vessels and for emergency, maintenance, and auxiliary engines in larger vessels.[20]

1.5.2 Marine Diesel Oil (MDO)

MDO is a distillate fuel that is a slightly heavier (i.e., higher density) gas oil and has a lower cetane value than MGO. MDO is designated as distillate marine fuel grade B (DMB) under ISO standards. Typically, MDO is created when MGO is blended with small amounts of residual fuel oil, which raises the sulfur content of the fuel beyond the maximum allowable level for MGO.

1.5.3 Intermediate Fuel Oil (IFO)

Typically, residual fuel oil is not usable as a stand-alone fuel because of purchasers' need for specific performance characteristics, primarily viscosity. Thus, residual fuel oil normally requires blending with lighter components to meet specifications for use in marine engines. Blending with lighter components typically lowers the viscosity of the residual fuel oil to produce IFO. IFO is the industry colloquial name for the most common fuel blends. These fuels are categorized by their kinematic viscosity at a set reference temperature. IFO-180 and IFO-380 are the most common fuel grades used in OGV, and these fuels are designated as residual marine fuel grades RME/F-180 and RMG/H-380 by ISO standard 8217. Additionally, since these fuels have such a high viscosity, they are normally in a 'solid' state at ambient temperatures and require constant heating in order to effectively pump and combust it in diesel engines.[5]

1.5.4 Marine Fuel Supply & Procurement

The actual volume of marine fuels supplied worldwide is the subject of great debate inside the maritime community. This is because the majority of marine fuel consumed is composed from residual waste, and other industries (such as power plants, asphalting, and roofing) use this waste as well. The current estimation is that the world consumes approximately 350 million metric tonnes of marine fuel per year (350 mmt/yr), with about eighty percent (80%), or 280 mmt/yr, being residual grade fuel.[21]

Marine fuels are purchased and delivered slightly differently than other fuels (like motor gasoline or highway diesel). Marine fuels have "brokers" to purchase fuel and arrange delivery. These broker companies typically never have custody of or title to the bunker fuel, but they represent ship operators in the solicitation and negotiation of marine fuel purchases, and they may help coordinate fuel delivery for the operators they represent. Fuel delivery can be achieved

through several ways; the most widely used method both in the United States and internationally is delivery by barge. Delivery by barge allows for bunkering of vessels at port berths or at anchorage within the port boundaries

1.5.5 Fuel Monitoring and Testing

In order to ensure that the fuel delivered is actually the fuel purchased, at least four marine fuel samples are taken at the time of delivery. One sample is for the vessel (Chief Engineer), one is for the bunker supplier, one is sent to an independent laboratory for testing (e.g., DNV Petroleum Services), and one is for the International Maritime Organization (as required by MARPOL Annex VI). Additionally, there are two other documents that provide information on the quality of the fuel delivered to the vessel: the material safety data sheet (MSDS) and the bill of sale or invoice.

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CHAPTER 2: AIR QUALITY, HEALTH AND WELFARE EFFECTS

CHAPTER 2: Air Quality, Health and Welfare Effects

2.1 Background on Pollutants Reduced by this Proposal

The coordinated strategy that we are referencing in this proposal will be reducing emissions of PM, SO_X and NO_X. These emissions are associated with ambient PM, ozone, NO_X and SO_X, and related health and environmental effects caused from exposure to these pollutants are presented in this section.

2.1.1 Particulate Matter

Particulate matter (PM) is a generic term for 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. Since 1987, EPA has delineated that subset of inhalable particles small enough to penetrate to the thoracic region (including the tracheobronchial and alveolar regions) of the respiratory tract (referred to as thoracic particles). Current National Ambient Air Quality Standards (NAAQS) use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 μm), and use PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 μm and less than or equal to 10 μm, or $PM_{10-2.5}$). Ultrafine particles are a subset of fine particles, generally less than 100 nanometers (0.1 μm) in aerodynamic diameter.

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles originate 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.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SO_X, NO_X and VOCs) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology and source category. Thus, $PM_{2.5}$ may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.[1]

2.1.2 Ozone

Ground-level ozone pollution is formed by the reaction of VOCs and 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 (including those subject to this rule), power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. Ozone can be transported hundreds of miles downwind of precursor emissions, resulting in elevated ozone levels even in areas with low VOC or NO_X emissions.

The highest levels of ozone are produced when both VOC and NO_X emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_X enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_X. Under these conditions, NO_X reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_X-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X-limited.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO_X, VOC, and ozone, all of which change with time and location. When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited". Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large.

Rural areas are usually NO_X-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NO_X-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

2.1.3 Nitrogen Oxides and Sulfur Oxides

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. Nitrogen dioxide (NO_2) is a member of the nitrogen oxide (NO_X) family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature.

SO_2 and NO_2 can dissolve in water vapor and further oxidize to form sulfuric and nitric acid which react with ammonia to form sulfates and nitrates, both of which are important components of ambient PM. The health effects of ambient PM are discussed in Section 2.2.1. NO_X along with non-methane hydrocarbons (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section 2.2.2.

2.1.4 Air Toxics – Diesel Exhaust PM

Marine diesel engines emit diesel exhaust (DE), a complex mixture composed of carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter (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 a large surface area which makes them an excellent medium for adsorbing organics, and their small size makes them highly respirable. Many of the organic compounds present in the gases and on the particles, such as polycyclic organic matter (POM), are individually known to have mutagenic and carcinogenic properties. In addition, while toxic trace metals emitted by marine diesel engines represent a very small portion of the national emissions of metals (less than one percent) and are a small portion of DPM (generally much less than one percent of DPM), 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). Also, there are emissions differences between on-road and nonroad engines because the nonroad engines are generally of older technology. This is especially true for marine diesel engines.[2] After being emitted in the engine exhaust, diesel exhaust undergoes dilution as well as chemical and physical changes in the atmosphere. The lifetime for some of the compounds present in diesel exhaust ranges from hours to days.[3]

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.

2.2 Health Effects Associated with Exposure to Pollutants

The coordinated strategy that we are referencing in this proposal will be reducing emissions of PM, SO_X and NO_X. These emissions are associated with ambient PM, ozone, NO_X and SO_X, and related health and environmental effects caused from exposure to these pollutants are presented in this section.

2.2.1 Particulate Matter

This section provides a summary of the health effects associated with exposure to ambient concentrations of PM.[A] The information in this section is based on the data and conclusions in the PM Air Quality Criteria Document (PM AQCD) and PM Staff Paper prepared by the U.S. Environmental Protection Agency (EPA).[B,4,5] We also present additional recent studies published after the cut-off date for the PM AQCD.[6,C] Taken together this information supports the conclusion that exposure to ambient concentrations of PM are associated with adverse health effects. Information specifically related to health effects associated with exposure to diesel exhaust PM is included in Section 2.2.5.1 of this document.

2.2.1.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases,[7] hospitalization and emergency department visits for cardiopulmonary diseases,[8] increased respiratory symptoms,[9] decreased lung function[10] and physiological changes or biomarkers for cardiac changes.[11,12] In addition, the PM AQCD described 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.[13]

Among the studies of effects associated with short-term exposure to $PM_{2.5}$, several specifically address the contribution of mobile sources to short-term $PM_{2.5}$-related effects on premature mortality. The results from these studies generally indicated that several combustion-related fine particle source-types are likely associated with mortality, including motor vehicle

[A] 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.

[B] The PM NAAQS is currently under review and the EPA is considering all available science on PM health effects, including information which has been published since 2004, in the development of the upcoming PM Integrated Science Assessment Document (ISA). A first draft of the PM ISA was completed in December 2008 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. Comments from the general public have also been requested. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201805.

[C] 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 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 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. Further, the provisional science assessment found that the results reported in the studies did not dramatically diverge from previous findings, and taken in context with the findings of the AQCD, the new information and findings did not materially change any of the broad scientific conclusions regarding the health effects of PM exposure made in the AQCD. However, it is important to note that this assessment was limited to screening, surveying, and preparing a provisional assessment of these studies. For reasons outlined in Section I.C of the preamble for the final PM NAAQS rulemaking in 2006 (see 71 FR 61148-49, October 17, 2006), EPA based its NAAQS decision on the science presented in the 2004 AQCD.

emissions as well as other sources.[14] The analyses incorporate source apportionment tools into short-term exposure studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death rates indicated a relationship between mobile source $PM_{2.5}$ and mortality.[15,16,17,18] 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.[19] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

2.2.1.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to ambient $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases and lung cancer,[20] and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease.[21] Of specific importance, the PM AQCD also noted 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.[22]

The PM AQCD and PM Staff Paper emphasized the results of two long-term epidemiologic studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors: the large air quality data set for PM in the Six Cities Study, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis.[23,24,25,26,27,28] These studies indicate that there are positive 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.[29]

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.[30] 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 a measure of atherosclerosis development in the Los Angeles basin.[31] 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.

2.2.2 Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects.[D] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[32,33] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

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. Cellular-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. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[34] 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 ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[35, 36, 37, 38, 39, 40] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[41, 42, 43, 44, 45] 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 affect premature aging of the lungs and/or the development of chronic respiratory illnesses, such as emphysema and chronic bronchitis.[46, 47, 48, 49]

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.[50] 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.[51] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported statistically significant reductions in lung function in

[D] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentrations but also by the individuals breathing route and rate.

children who are active outdoors.[52, 53, 54, 55, 56, 57, 58, 59] 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.[60, 61, 62, 63]

2.2.3 Sulfur Oxides

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment for Sulfur Oxides.[64] Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the U.S. EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. This response is mediated by chemosensitive receptors in the tracheobronchial tree. These receptors trigger reflexes at the central nervous system level resulting in bronchoconstriction, mucus secretion, mucosal vasodilation, cough, and apnea followed by rapid shallow breathing. In some cases, local nervous system reflexes also may be involved. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. This inflammation may lead to enhanced release of mediators, alterations in the autonomic nervous system and/or sensitization of the chemosensitive receptors. These biological processes are likely to underlie the bronchoconstriction and decreased lung function observed in response to SO_2 exposure. In laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations $\geq$ 0.2 ppm in asthmatics engaged in moderate to heavy levels of exercise. In these studies, 5-30% of relatively healthy exercising asthmatics are shown to experience moderate or greater decrements in lung function ($\geq$ 100% increase in sRaw (specific airway resistance) or $\geq$ 15% decrease in FEV_1 (forced expiratory volume in 1 second)) with peak exposures to SO_2 concentrations of 0.2-0.3 ppm. At concentrations $\geq$ 0.4 ppm, a greater percentage of asthmatics (20-60%) experience SO_2-induced decrements in lung function, which are frequently accompanied by respiratory symptoms. A clear concentration-response relationship has been demonstrated in laboratory studies following exposures to SO_2 at concentrations between 0.2 and 1.0 ppm, both in terms of increasing severity of effect and percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Furthermore, limited epidemiologic evidence indicates that atopic children and adults may be at increased risk for SO_2-induced respiratory symptoms. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults ($\geq$ 65 years), and for asthma. Intervention studies provide additional evidence that supports a causal relationship between SO_2 exposure and respiratory health effects. Two notable studies conducted in several cities in Germany and in

Hong Kong reported that decreases in SO_2 concentrations were associated with improvements in respiratory symptoms, though the possibility remained that these health improvements may be partially attributable to declining concentrations of air pollutants other than SO_2, most notably PM or constituents of PM. A limited subset of epidemiologic studies have examined potential confounding by copollutants using multipollutant regression models. These analyses indicate that although copollutant adjustment has varying degrees of influence on the SO_2 effect estimates, the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous and particulate copollutants, suggesting that the observed effects of SO_2 on respiratory endpoints occur independent of the effects of other ambient air pollutants.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these associations due to potential confounding by various copollutants. The U.S. EPA has therefore concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality. Significant associations between short-term exposure to SO_2 and emergency department visits and hospital admissions for cardiovascular diseases have also been reported. However, these findings have been inconsistent across studies and do not provide adequate evidence to infer a causal relationship between SO_2 exposure and cardiovascular morbidity.

2.2.4 Nitrogen Oxides

This section provides an overview of the health effects associated with NO_2. Additional information on the health effects of NO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment (ISA) for Nitrogen Oxides.[65] The U.S. EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure.[66] The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions.[67] The effect estimates from U.S. and Canadian studies generally indicate that ambient NO_2 is associated with a 2-20% increase in risks for emergency department visits and hospital admissions. Risks associated with respiratory symptoms are generally higher.[68] These epidemiologic studies are supported by evidence from experimental studies, in particular by controlled human exposure studies that evaluate airway hyperresponsiveness in asthmatic individuals.[69] The ISA draws two broad conclusions regarding airway responsiveness following NO_2 exposure.[70] First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response at exposures as low as 0.26 ppm NO_2 for 30 minutes.[71] Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies.[72] In general, small but significant increases in nonspecific airway responsiveness were observed in the range of 0.2 to 0.3 ppm NO_2 for 30-minute exposures and at 0.1 ppm NO_2 for 60-minute exposures in asthmatics. These conclusions are consistent with results from animal toxicological studies which have detected (1) increased immune-mediated

pulmonary inflammation in rats exposed to house dust mite allergen following exposure to 5 ppm NO_2 for 3-hour and (2) increased responsiveness to non-specific challenges following sub-chronic (6-12 weeks) exposure to 1 to 4 ppm NO_2.[73] Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control.[74] Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

Although the weight of evidence supporting a causal relationship is somewhat less certain than that associated with respiratory morbidity, NO_2 has also been linked to other health endpoints. For example, results from several large U.S. and European multi-city studies and a meta-analysis study indicate positive associations between ambient NO_2 concentrations and the risk of all-cause (nonaccidental) mortality, with effect estimates ranging from 0.5 to 3.6% excess risk in mortality per standardized increment (20 ppb for 24-hour averaging time, 30 ppb for 1-hour averaging time).[75] In general, the NO_2 effect estimates were robust to adjustment for co-pollutants. In addition, generally positive associations between short-term ambient NO_2 concentrations and hospital admissions or emergency department visits for cardiovascular disease have been reported.[76] A number of epidemiologic studies have also examined the effects of long-term exposure to NO_2 and reported positive associations with decrements in lung function and partially irreversible decrements in lung function growth.[77] Specifically, results from the California-based Children's Health Study, which evaluated NO_2 exposures in children over an 8-year period, demonstrated deficits in lung function growth.[78] This effect has also been observed in Mexico City, Mexico[79] and in Oslo, Norway,[80] with decrements ranging from 1 to 17.5 ml per 20- ppb increase in annual NO_2 concentration. Animal toxicological studies may provide biological plausibility for the chronic effects of NO_2 that have been observed in these epidemiologic studies.[81] The main biochemical targets of NO_2 exposure appear to be antioxidants, membrane polyunsaturated fatty acids, and thiol groups. NO_2 effects include changes in oxidant/antioxidant homeostasis and chemical alterations of lipids and proteins. Lipid peroxidation has been observed at NO_2 exposures as low as 0.04 ppm for 9 months and at exposures of 1.2 ppm for 1 week, suggesting lower effect thresholds with longer durations of exposure. Other studies showed decreases in formation of key arachidonic acid metabolites in mornings following NO_2 exposures of 0.5 ppm. NO_2 has been shown to increase collagen synthesis rates at concentrations as low as 0.5 ppm. This could indicate increased total lung collagen, which is associated with pulmonary fibrosis, or increased collagen turnover, which is associated with remodeling of lung connective tissue. Morphological effects following chronic NO_2 exposures have been identified in animal studies that link to these increases in collagen synthesis and may provide plausibility for the deficits in lung function growth described in epidemiologic studies.[82]

2.2.5 Air Toxics

C3 vessel emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to air toxics.[83] A number of these compounds would be impacted by the standards proposed in this rule, including polycyclic organic matter (POM) and DPM. These compounds were identified as national or regional risk drivers in the 1999 National-Scale Air Toxics Assessment (NATA).

According to NATA for 1999, mobile sources were responsible for 44 percent of outdoor toxic emissions and almost 50 percent of the cancer risk. Noncancer health effects can result from chronic,[E] subchronic,[F] or acute[G] inhalation exposures to air toxics, and include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems. 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.

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.[84] 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.

2.2.5.1 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.[85,86] In accordance with earlier EPA guidelines, exposure to diesel exhaust would similarly be classified as probably carcinogenic to humans (Group B1).[87,88] A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) have made similar classifications.[89, 90,91,92,93] The

[E] 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 used laboratory animal species).

[F] Defined in the IRIS database as repeated exposure by the oral, dermal, or inhalation route for more than 30 days, up to approximately 10% of the life span in humans (more than 30 days up to approximately 90 days in typically used laboratory animal species)..

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

Health Effects Institute has prepared numerous studies and reports on the potential carcinogenicity of exposure to diesel exhaust.[94,95,96]

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 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 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. 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.[97,98,99]

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.[100,101] This national assessment estimates average population inhalation exposures to DPM 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 marine engines present public health issues of concern to this rule.

2.2.5.2 Other Health Effects of Exposure to 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.[102,103,104,105] The diesel RfC is based on a "no observable adverse effect" level of 144 $\mu g/m^3$ 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 $\mu g/m^3$ for diesel exhaust as measured by DPM. 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."

While there have been relatively few human studies associated specifically with the noncancer impact of exposure to DPM alone, DPM 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 DPM is supported by studies that specifically associate observable human noncancer health effects with exposure to DPM. 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."[106] There is also evidence for an immunologic effect such as the exacerbation of allergenic responses to known allergens and asthma-like symptoms.[107,108,109]

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 2.2.1 of this DRIA), 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.

2.2.5.3 Ambient Levels of Diesel Exhaust PM {tc "2.2.1.3 Diesel Exhaust PM Ambient Levels " \l 4}

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

2.2.5.3.1 Toxics Modeling and Methods {tc "2.2.1.3.1 Toxics Modeling and Methods " \l 5}

In addition to the general ambient PM modeling conducted for this rulemaking, DPM concentrations were recently estimated as part of the 1999 National-Scale Air Toxics Assessment.[110] Ambient impacts of mobile source emissions were predicted using the Assessment System for Population Exposure Nationwide (ASPEN) dispersion model.

Concentrations of DPM were calculated at the census tract level in the 1999 NATA. The median DPM 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 2-1 below summarizes the distribution of ambient DPM concentrations at the national scale. Over half of the DPM and diesel exhaust organic gases can be attributed to nonroad diesels. A map of median ambient concentrations is provided in Figure 2-1. 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 of the U.S.

Table 2-1 Distribution of Census Tract Ambient Concentrations of DPM at the National Scale in 1999 NATA[a]

	NATIONWIDE (MG/M^3)	URBAN (MG/M^3)	RURAL (MG/M^3)
5^{th} Percentile	0.22	0.33	0.08
25^{th} Percentile	0.54	0.70	0.28
Median	0.91	1.06	0.43
75^{th} 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

Note:

[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).

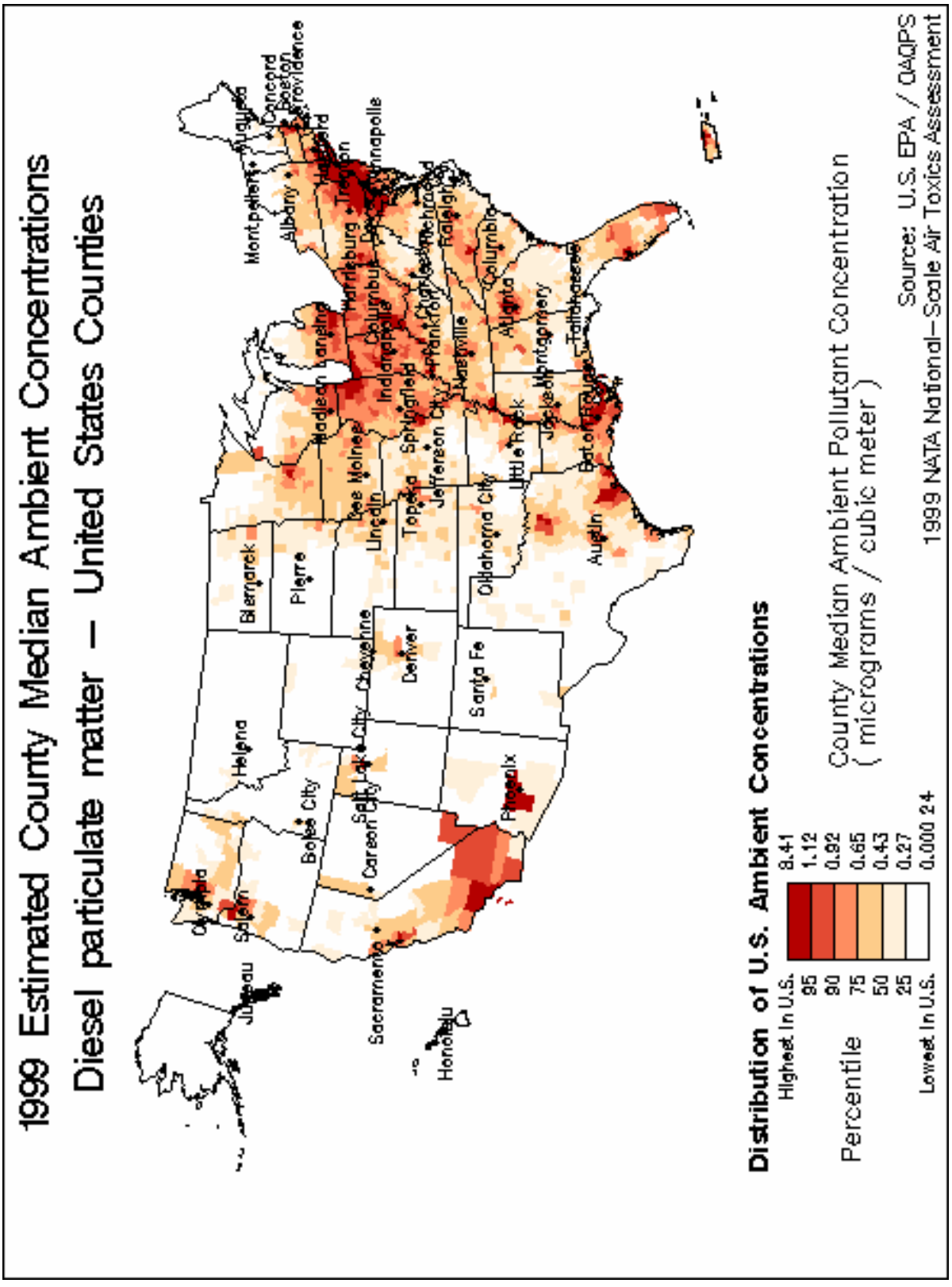


Figure 2-1 Estimated County Median Ambient Concentration of Diesel Particulate Matter

2.2.5.4 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.

2.2.5.4.1 Occupational Exposures

Occupational exposures to diesel exhaust from mobile sources, including 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. 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 marine diesel engines.

2.2.5.4.2 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, [111] rail yards, [112] and marine ports[113] 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 marine ports may experience elevated ambient concentrations of directly-emitted $PM_{2.5}$ from diesel engines. Due to the nature of marine ports, emissions from a large number of diesel engines are concentrated in a small area.

A recent study from the California Air Resources Board (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.[114] The port study employed the ISCST3 dispersion model. With local meteorological data used in the modeling, annual average concentrations of DPM 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 $\mu g/m^3$ of port-related DPM in ambient air, about 360,000 people lived in areas with at least 0.6 $\mu g/m^3$ of DPM, and about 50,000 people lived in areas with at least 1.5 $\mu g/m^3$ of ambient DPM emitted directly from the port. Figure 2-2 provides an aerial shot of the Port of Long Beach and Los Angeles in California.

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

This port study highlights the substantial contribution these facilities make to ambient concentrations of DPM in large, densely populated areas.

EPA recently updated its initial screening-level analysis[115,116] of selected marine port areas to better understand the populations, including minority, low-income, and children, that are exposed to diesel particulate matter (DPM) emissions from these facilities.[H] The results of this study are discussed here and are also available in the public docket.[117,118]

This screening-level analysis focused on a representative selection of national marine ports.[I] Of the 45 marine ports studied, the results indicate that at least 18 million people, including a disproportionate number of low-income households, African-Americans, and Hispanics, live in the vicinity of these facilities and are being exposed to ambient DPM levels that are 2.0 $\mu g/m^3$ and 0.2 $\mu g/m^3$ above levels found in areas further from these facilities. Considering only ocean-going marine engine DPM emissions, the results indicate that 6.5 million people are exposed to ambient DPM levels that are 2.0 $\mu g/m^3$ and 0.2 $\mu g/m^3$ above levels found in areas further from these facilities. Because those populations exposed to DPM emissions from marine ports are more likely to be low-income and minority residents, these populations would benefit from the standards being proposed by the coordinated strategy. The detailed findings of this study are available in the public docket for this rulemaking.

[H] 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.

[I] The Agency selected a representative sample from the top 150 U.S. ports including coastal, inland, and Great Lake ports.

With regard to children, this analysis shows that at least four million children live in the vicinity of the marine ports studied and are also exposed to ambient DPM levels that are 2.0 $\mu g/m^3$ and 0.2 $\mu g/m^3$ above levels found in areas further from these facilities. Of the 6.5 million people exposed to DPM emissions from ocean-going vessel emissions, 1.7 million are children. The age composition of the total affected population in the screening analysis matches closely with the age composition of the overall U.S. population. However, for some individual facilities, the young (0-4 years) appear to be over-represented in the affected population compared to the overall U.S. population. Detailed results for individual harbors 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 the harbor areas, and determine the size and demographic characteristics of the populations living near these facilities. These facilities are listed in Table 2-2. Figures 2-3 and 2-4 provide examples of digitized footprints of the marine harbor areas included in this study.

Table 2-2 Marine Harbor Areas

Baltimore, MD	Los Angeles, CA	Port of Baton Rouge, LA
Boston, MA	Louisville, KY	Port of Plaquemines, LA
Charleston, SC	Miami, FL	Portland, ME
Chicago, IL	Mobile, AL	Portland, OR
Cincinnati, OH	Mount Vernon, IN	Richmond, CA
Cleveland, OH	Nashville, TN	Savannah, GA
Corpus Christi, T_X	New Orleans, LA	Seattle, WA
Detroit, MI	New York, NY	South Louisiana, LA
Duluth-Superior, MN	Oakland, CA	St. Louis, MO
Freeport, T_X	Panama City, FL	Tacoma, WA
Gary, IN	Paulsboro, NJ	Tampa, FL
Helena, AR	Philadelphia, PA	Texas City, T_X
Houston, T_X	Pittsburgh, PA	Tulsa - Port of Catoosa, OK
Lake Charles, LA	Port Arthur, T_X	Two Harbors, MN
Long Beach, CA	Port Everglades, FL	Wilmington, NC

Figure 2-3 Digitized Footprint of New York, NY harbor area.

Figure 2-4 Digitized Footprint of Portland, OR harbor area.

In order to better understand the populations that live in the vicinity of marine harbor areas and their potential exposures to ambient DPM, concentration isopleths surrounding the 45 marine port areas were created and digitized for all emission sources at the marine port and for ocean-going vessel Category 3 engine emissions only. The concentration isopleths of interest were selected to correspond to two DPM concentrations above urban background, 2.0 $\mu g/m^3$ and 0.2 $\mu g/m^3$. The isopleths were estimated using the AERMOD air dispersion model. Figures 2-5 and 2-6 provide examples of concentration isopleths surrounding the New York, NY harbor area for all emission sources and for ocean-going vessel Category 3 only engine emissions, respectively.

Figure 2-5 Concentration Isopleths of New York, NY Harbor Area Resulting from All Emission Sources.

Figure 2-6 Concentration Isopleths of New York, NY Harbor Area Resulting from All Emission Sources.

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

In summary, the screening-level analysis found that for the 45 U.S. marine ports studied, al least 18 million people live in the vicinity of these facilities and are exposed to ambient DPM levels from all port emission sources that are 2.0 $\mu g/m^3$ and 0.2 $\mu g/m^3$ above those found in areas further from these facilities. If only Category 3 engine DPM emissions are considered, then the number of people exposed is 6.5 million.

2.3 Environmental Impacts Associated with Pollutants

2.3.1 Deposition of Nitrogen and Sulfur

Large ships release emissions over a wide area, and depending on prevailing winds and other meteorological conditions, these emissions may be transported hundreds and even thousands of kilometers across North America.[119] Section 2.4 discusses the results of U.S. air quality modeling which documents this phenomenon. Overall, these engines emit a large amount of NO_X, SO_X and direct PM, which impact not only ambient air concentrations but also contribute to deposition of nitrogen and sulfur in many sensitive ecological areas throughout the U.S.

Sulfur in marine fuel is primarily emitted as SO_2, with a small fraction (about 2 percent) being converted to SO_3.[120] SO_3 almost immediately forms sulfate and is emitted as primary PM by the engine and consists of carbonaceous material, sulfuric acid, and ash (trace metals). The vast majority of the primary PM is less than or equal to 2.5 μm in diameter, and accounts for the majority of the number of particles in exhaust, but only a small fraction of the mass of DPM. These particles also react in the atmosphere to form secondary PM, which exist there as a carbon core with a coating of organic carbon compounds, nitrate particles, or as sulfuric acid and ash, sulfuric acid aerosols, or sulfate particles associated with organic carbon.

At the same time, ships emit large amounts of NO and NO_2 (NO_X) emissions which are carried into the atmosphere where they may be chemically altered and transformed into new compounds. For example, NO_2 can also be further oxidized to nitric acid ($HNO_{3)}$ and can contribute in that form to the acidity of clouds, fog, and rain water and can also form ambient particulate nitrate (pNO_3) which may be deposited either directly onto terrestrial and aquatic ecosystems ("direct deposition") or deposited onto land surfaces where it subsequently runs off and is transferred into downstream waters ("indirect deposition").

Deposition of nitrogen and sulfur resulting from ship operations can occur either in a wet or dry form. Wet deposition includes rain, snow, sleet, hail, clouds, or fog. Dry deposition includes gases, dust, and minute particulate matters. Wet and dry atmospheric deposition of $PM_{2.5}$ delivers a complex mixture of metals (such as mercury, zinc, lead, nickel, arsenic, aluminum, and cadmium), organic compounds (such as polycyclic organic matter, dioxins, and furans) and inorganic compounds (such as nitrate and sulfate). Together these emissions from ships are deposited onto terrestrial and aquatic ecosystems across the U.S., contributing to the problems of acidification and nutrient enrichment.

Deposition of nitrogen and sulfur causes acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. Major effects include a decline in sensitive tree species, such as red spruce (*Picea rubens*) and sugar maple (*Acer saccharum*); and a loss of biodiversity of fishes, zooplankton, and macro invertebrates. The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geological characteristics.

Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations. Decreases in the

acid neutralizing capacity and increases in inorganic aluminum concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems. Across the U.S., ecosystems will continue to be acidified by current NO_X and SO_X emissions from stationary sources, area sources, and mobile sources. For example, in the Adirondacks Mountains of New York State, the current rates of nitrogen and sulfur deposition exceed the amount that would allow recovery of the most acid sensitive lakes to a sustainable acid neutralizing capacity (ANC) level.[121]

Excess nitrogen deposition also leads to nutrient enrichment which can result in eutrophication of aquatic ecosystems. In terrestrial ecosystems, nitrogen nutrient enrichment can lead to the loss of sensitive lichen species as they are outcompeted by invasive grasses. Nitrogen nutrient enrichment can also alter the biodiversity of terrestrial ecosystems, such as forests and grasslands. Excess nitrogen deposition contributes to eutrophication of estuaries and coastal waters which result in toxic algal blooms and fish kills. For example, the Chesapeake Bay Estuary is highly eutrophic and 21 - 30% of total nitrogen load comes from atmospheric deposition.[122] Freshwater ecosystems may also be impacted by nitrogen deposition. For example, high elevation freshwater lakes in the western U.S. experience negative ecological effects at nitrogen deposition rates as low as 2 kg N/ha/yr.[123]

There are a number of important quantified relationships between nitrogen deposition levels and ecological effects. Certain lichen species are the most sensitive terrestrial taxa to nitrogen with species losses occurring at just 3 kg N/ha/yr in the Pacific Northwest and the southern portion of the State of California (See Figure 2-9 for the geographic distribution of these lichens in the continental U.S.). The onset of declining biodiversity was found to occur at levels of 5 kg N/ha/yr and above within grasslands in Minnesota and in Europe. Altered species composition of Alpine ecosystems and forest encroachment into temperate grasslands was found at 10 kg N/ha/yr and above in the U.S.[124]

The biogeochemical cycle of mercury, a well-known neurotoxin, is closely tied to the sulfur cycle. Mercury is taken up by living organisms in the methylated form, which is easily bioaccumulated in the food web. Sulfate-reducing bacteria in wetland and lake sediments play a key role in mercury methylation. Changes in sulfate deposition have resulted in changes in both the rate of mercury methylation and the corresponding mercury concentrations in fish. In 2006, 3,080 fish advisories were issued in the U.S. due to the presence of methyl mercury in fish.

Although sulfur deposition is important to mercury methylation, several other interrelated factors seem to also be related to mercury uptake, including low lake water pH, dissolved organic carbon, suspended particulate matter concentrations in the water column, temperature, and dissolved oxygen. In addition, the proportion of upland to wetland land area within a watershed, as well as wetland type and annual water yield, appear to be important.

2.3.1.1 Areas Potentially Sensitive to Nitrogen and Sulfur Deposition in the U.S.

Currently the secondary NAAQS for NO_X and SO_X are being reviewed, specifically addressing the welfare effects of acidification and nitrogen nutrient enrichment.[J] As part of this review, ecosystem maps (Figures 2-7 through 2-10) [125] for the continental U.S. have been created that depict areas that are potentially sensitive to aquatic and terrestrial acidification, and aquatic and terrestrial nutrient enrichment. Taken together, these sensitive ecological areas are of greatest concern with regard to the deposition of nitrogen and sulfur compounds resulting from ship emissions. NO_X and SO_X emissions from ships today and in 2020 will significantly contribute to higher annual total nitrogen and sulfur deposition in all of these potentially sensitive ecosystems. See Section 2.4.3.2 for a discussion and accompanying maps which document both the level and geographic impact of ship emissions in 2020 on nitrogen and sulfur deposition in the U.S.

2.3.1.1.1 Terrestrial Acidification-U.S. Geography

Deposition of total nitrogen (including both oxidized and reduced forms) and sulfur species contributing to acidification were routinely measured in the U.S. between 2004 and 2006 and those results are shown in Figures 2-7 and 2-8. Figure 2-7 depicts areas across the U.S. which are potentially sensitive to terrestrial acidification including forest ecosystems in the Adirondack Mountains located in the State of New York, the Green Mountains in the State of Vermont, the White Mountains in the State of New Hampshire, the Allegheny Plateau in the State of Pennsylvania, in the southeastern part of the U.S., and high-elevation ecosystems in the southern Appalachians. In addition, areas of the Upper Midwest and parts of the State of Florida are also at significant risk with regard to terrestrial acidification.

[J] The first draft risk and exposure assessment and other documents associated with this review are available at: http://www.epa.gov/ttn/naaqs/standards/no2so2sec/cr_rea.html

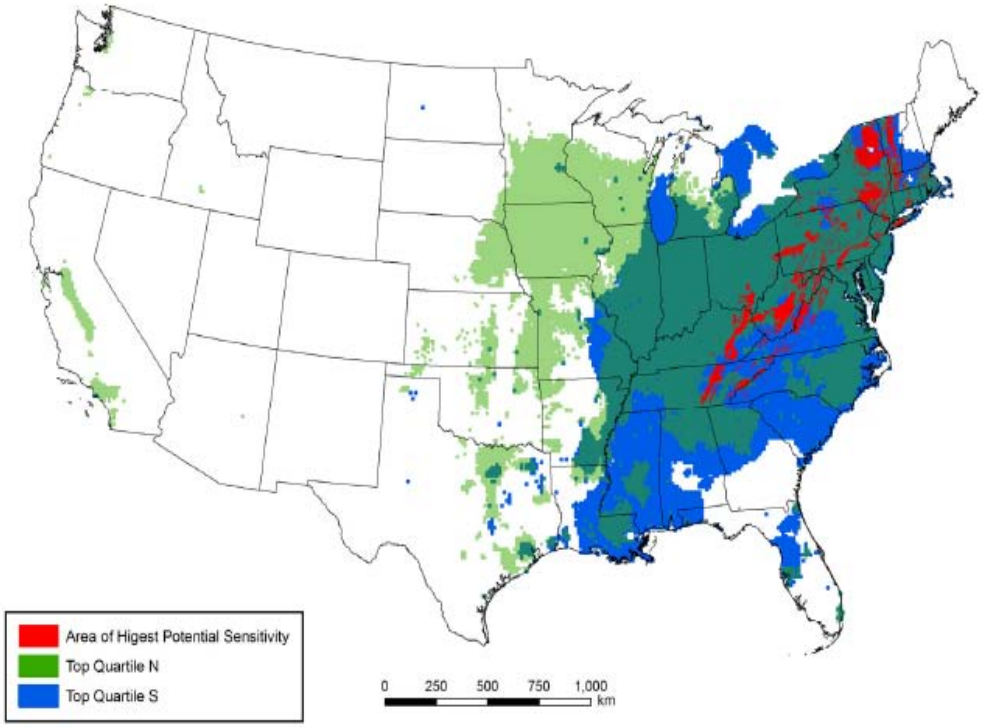


Figure 2-7 Areas Potentially Sensitive to Terrestrial Acidification

2.3.1.1.2 Aquatic Acidification-U.S. Geography

A number of national and regional assessments have been conducted to estimate the distribution and extent of surface water acidity in the U.S.[126,127,128,129,130,131,132,133 ,134] As a result, several regions of the U.S. have been identified as containing a large number of lakes and streams which are seriously impacted by acidification.

Figure 2-8 illustrates those areas of the U.S. where aquatic ecosystems are at risk from acidification. These sensitive ecological regions include: portions of the Northeast U.S., especially all the New England States, the Adirondacks, and the Catskill Mountains in the State of New York; the Southeast U.S., including the Appalachian Mountains and the northern section of the State of Florida; all upper Midwest States; and parts of the western U.S.,[135] especially the Los Angeles Basin and surrounding area and the Sierra Nevada Mountains in the State of California. Two western mountain ranges with the greatest number of acid sensitive lakes[136] are the Cascade Mountains, stretching from northern California, through the entire States of Oregon and Washington, and the Sierra Nevada's, found within the State of California. The hydrologic cycles in these two mountain ranges are dominated by the annual accumulation and melting of a dilute, mildly acidic snow pack. Finally, also in the western U.S., many Rocky Mountain lakes in the State of Colorado are also sensitive to acidifying deposition effects.[137] However, it does not appear that chronic acidification has occurred to any significant degree in these lakes, although episodic acidification has been reported for some.[138]

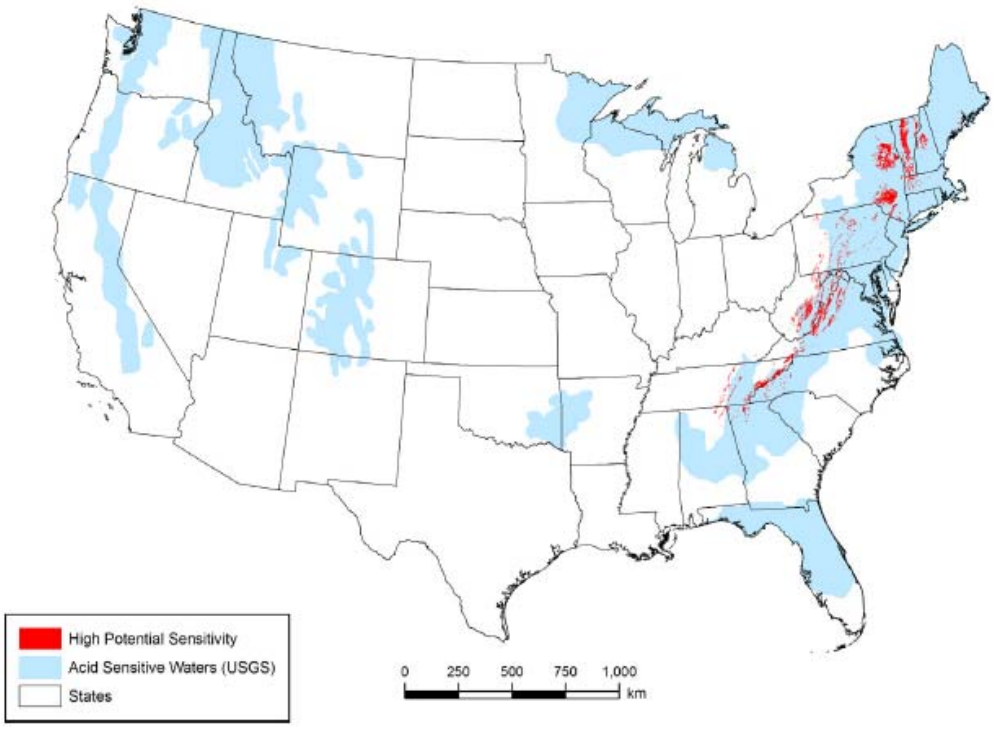


Figure 2-8 Areas Potentially Sensitive to Aquatic Acidification

2.3.1.1.3 Terrestrial Nutrient Enrichment-U.S. Geography

Nitrogen deposition affects terrestrial ecosystems throughout large areas of the U.S.[139] Atmospheric nitrogen deposition is the main source of new nitrogen in many terrestrial ecosystems throughout the U.S and impacts large numbers of forests, wetlands, freshwater bogs and salt marshes.[140] Figure 2-9 depicts those ecosystems potentially sensitive to terrestrial nutrient enrichment resulting from nitrogen deposition, including nitrogen deposition from ships.

Severe symptoms of nutrient enrichment or nitrogen saturation, have been observed in forest ecosystems of the State of West Virginia's northern hardwood watersheds;[141] in high-elevation spruce-fir ecosystems in the Appalachian Mountains;[142] in spruce-fir ecosystems throughout the northeastern U.S.;[143,144] and in lower-elevation eastern U.S. forests.[145,146,147,148] In addition, mixed conifer forests in the Los Angeles Air Basin within the State of California are also heavily impacted and exhibit the highest stream water nitrate concentrations documented within wild lands in North America.[149,150] In general, it is believed that deciduous forest stands in the eastern U.S. have not progressed toward nitrogen saturation as rapidly or as far as coniferous stands in the eastern U.S.[151]

In addition to these forest ecosystems, nitrogen deposition adversely impacts U.S. grasslands or prairies which are located throughout the U.S.[152] The vast majority of these grasslands are found in the Central Plains regions of the U.S. between the Mississippi River and the foothills of the Rocky Mountains. However, some native grasslands are scattered throughout

the Midwestern and Southeastern U.S.[153] Also considered sensitive to nitrogen nutrient enrichment effects, and receiving high levels of atmospheric deposition, are some arid and semi-arid ecosystems and desert ecosystems in the southwestern U.S.[154] However, water is generally more limiting than nitrogen in these areas. The alpine ecosystems in the State of Colorado, chaparral watersheds of the Sierra Nevada Mountains in the State of California, lichen and vascular plant communities in the San Bernardino Mountains in California and the entire U.S. Pacific Northwest, and the Southern California coastal sage scrub community are among the most sensitive terrestrial ecosystems to nitrogen deposition in the U.S. [155,156]

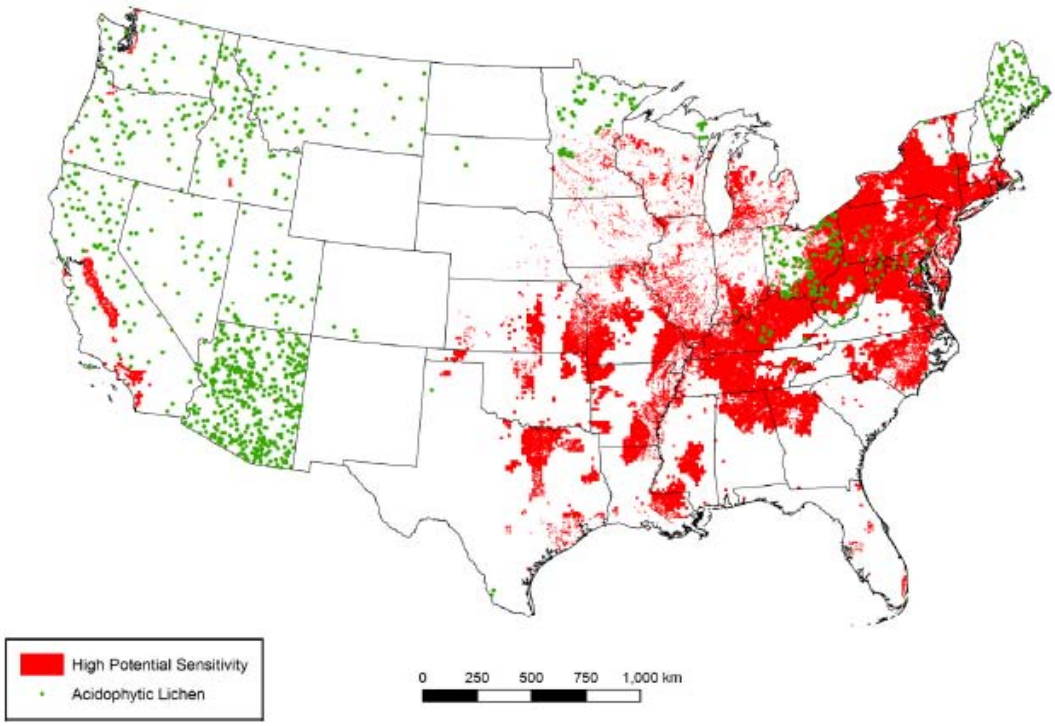


Figure 2-9 Areas Potentially Sensitive to Terrestrial Nutrient Enrichment

2.3.1.1.4 Aquatic Nutrient Enrichment –U.S. Geography

Aquatic nutrient enrichment impacts a wide range of waters within the U.S. from wetlands, to streams, rivers, lakes, estuaries and coastal waters. All are vital ecosystems to the U.S. and all are impacted by ship emissions that contribute to the annual total nitrogen deposition in the U.S.

Wetlands are found throughout the U.S. and support over 4200 native plant species, of which 121 have been designated by the U.S. Government as threatened or endangered.[157] Freshwater wetlands are particularly sensitive to nutrient enrichment resulting from nitrogen deposition since they contain a disproportionately high number of rare plant species that have evolved under nitrogen-limited conditions.[158] Freshwater wetlands receive nitrogen mainly from precipitation, land runoff or ground water. Intertidal wetlands develop on sheltered coasts or in estuaries where they are periodically inundated by marine water that often carries high nitrogen loads, in addition to receiving water and nutrient inputs from precipitation and ground/surface

water. Wetlands can be divided into three general categories based on hydrology: (1) Peatlands and bogs, (2) fens, freshwater marshes, freshwater swamps and (3) intertidal wetlands.

Fens and bogs are the most vulnerable type of wetland ecosystems with regard to nutrient enrichment effects of nitrogen deposition.[159] In the U.S., they are mostly found in the glaciated northeast and Great Lakes regions and in the State of Alaska, but also in the southeast U.S. along the Atlantic Coastal Plain stretching from the States of Virginia through North Carolina to northern Florida.[160] Like bogs, fens are mostly a northern hemisphere phenomenon, occurring in the northeastern United States, the Great Lakes region, western Rocky Mountains, and much of Canada, and are generally associated with low temperatures and short growing seasons where ample precipitation and high humidity cause excessive moisture to accumulate.[161]

The third type of wetlands sensitive to nitrogen deposition are marshes, characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions. There are many different kinds of marshes in the U.S., ranging from the prairie potholes in the interior of the U.S. to the Everglades found in the extreme southern portion of the State of Florida. U.S. fresh water marshes are important for recharging groundwater supplies, and moderating stream flow by providing water to streams and as habitats for many wildlife species.[162]

Nitrogen deposition is the main source of nitrogen for many surface waters in the U.S. including headwater streams, lower order streams, and high elevation lakes.[163,164] Elevated surface water nitrate concentrations due to nitrogen deposition occur in both the eastern and western U.S., although high concentrations of nitrate in surface waters in the western U.S. are not as widespread as in the eastern U.S.

High concentrations of lake or stream water nitrate, indicative of ecosystem nitrogen-saturation, have been found at a variety of locations throughout the U.S. including the San Bernardino and San Gabriel Mountains within the Los Angeles Air Basin in the State of California, [165] the Front Range Mountains in the State of Colorado,[166,167] the Allegheny Mountains in the State of West Virginia,[168] the Catskill and Adirondack Mountains in the State of New York,[169, 170,171,172] and the Great Smoky Mountains in the State of Tennessee.

Nitrogen nutrient enrichment is a major environmental problem facing all U.S. coastal regions, but especially the Eastern, mid-Atlantic, and Gulf Coast regions, as excess nitrogen leads to eutrophication. There is broad scientific consensus that nitrogen-driven eutrophication of shallow estuaries in the U.S. has increased over the past several decades and that environmental degradation of coastal ecosystems is now a widespread occurrence.[173,174,175] A recent national assessment of eutrophic conditions in U.S. estuaries found that 65% of the assessed systems had moderate to high overall eutrophic conditions.[176] Estuaries and coastal waters tend to be nitrogen-limited and are therefore inherently sensitive to increased atmospheric nitrogen deposition.[177] Of 138 estuaries examined in the National Assessment, 44 were identified as showing symptoms of nutrient enrichment. Of the 23 estuaries examined in the Northeast U.S., 61% were classified as moderately to severely degraded. Other regions of the U.S. had mixtures of low, moderate, and high degree of eutrophication.[178] The contribution from atmospheric nitrogen deposition can be greater than 30% of total nitrogen loads in some of the most highly eutrophic estuaries in the U.S., including the Chesapeake Bay.

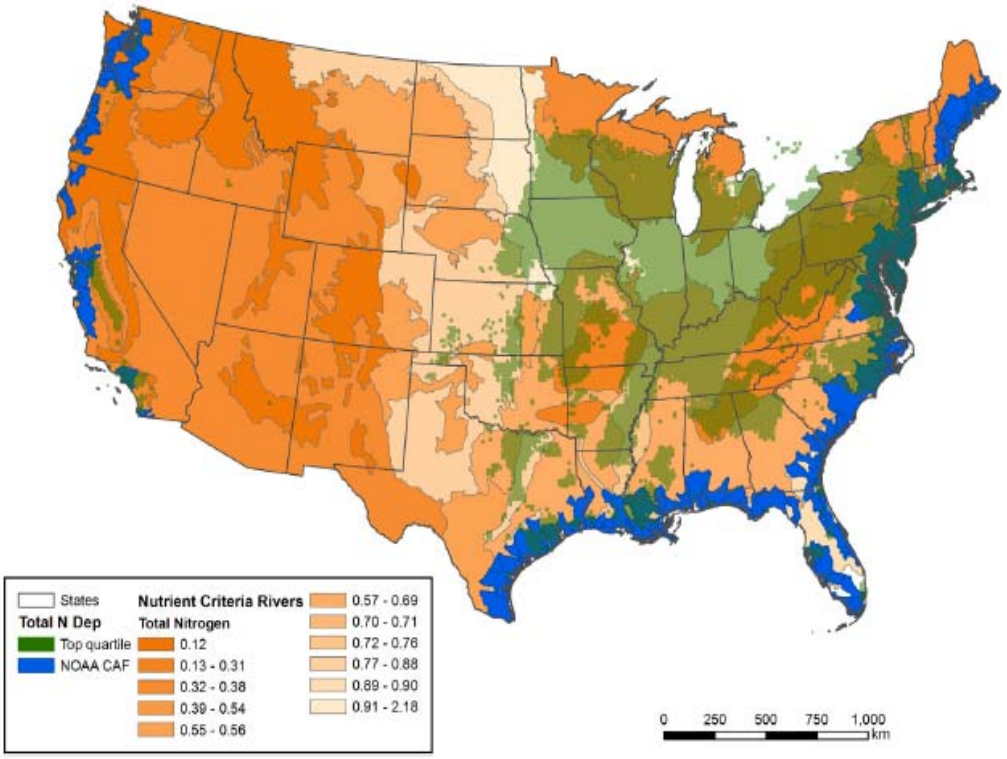


Figure 2-10 Areas Potentially Sensitive to Aquatic Nutrient Enrichment

The most extreme effects of nitrogen deposition on U.S. aquatic ecosystems result in severe nitrogen-loading to these ecosystems that contribute to hypoxic zones devoid of life**.** Three hypoxia zones of special concern in the U.S. are (1) the zone located in the Gulf of Mexico straddling the States of Louisiana and Texas, (2) The Chesapeake Bay located between the States of Maryland and Virginia, and (3) Long Island Sound located between the States of New York and Connecticut. The largest hypoxia zone in the U.S. is in the northern Gulf of Mexico along the continental shelf. During midsummer, this zone has regularly been larger than 16,000km^2.[179] Figures 2-11, 2-12, and 2-13 depict the location of these three hypoxic zones.

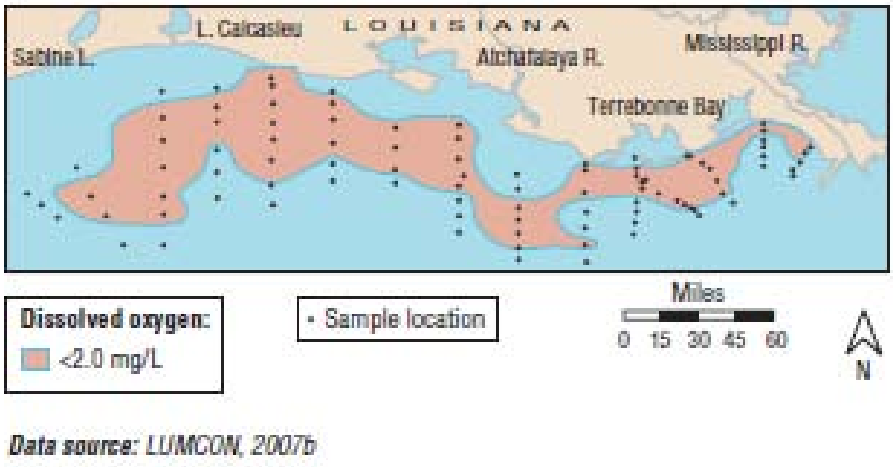


Figure 2-11 Hypoxia Zone in 2007 for the Gulf of Mexico

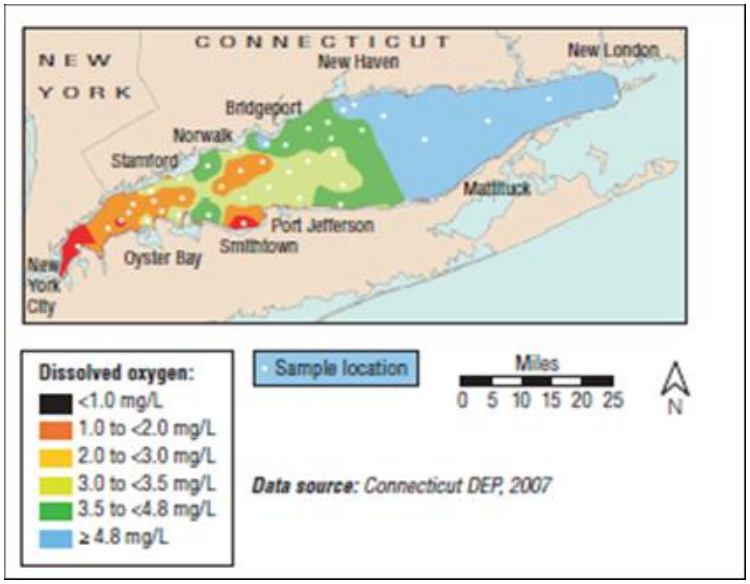
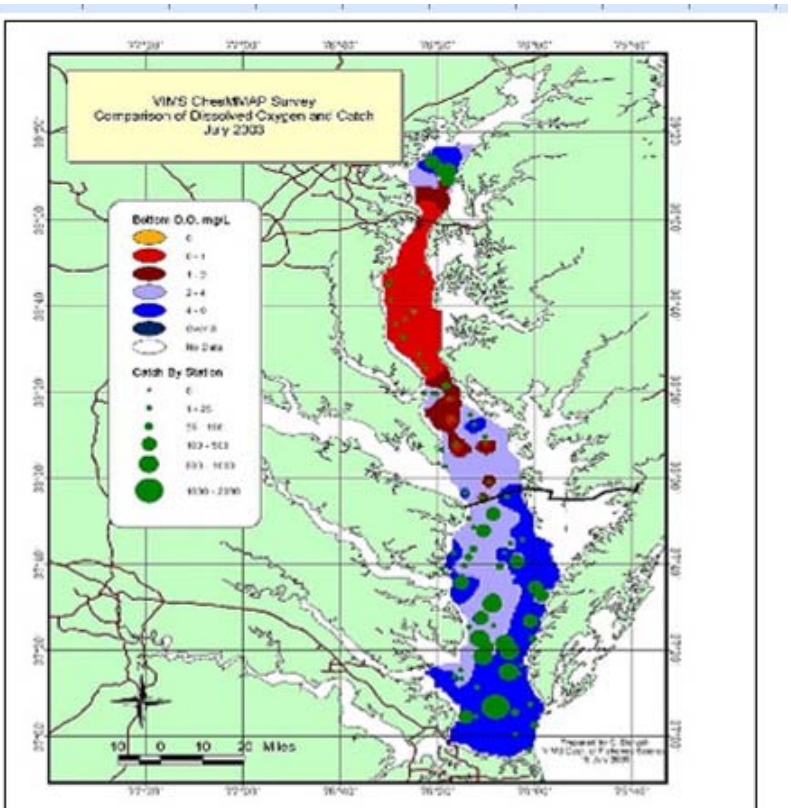


Figure 2-12 Hypoxia Zone in 2007 for Long Island Sound



Varying dissolved oxygen levels and overall fish catch in the Chesapeake Bay through July, 2003. Source: Virginia Institute of Marine Science

Figures 2-13 Hypoxia Zone for Chesapeake Bay in 2003

2.3.1.2 Science of Nitrogen and Sulfur Deposition

Nitrogen and sulfur interactions in the environment are highly complex. Both are essential and sometimes limiting nutrients needed for growth and productivity. Excess of nitrogen or sulfur can lead to acidification, nutrient enrichment, and eutrophication.

Ships release emissions over a wide area, and depending on prevailing winds and other meteorological conditions, these emissions may be transported hundreds and even thousands of kilometers across North America.[180] Section 2.4 discusses the results of U.S. air quality modeling which documents this phenomenon. Overall, these engines emit a large amount of NO_X, SO_X, and direct PM, which impact not only ambient air concentrations but also contribute to deposition of nitrogen and sulfur in many sensitive ecological areas throughout the U.S.

Sulfur in marine fuel is primarily emitted as SO_2, with a small fraction (about 2 percent) being converted to SO_3.[181] SO_3 almost immediately forms sulfate and is emitted as primary PM by the engine and consists of carbonaceous material, sulfuric acid, and ash (trace metals). The vast majority of the primary PM is less than or equal to 2.5 μm in diameter, and accounts for the majority of the number of particles in exhaust, but only a small fraction of the mass of DPM.

These particles also react in the atmosphere to form secondary PM, which exist there as a carbon core with a coating of organic carbon compounds, nitrate particles, or as sulfuric acid and ash, sulfuric acid aerosols, or sulfate particles associated with organic carbon.

At the same time, ships emit large amounts of NO and NO_2 (NO_X) emissions which are carried into the atmosphere where they may be chemically altered and transformed into new compounds. For example, NO_2 can also be further oxidized to nitric acid ($HNO_{3)}$ and can contribute in that form to the acidity of clouds, fog, and rain water and can also form ambient particulate nitrate (pNO_3) which may be deposited either directly onto terrestrial and aquatic ecosystems ("direct deposition") or deposited onto land surfaces where it subsequently runs off and is transferred into downstream waters ("indirect deposition").

Deposition of nitrogen and sulfur resulting from ship operations can occur either in a wet or dry form. Wet deposition includes rain, snow, sleet, hail, clouds, or fog. Dry deposition includes gases, dust, and minute particulate matters. Wet and dry atmospheric deposition of $PM_{2.5}$ delivers a complex mixture of metals (such as mercury, zinc, lead, nickel, arsenic, aluminum, and cadmium), organic compounds (such as polycyclic organic matter, dioxins, and furans) and inorganic compounds (such as nitrate and sulfate). Together these emissions from ships are deposited onto terrestrial and aquatic ecosystems across the U.S., contributing to the problems of acidification and nutrient enrichment.

The chemical form of deposition is determined by ambient conditions (e.g., temperature, humidity, oxidant levels) and the pollutant source. Chemical and physical transformations of ambient particles occur in the atmosphere and in the media (terrestrial or aquatic) on which they deposit. These transformations influence the fate, bioavailability and potential toxicity of these compounds. The atmospheric deposition of metals and toxic compounds is implicated in severe ecosystem effects.[182]

Ships also emit primary PM. In addition, secondary PM is formed from NO_X and SO_X gaseous emissions and associated chemical reactions in the atmosphere. The major constituents of secondary PM are sulfate, nitrate, ammonium, and hydrogen ions. Secondary aerosol formation depends on numerous factors including the concentrations of precursors; the concentrations of other gaseous reactive species such as ozone, hydroxyl radical, peroxy radicals, and hydrogen peroxide; atmospheric conditions, including solar radiation and relative humidity; and the interactions of precursors and preexisting particles within cloud or fog droplets or on or in the liquid film on solid particles.[183]

The lifetimes of particles vary with particle size. Accumulation-mode particles such as the sulfates and nitrates are kept in suspension by normal air motions and have a lower deposition velocity than coarse-mode particles; they can be transported thousands of kilometers and remain in the atmosphere for a number of days. They are removed from the atmosphere primarily by cloud processes. Dry deposition rates are expressed in terms of deposition velocity that varies with the particle size, reaching a minimum between 0.1 and 1.0 μm D_a.[184]

Particulate matter is a factor in acid deposition. Particles serve as cloud condensation nuclei and contribute directly to the acidification of rain. In addition, the gas-phase species that lead to the dry deposition of acidity are also precursors of particles. Therefore, reductions in

NO_X and SO_2 emissions will decrease both acid deposition and PM concentrations, but not necessarily in a linear fashion. Sulfuric acid, ammonium nitrate, and organic particles also are deposited on surfaces by dry deposition and can contribute to environmental effects.[185]

2.3.1.3 Computing Atmospheric Nitrogen and Sulfur Deposition to Specific Locations

Inputs of new nitrogen, i.e., non-recycled mostly anthropogenic in origin, are often key factors controlling primary productivity in nitrogen-sensitive estuarine and coastal waters.[186] Increasing trends in urbanization, agricultural intensity, and industrial expansion have led to increases in nitrogen deposited from the atmosphere on the order of a factor of 10 in the previous 100 years.[187] Direct fluxes of atmospheric nitrogen to ocean and gulf waters along the Northeast and Southeast U.S. are now roughly equal to or exceed the load of new nitrogen from riverine inputs at 11, 5.6, and 5.6 kg N/ha for the Northeast Atlantic coast of the U.S., the Southeast Atlantic coast of the U.S., and the U.S. Eastern Gulf of Mexico, respectively.[188] Atmospheric nitrogen is dominated by a number of sources, most importantly transportation sources, including ships.

Nitrogen deposition takes different forms physically. Physically, deposition can be direct, with the loads resulting from air pollutants depositing directly to the surface of a body of water, usually a large body of water like an estuary or lake. In addition, there is an indirect deposition component derived from deposition of nitrogen or sulfur to the rest of the watershed, both land and water, of which some fraction is transported through runoff, rivers, streams, and groundwater to the water body of concern.

Direct and indirect deposition of nitrogen and sulfur to watersheds depend on air pollutant concentrations in the airshed above the watershed. The shape and extent of the airshed is quite different from that of the watershed. In a watershed, everything that falls in its area, by definition, flows into a single body of water. An airshed, by contrast, is a theoretical concept that defines the source area containing the emissions contributing a given level, often 75%, to the deposition in a particular watershed or to a given water body. Hence, airsheds are modeled domains containing the sources estimated to contribute a given level of deposition from each pollutant of concern. The principal NO_X airsheds and corresponding watersheds for several regions in the eastern U.S. are shown in Figure 2-14.[189] These airsheds extend well into U.S. coastal waters where ships operate.

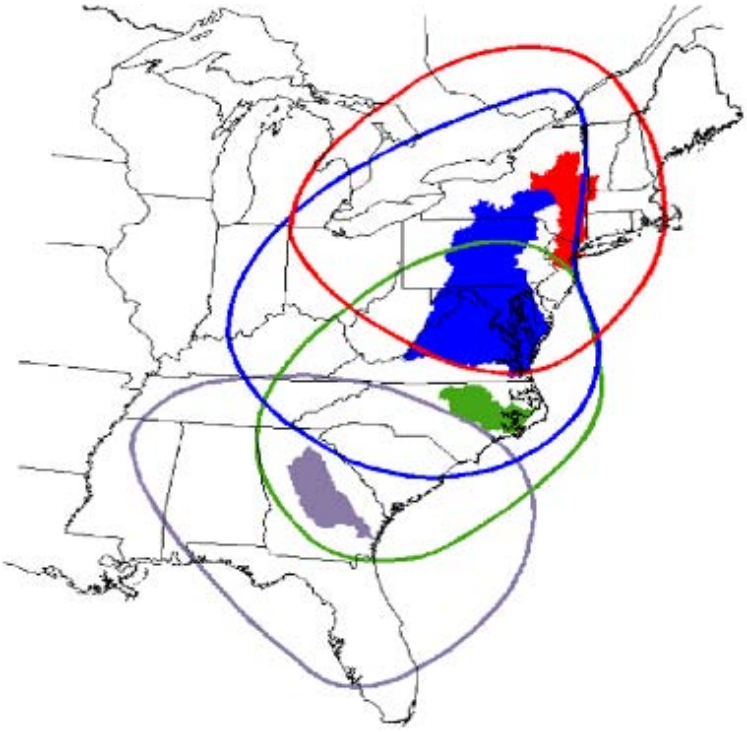


Figure 2-14 Principal Airsheds and Watersheds for Oxides of Nitrogen for Estuaries. Hudson/Raritan Bay; Chesapeake Bay; Pamlico Sound; and Altamaha Sound (listed from north to south).

Nitrogen inputs have been studied in several U.S. Gulf Coast estuaries, as well, owing to concerns about eutrophication there. Nitrogen from atmospheric deposition in these locations is estimated to be 10 to 40% of the total input of nitrogen to many of these estuaries, and could be higher for some. Estimates of total nitrogen loadings to estuaries or to other large-scale elements in the landscape are then computed using measurements of wet and dry deposition, where these are available, and interpolated with or without a set of air quality model predictions such as the Extended Regional Acid Deposition Model (Ext-RADM).[190]

Table 2-3 lists several water bodies for which atmospheric nitrogen inputs have been computed and the ratio to total nitrogen loads is given. The contribution from the atmosphere ranges from a low of 2–8% for the Guadalupe Estuary in the southern part of the State of Texas to highs of ~38% in the New York State Bight and the Albemarle-Pamlico Sound in the State of North Carolina.

Table 2-3 Atmospheric Nitrogen Loads Relative to Total Nitrogen Loads in Selected U.S. Great Waters.*

Waterbody	Total N Load (million kg/yr)	Atmospheric N Load (million kg/yr)	Percent Load from the Atmosphere
Albemarle-Pamlico Sounds	23	9	38
Chesapeake Bay	170	36	21
Delaware Bay	54	8	15
Long Island Sound	60	12	20
Narragansett Bay	5	0.6	12
New York Bight	164	62	38
Based on ADN N loads from the watershed only (excluding direct N deposition to the bay surface):			
Waquoit Bay, MA	0.022	0.0065	29
Based on ADN directly to the waterbody (excluding ADN loads from the watershed):			
Delaware Inland Bays	1.3	0.28	21
Flanders Bay, NY	0.36	0.027	7
Guadalupe Estuary, TX	4.2–15.9	0.31	2–8
Massachusetts Bays	22–30	1.6–6	5–27
Narragansett Bay	9	0.4	4
Newport River Coastal Waters, NC	0.27–0.85	0.095–0.68	>35
Potomac River, MD	35.5	1.9	5
Sarasota Bay, FL	0.6	0.16	26
Tampa Bay, FL	3.8	1.1	28

ADN = atmospheric deposition of N

Source: *Table from Deposition of Air Pollutants to the Great Waters-3rd Report to Congress (EPA, 2000)

2.3.1.4 Summary of Ecological Effects Associated with Nitrogen and Sulfur Deposition

Deposition of reduced and oxidized nitrogen and sulfur species cause acidification, altering biogeochemistry and affecting animal and plant life in terrestrial and aquatic ecosystems across the U.S. Major effects include a decline in sensitive tree species, such as red spruce and sugar maple; and a loss of biodiversity of fishes, zooplankton, and macro invertebrates. The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geological characteristics (bedrock, weathering rates, etc.).

Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations. Decreases in acid neutralizing capacity and increases in inorganic aluminum concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems. Across the U.S., ecosystems continue to be acidified by current emissions from both stationary sources, area sources, and mobile sources. For example, in the Adirondack Mountains of New York State, the

current rates of nitrogen and sulfur deposition exceed the amount that would allow recovery of the most acid sensitive lakes to a sustainable acid neutralizing capacity (ANC) level.[191]

In addition to the role nitrogen deposition plays in acidification, nitrogen deposition also causes ecosystem nutrient enrichment leading to eutrophication that alters biogeochemical cycles. Excess nitrogen also leads to the loss of nitrogen sensitive lichen species as they are outcompeted by invasive grasses as well as altering the biodiversity of terrestrial ecosystems, such as grasslands and meadows. Nitrogen deposition contributes to eutrophication of estuaries and the associated effects including toxic algal blooms and fish kills. For example, the Chesapeake Bay Estuary is highly eutrophic and 21 - 30% of total nitrogen load comes from deposition.[192] Eutrophication also occurs in freshwater ecosystems. Symptoms, such as altered algal communities occur in western U.S. high elevation lakes at nitrogen deposition rates a low as 2 kg/ha/yr.[193] Across the U.S., there are many terrestrial and aquatic ecosystems that have been identified as particularly sensitive to nitrogen deposition**.**

The addition of nitrogen to most ecosystems causes changes in primary productivity and growth of plants and algae, which can alter competitive interactions among species. Some species grow more than others, leading to shifts in population dynamics, species composition, and community structure. The most extreme effects of nitrogen deposition include a shift of ecosystem types in terrestrial ecosystems, and hypoxic zones that are devoid of life in aquatic ecosystems**.**[194]

There are a number of important quantified relationships between nitrogen deposition levels and ecological effects. Certain lichen species are the most sensitive terrestrial taxa to nitrogen with species losses occurring at just 3 kg N/ha/yr in the U.S. Pacific Northwest and in the southern portion of the State of California. The onset of declining biodiversity was found to occur at levels of 5 kg N/ha/yr and above within grasslands in both the State of Minnesota and in Europe. Altered species composition of Alpine ecosystems and forest encroachment into temperate grasslands was found at 10 kg N/ha/yr and above in both the U.S. and Canada.[195]

A United States Forest Service study conducted in areas within the Tongass Forest in Southeast Alaska found evidence of sulfur emissions impacting lichen communities. The authors concluded that the main source of sulfur and nitrogen found in lichens from Mt. Roberts is likely the burning of fossil fuels by cruise ships and other vehicles and equipment in downtown Juneau.[196]

Lichen are an important food source for caribou. This is causing concern about the potential role damage to lichens may be having on the Southern Alaska Peninsula Caribou Herd, which is an important food source to local subsistence based cultures. This herd has been decreasing in size, exhibiting both poor calf survival and low pregnancy rates, which are signs of dietary stress. Currently there is a complete caribou hunting ban, including a ban on subsistence hunting. If regulation of marine fuels could potentially enhance lichen biomass in the area, it would contribute in turn to maintenance of an important subsistence resource for local human populations.

The biogeochemical cycle of mercury, a well-known neurotoxin, is closely tied to the sulfur cycle. Mercury is taken up by living organisms in the methylated form, which is easily

bioaccumulated in the food web. Sulfate-reducing bacteria in wetland and lake sediments play a key role in mercury methylation. Changes in sulfate deposition have resulted in changes in both the rate of mercury methylation and the corresponding mercury concentrations in fish. In 2006, 3,080 fish advisories were issued in the U.S. due to the presence of methyl mercury in fish.

Although sulfur deposition is important to mercury methylation, several other interrelated factors seem to also be related to mercury uptake, including low lake water pH, dissolved organic carbon, suspended particulate matter concentrations in the water column, temperature, and dissolved oxygen. In addition, the proportion of upland to wetland land area within a watershed, as well as wetland type and annual water yield, appear to be important.

2.3.1.5 Ecological Effects Nutrient Enrichment

In general, ecosystems that are most responsive to nutrient enrichment from atmospheric nitrogen deposition are those that receive high levels of nitrogen loading, are nitrogen-limited, or contain species that have evolved in nutrient-poor environments. Species that are adapted to low nitrogen supply will often be more readily outcompeted by species that have higher nitrogen demands when the availability of nitrogen is increased.[197,198,199,200] As a consequence, some native species can be eliminated by nitrogen deposition.[201,202,203,204, 205] Note the terms "low" and "high" are relative to the amount of bioavailable nitrogen in the ecosystem and the level of deposition.

Eutrophication effects resulting from excess nitrogen are more widespread than acidification effects in western North America. Figure 2-15 highlights areas in the Western U.S. where nitrogen effects have been extensively reported. The discussion of ecological effects of nutrient enrichment that follows is organized around three types of ecosystem categories which experience impacts from nutrient enrichment: terrestrial, transitional, and aquatic.

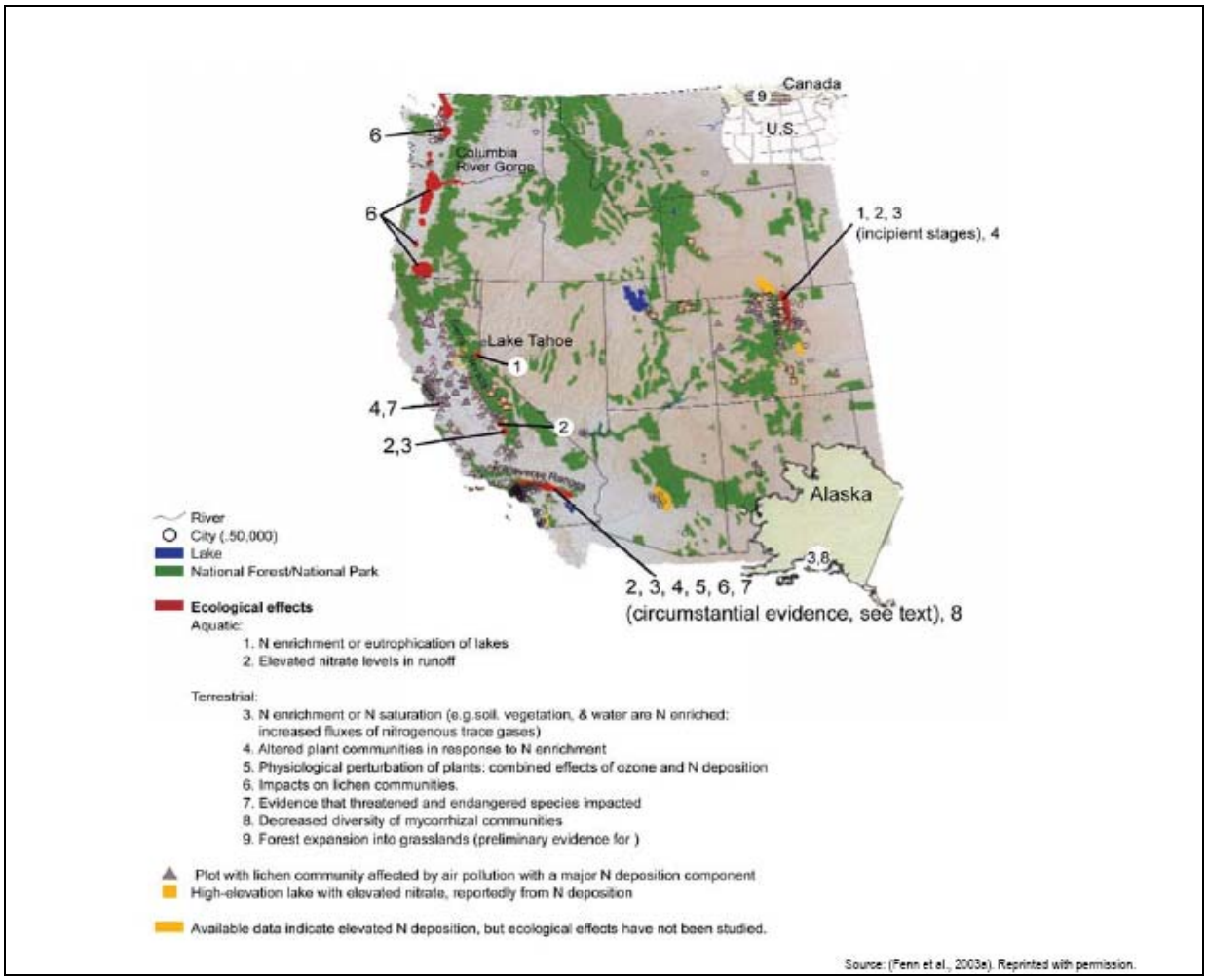


Figure 2-15 Map of the Western U.S. Showing the Primary Geographic Areas where Nitrogen Deposition Effects have been Reported

2.3.1.5.1 Terrestrial

Ecological effects of nitrogen deposition occur in a variety of taxa and ecosystem types including: forests, grasslands, arid and semi-arid areas, deserts, lichens, alpine, and mycorrhizae. Atmospheric inputs of nitrogen can alleviate deficiencies and increase growth of some plants at the expense of others. Nitrogen deposition alters the competitive relationships among terrestrial plant species and therefore alters species composition and diversity.[206,207,208] Wholesale shifts in species composition are easier to detect in short-lived terrestrial ecosystems such as annual grasslands, in the forest understory, or mycorrhizal associations, than for long-lived forest trees where changes are evident on a decade or longer time scale. Note species shifts and ecosystem changes can occur even if the ecosystem does not exhibit signs of nitrogen saturation.

There are a number of important quantified relationships between nitrogen deposition levels and ecological effects.[209] Certain lichen species are the most sensitive terrestrial taxa to nitrogen in the U.S. with clear adverse effects occurring at just 3 kg N/ha/yr. Figure 2-9 shows

the geographic distribution of lichens in the U.S. Among the most sensitive U.S. ecosystems are Alpine ecosystems where alteration of plant covers of an individual species (*Carex rupestris*) was estimated to occur at deposition levels near 4 kg N/ha/yr and modeling indicates that deposition levels near 10 kg/N/ha/yr alter plant community assemblages.[210] Within grasslands, the onset of declining biodiversity was found to occur at levels of 5 kg N/ha/yr. Forest encroachment into temperate grasslands was found at 10 kg N/ha/yr and above in the U.S. Table 2-4 provides a brief list of nitrogen deposition levels and associated ecological effects.

Table 2-4 Examples of Quantified Relationship between Nitrogen Deposition Levels and Ecological Effects[a]

Kg N/ha/yr	Ecological effect
~1.5	Altered diatom communities in high elevation freshwater lakes and elevated nitrogen in tree leaf tissue high elevation forests in the U.S.
3.1	Decline of some lichen species in the Western U.S. (critical load)
4	Altered growth and coverage of alpine plant species in U.S.
5	Onset of decline of species richness in grasslands of the U.S. and U.K.
5.6 - 10	Onset of nitrate leaching in Eastern forests of the U.S.
5-10	Multiple effects in tundra, bogs and freshwater lakes in Europe (critical loads)
5-15	Multiple effects in arctic, alpine, subalpine and scrub habitats in Europe (critical loads)

Note:
[a] EPA, Integrated Science Assessment for Oxides of Nitrogen and Sulfur-Ecological criteria

Most terrestrial ecosystems are nitrogen-limited, therefore they are sensitive to perturbation caused by nitrogen additions.[211] The factors that govern the vulnerability of terrestrial ecosystems to nutrient enrichment from nitrogen deposition include the degree of nitrogen limitation, rates and form of nitrogen deposition, elevation, species composition, length of growing season, and soil nitrogen retention capacity.

Regions and ecosystems in the western U.S. where nitrogen nutrient enrichment effects have been documented in terrestrial ecosystems are shown on Figure 2-15.[212] The alpine ecosystems of the Colorado Front Range, chaparral watersheds of the Sierra Nevada, lichen and vascular plant communities in the San Bernardino Mountains and the Pacific Northwest, and the southern California coastal sage scrub community are among the most sensitive terrestrial ecosystems in the western U.S.

In the eastern U.S., the degree of nitrogen saturation of the terrestrial ecosystem is often assessed in terms of the degree of nitrate leaching from watershed soils into ground water or surface water. Studies have estimated the number of surface waters at different stages of

saturation across several regions in the eastern U.S.[213] Of the 85 northeastern watersheds examined, 40% were in nitrogen-saturation Stage 0,[K] 52% in Stage 1, and 8% in Stage 2. Of the northeastern sites for which adequate data were available for assessment, those in Stage 1 or 2 were most prevalent in the Adirondack and Catskill Mountains in the State of New York.

2.3.1.5.2 Transitional

About 107.7 million acres of wetlands are widely distributed in the conterminous U.S., 95% of which are freshwater wetlands and 5% are estuarine or marine wetlands[214] (Figure 2-16). At one end of the spectrum, bogs or peatland are very sensitive to nitrogen deposition because they receive nutrients exclusively from precipitation, and the species in them are adapted to low levels of nitrogen.[215,216,217] Intertidal wetlands are at the other end of the spectrum; in these ecosystems, marine/estuarine water sources generally exceed atmospheric inputs by one or two orders of magnitude.[218] Wetlands are widely distributed, including some areas that receive moderate to high levels of nitrogen deposition.

Nitrogen deposition alters species richness, species composition and biodiversity in U.S. wetland ecosystems.[219] The effect of nitrogen deposition on these ecosystems depends on the fraction of rainfall in its total water budget. Excess nitrogen deposition can cause shifts in wetland community composition by altering competitive relationships among species, which potentially leads to effects such as decreasing biodiversity, increasing non-native species establishment, and increasing the risk of extinction for sensitive and rare species.

U.S. wetlands contain a high number of rare plant species.[220,221, 222] High levels of atmospheric nitrogen deposition increase the risk of decline and extinction of these species that are adapted to low nitrogen conditions. In general, these include the genus *Isoetes sp*., of which three species are federally endangered; insectivorous plants like the endangered green pitcher *Sarracenia oreophila*; and the genus *Sphagnum*, of which there are 15 species listed as endangered by eastern U.S. Roundleaf sundew (*Drosera rotundifolia*) is also susceptible to elevated atmospheric nitrogen deposition.[223] This plant is native to, and broadly distributed across, the U.S. and is federally listed as endangered in Illinois and Iowa, threatened in Tennessee, and vulnerable in New York.[224] In the U.S., *Sarracenia purpurea* can be used as a biological indicator of local nitrogen deposition in some locations.[225]

[K] In Stage 0, nitrogen inputs are low and there are strong nitrogen limitations on growth. Stage 1 is characterized by high nitrogen rentention and fertilization effect of added nitrogen on tree growth. Stage 2 includes the induction of nitrification and some nitrate leaching, though growth may still be high. In Stage 3 tree growth declines, nitrification and nitrate loss continue to increase, but nitrogen mineralization rates begin to decline.

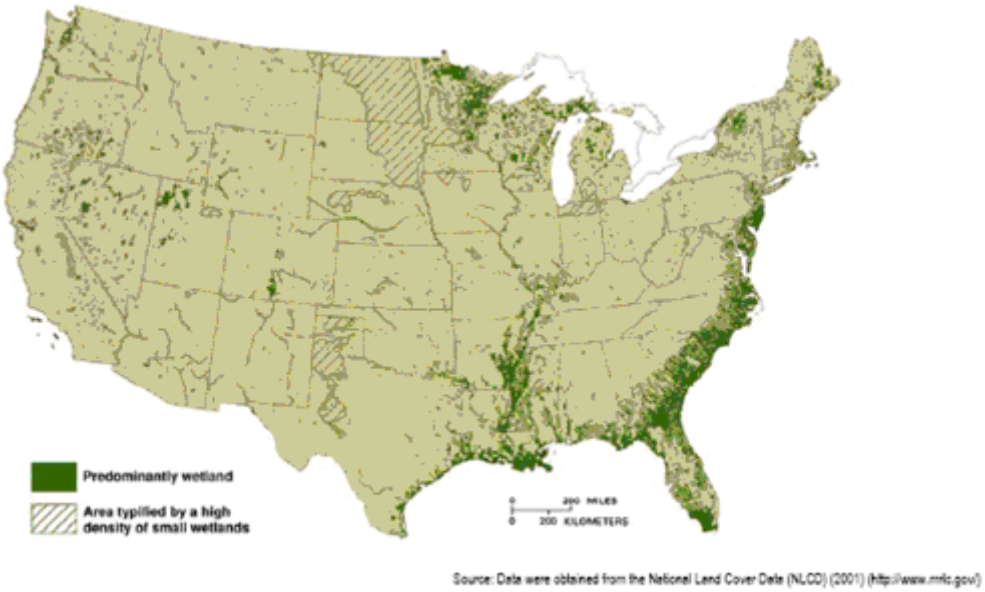


Figure 2-16 Location of Wetlands in Continental U.S.

2.3.1.5.3 Freshwater Aquatic

Nitrogen deposition alters species richness, species composition and biodiversity in freshwater aquatic ecosystems across the U.S.[226] Evidence from multiple lines of research and experimental approaches support this observation, including paleolimnological reconstructions, bioassays, mesocosm and laboratory experiments. Increased nitrogen deposition can cause a shift in community composition and reduce algal biodiversity. Elevated nitrogen deposition results in changes in algal species composition, especially in sensitive oligotrophic lakes. In the West, a hindcasting exercise determined that the change in Rocky Mountain National Park lake algae that occurred between 1850 and 1964 was associated with an increase in wet nitrogen deposition that was only about 1.5 kg N/ha.[227] Similar changes inferred from lake sediment cores of the Beartooth Mountains of Wyoming also occurred at about 1.5 kg N/ha deposition.[228]

Some freshwater algae are particularly sensitive to added nutrient nitrogen and experience shifts in community composition and biodiversity with increased nitrogen deposition. For example, two species of diatom (a taxanomic group of algae), *Asterionella formosa* and *Fragilaria crotonensis*, now dominate the flora of at least several alpine and montane Rocky Mountain lakes. Sharp increases have occurred in Lake Tahoe.[229,230,231,232,233,234] The timing of this shift has varied, with changes beginning in the 1950s in the southern Rocky Mountains and in the 1970s or later in the central Rocky Mountains. These species are opportunistic algae that have been observed to respond rapidly to disturbance and slight nutrient enrichment in many parts of the world.

2.3.1.5.4 Estuarine Aquatic

Nitrogen deposition also alters species richness, species composition and biodiversity in estuarine ecosystems throughout the U.S.[235] Nitrogen is an essential nutrient for estuarine and

marine fertility. However, excessive nitrogen contributes to habitat degradation, algal blooms, toxicity, hypoxia (reduced dissolved oxygen), anoxia (absence of dissolved oxygen), reduction of sea grass habitats, fish kills, and decrease in biodiversity.[236,237,238,239,240 241] Each of these potential impacts carries ecological and economic consequences. Ecosystem services provided by estuaries include fish and shellfish harvest, waste assimilation, and recreational activities.[242]

Increased nitrogen deposition can cause shifts in community composition, reduced hypolimnetic DO, reduced biodiversity, and mortality of submerged aquatic vegetation. The form of deposited nitrogen can significantly affect phytoplankton community composition in estuarine and marine environments. Small diatoms are more efficient in using nitrate than NH_4^+. Increasing NH_4^+ deposition relative to nitrate in the eastern U.S. favors small diatoms at the expense of large diatoms. This alters the foundation of the food web. Submerged aquatic vegetation is important to the quality of estuarine ecosystem habitats because it provides habitat for a variety of aquatic organisms, absorbs excess nutrients, and traps sediments. Nutrient enrichment is the major driving factor contributing to declines in submerged aquatic vegetation coverage. The Mid-Atlantic region is the most heavily impacted area in terms of moderate or high loss of submerged aquatic vegetation due to eutrophication.

2.3.1.5.5 Estuarine and Coastal Aquatic

Estuaries and coastal waters tend to be nitrogen-limited and are therefore inherently sensitive to increased atmospheric nitrogen loading.[243,244] The U.S. national estuary condition assessment completed in 2007[245] found that the most impacted estuaries in the U.S. occurred in the mid- Atlantic region and the estuaries with the lowest symptoms of eutrophication were in the North Atlantic. Nitrogen nutrient enrichment is a major environmental problem for coastal regions of the U.S., especially in the eastern and Gulf Coast regions. Of 138 estuaries examined in the national estuary assessment, 44 were identified as showing symptoms of nutrient over-enrichment. Estuaries are among the most biologically productive ecosystems on Earth and provide critical habitat for an enormous diversity of life forms, especially fish. Of the 23 estuaries examined in the national assessment in the Northeast, 61% were classified as moderately to severely degraded.[246] Other regions had mixtures of low, moderate, and high degree of eutrophication (See Figure 2-17).

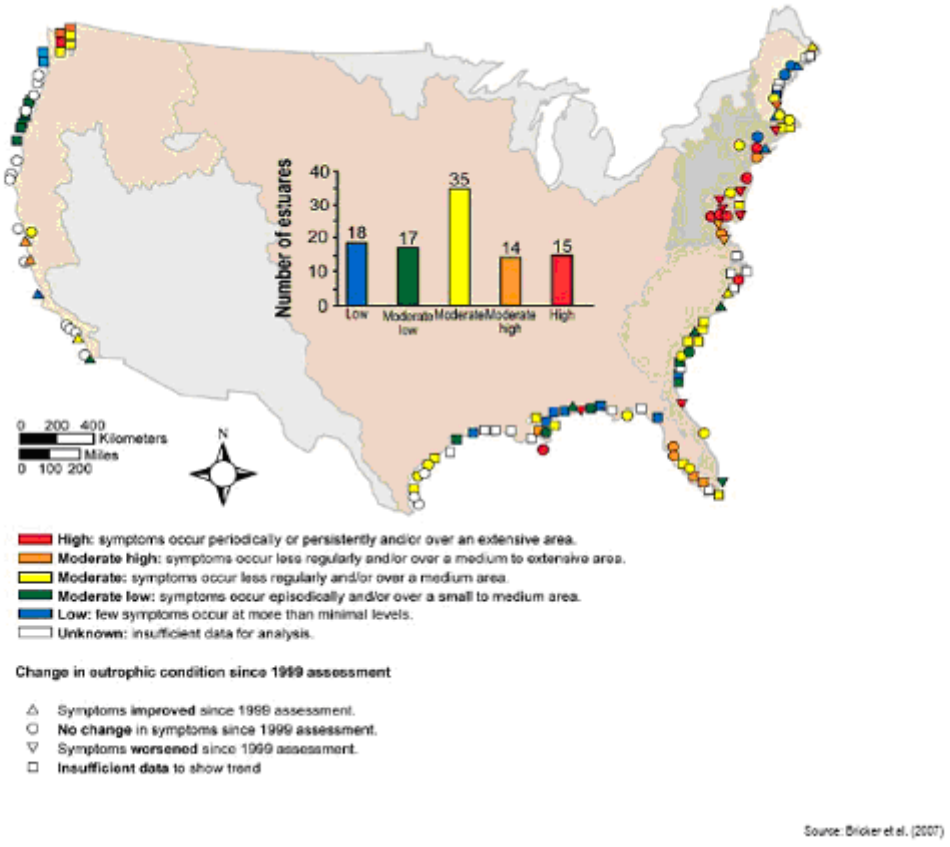


Figure 2-17 Overall Eutrophication Condition on a National Scale

The national assessment also evaluated the future outlook of the nation's estuaries based on population growth and future management plans. They predicted that trophic conditions would worsen in 48 estuaries, stay the same in 11, and improve in only 14 by the year 2020. Between 1999 and 2007, an equal number of estuary systems have improved their trophic status as have worsened. The assessed estuarine surface area with high to moderate/high eutrophic conditions have stayed roughly the same, from 72% in1999,[247] to 78% in the 2007 assessment.[248]

2.3.1.6 Ecological Effects of Acidification

The U.S. EPA's Integrated Science Assessment for Oxides of Nitrogen and Sulfur-Ecological Criteria found that the principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is geology (particularly surficial geology).[249] Geologic formations having low base cation supply generally underlie the watersheds of acid-sensitive lakes and streams. Bedrock geology has been used in numerous acidification studies.[250,251,252,253,254] Other factors contribute to the sensitivity of soils and surface waters to acidifying deposition, including topography, soil chemistry, land use, and hydrologic flow path.

2.3.1.6.1 Terrestrial

Acidifying deposition has altered major biogeochemical processes in the U.S. by increasing the nitrogen and sulfur content of soils, accelerating nitrate and sulfate leaching from soil to drainage waters, depleting base cations (especially calcium and magnesium) from soils, and increasing the mobility of aluminum. Inorganic aluminum is toxic to some tree roots. Plants affected by high levels of aluminum from the soil often have reduced root growth, which restricts the ability of the plant to take up water and nutrients, especially calcium.[255] These direct effects can, in turn, influence the response of these plants to climatic stresses such as droughts and cold temperatures. They can also influence the sensitivity of plants to other stresses, including insect pests and disease[256] leading to increased mortality of canopy trees. In the U.S., terrestrial effects of acidification are best described for forested ecosystems (especially red spruce and sugar maple ecosystems) with additional information on other plant communities, including shrubs and lichen.[257] There are several indicators of stress to terrestrial vegetation including percent dieback of canopy trees, dead tree basal area (as a percent), crown vigor index and fine twig dieback.[258]

2.3.1.6.1.1 Health, Vigor, and Reproduction of Tree Species in Forests

Both coniferous and deciduous forests throughout the eastern U.S. are experiencing gradual losses of base cation nutrients from the soil due to accelerated leaching for acidifying deposition. This change in nutrient availability may reduce the quality of forest nutrition over the long term. Evidence suggests that red spruce and sugar maple in some areas in the eastern U.S. have experienced declining health as a consequence of this deposition. For red spruce, (*Picea rubens*) dieback or decline has been observed across high elevation landscapes of the northeastern U.S., and to a lesser extent, the southeastern U.S. Acidifying deposition has been implicated as a causal factor.[259] Since the 1980s, red spruce growth has increased at both the higher- and lower-elevation sites corresponding to a decrease in SO_2 emissions in the U.S. (to about 20 million tons/year by 2000), while NO_X emissions held fairly steady (at about 25 million tons/year). Research indicates that annual emissions of sulfur plus NO_X explained about 43% of the variability in red spruce tree ring growth between 1940 and 1998, while climatic variability accounted for about 8% of the growth variation for that period.[260] The observed dieback in red spruce has been linked, in part, to reduced cold tolerance of the spruce needles, caused by acidifying deposition. Results of controlled exposure studies showed that acidic mist or cloud water reduced the cold tolerance of current-year needles by 3 to 10° F.[261] More recently, studies have found a link between availability of soil calcium and winter injury.[262] Figure 2-18 shows the distribution of red spruce (brown) and sugar maple (green) in the eastern U.S.

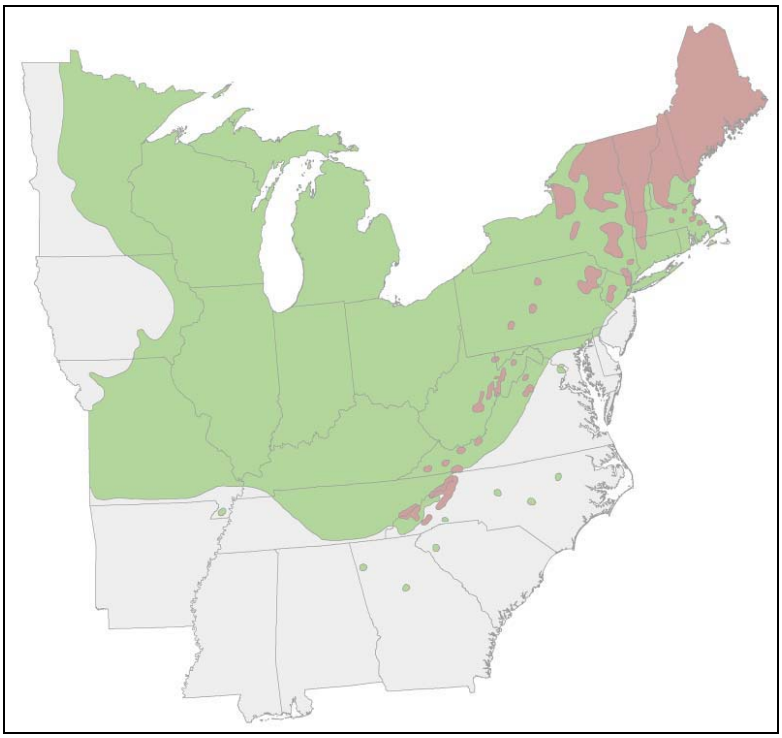


Figure 2-18 Distribution of Red Spruce (pink) and Sugar Maple (green) in the Eastern U.S.[263]

In hardwood forests, species nutrient needs, soil conditions, and additional stressors work together to determine sensitivity to acidifying deposition. Stand age and successional stage also can affect the susceptibility of hardwood forests to acidification effects. In northeastern hardwood forests, older stands exhibit greater potential for calcium depletion in response to acidifying deposition than younger stands. Thus, with the successional change from pin cherry (*Prunus pensylvanica*), striped maple (*Acer pensylvanicum*), white ash (*Fraxinus americana*), yellow birch (*Betula alleghaniensis*) and white birch (*Betula papyrifera*) in younger stands to beech (*Fagus grandifolia*) and red maple (*Acer rubrum*) in older stands, there is an increase in sensitivity to acidification.[264]

Sugar maple (*Acer saccharum*) is the deciduous tree species of the northeastern U.S. and central Appalachian Mountain region (See Figure 2-18) that is most commonly associated with adverse acidification-related effects of nitrogen and sulfur deposition.[265] In general, evidence indicates that acidifying deposition in combination with other stressors is a likely contributor to the decline of sugar maple trees that occur at higher elevation, on geologies dominated by sandstone or other base-poor substrate, and that have base-poor soils having high percentages of rock fragments.[266]

Loss of calcium ions in the base cations has also been implicated in increased susceptibility of flowering dogwood (*Cornus florida*) to its most destructive disease, dogwood anthracnose, a mostly fatal disease. Figure 2-19 shows the native range of flowering dogwood in the U.S. (dark gray) as well as the range of the anthracnose disease as of 2002 in the eastern U.S. (red). Flowering dogwood is a dominant understory species of hardwood forests in the eastern U.S.[267]

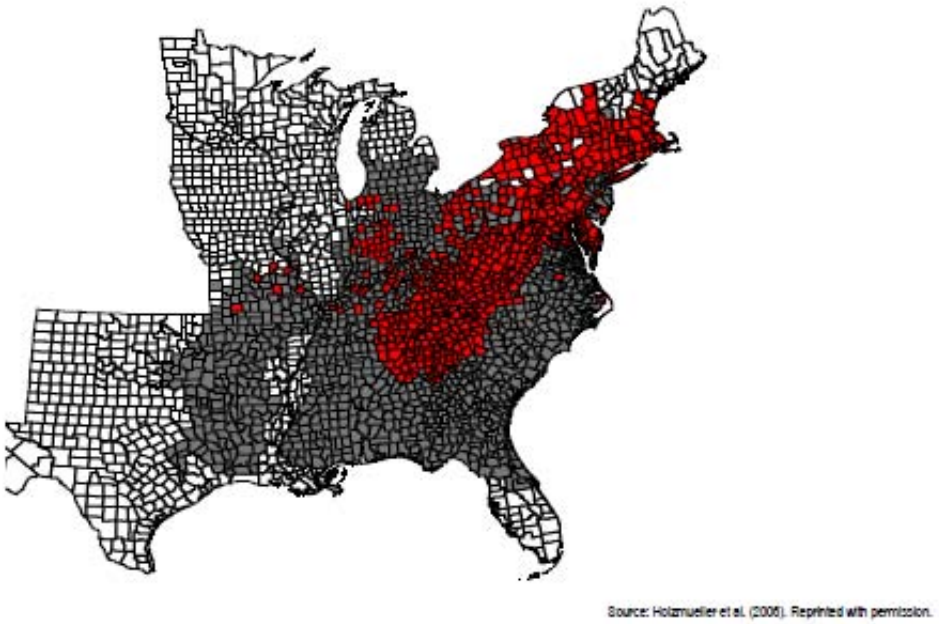


Figure 2-19 Native Range of Flowering Dogwood (dark gray) and the Documented Range of Dogwood Anthracnose (red)[268]

The NO_XSO_X ISA[269] found limited data on the possible effects of nitrogen and sulfur deposition on the acid-based characteristics of forests in the U.S., other than spruce-fire and northern hardwood forests ecosystems as described above.

2.3.1.6.1.2 Health and Biodiversity of Other Plant Communities

Shrubs

The ISA found that available data suggest that it is likely that a variety of shrub and herbaceous species are sensitive to base cation depletion and/or aluminum toxicity. However, conclusive evidence is generally lacking.

Lichens

The U.S. EPA NO_XSO_X ISA found that lichens and bryophytes are among the first components of the terrestrial ecosystem to be affected by acidifying deposition. Vulnerability of lichens to increased nitrogen input is generally greater than that of vascular plants.[270] Even in the Pacific Northwest, which receives uniformly low levels of nitrogen deposition, changes from acid-sensitive and nitrogen-sensitive to pollution tolerant nitrophillic lichen taxa are occurring in some areas.[271] Lichens remaining in areas affected by acidifying deposition were found to contain almost exclusively the families Candelariaccae, Physciaceae, and Teloschistaceae.[272]

Effects of sulfur dioxide exposure to lichens includes: reduced photosynthesis and respiration, damage to the algal component of the lichen, leakage of electrolytes, inhibition of nitrogen fixation, reduced K absorption, and structural changes.[273,274] Additional research has concluded that the sulfur:nitrogen exposure ratio is as important as pH in causing toxic effects on

lichens. Thus, it is not clear to what extent acidity may be the principal stressor under high levels of air pollution exposure. The toxicity of sulfur dioxide to several lichen species is greater under acidic conditions than under neutral conditions.[275,276] The effects of excess nitrogen deposition to lichen communities are discussed in Section 2.3.1.4.

Arctic and Alpine Tundra

The NO_XSO_X ISA found that the possible effects of acidifying deposition on arctic and alpine plant communities are also of concern. Especially important in this regard is the role of nitrogen deposition in regulating ecosystem nitrogen supply and plant species composition. Soil acidification and base cation depletion in response to acidifying deposition have not been documented in arctic or alpine terrestrial ecosystems in the U.S. Such ecosystems are rare and spatially limited in the eastern U.S., where acidifying deposition levels have been high. These ecosystems are more widely distributed in the western U.S. and throughout much of Alaska, but acidifying deposition levels are generally low in these areas. Key concerns are for listed threatened or endangered species and species diversity.

2.3.1.6.1.3 Aquatic Ecosystems

Aquatic effects of acidification have been well studied in the U.S. and elsewhere at various trophic levels. These studies indicate that aquatic biota have been affected by acidification at virtually all levels of the food web in acid sensitive aquatic ecosystems. Effects have been most clearly documented for fish, aquatic insects, other invertebrates, and algae.

Biological effects are primarily attributable to a combination of low pH and high inorganic aluminum concentrations. Such conditions occur more frequently during rainfall and snowmelt that cause high flows of water and less commonly during low-flow conditions, except where chronic acidity conditions are severe. Biological effects of episodes include reduced fish condition factor, changes in species composition and declines in aquatic species richness across multiple taxa, ecosystems and regions. These conditions may also result in direct mortality.[277] Biological effects in aquatic ecosystems can be divided into two major categories: effects on health, vigor, and reproductive success; and effects on biodiversity.

2.3.1.7 Case Study: Critical Load Modeling in the Adirondack Mountains of New York State and the Blue Ridge Mountains in the State of Virginia

The Adirondack Mountains of New York and the Blue Ridge Mountains of Virginia have long been a locus for awareness of the environmental issues related to acidifying deposition. Soils and water bodies, such as lakes and streams, usually buffer the acidity from natural rain with "bases," the opposite of acids, from the environment. The poor buffering capability of the soils in both these regions make the lakes and streams particularly susceptible to acidification from anthropogenic nitrogen and sulfur atmospheric deposition resulting from nitrogen and sulfur oxides emissions. Consequently, acidic deposition has affected hundreds of lakes and thousands of miles of headwater streams in both of these regions. The diversity of life in these acidic waters has been reduced as a result of acidic deposition.

The critical load approach provides a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge. The critical load for a lake or stream provides a means to gauge the extent to which a water body has recovered from past acid deposition, or is potentially at risk due to current deposition levels. Acid neutralizing capacity (ANC) is an excellent indicator of the health of aquatic organisms such as fish, insects, and invertebrates.

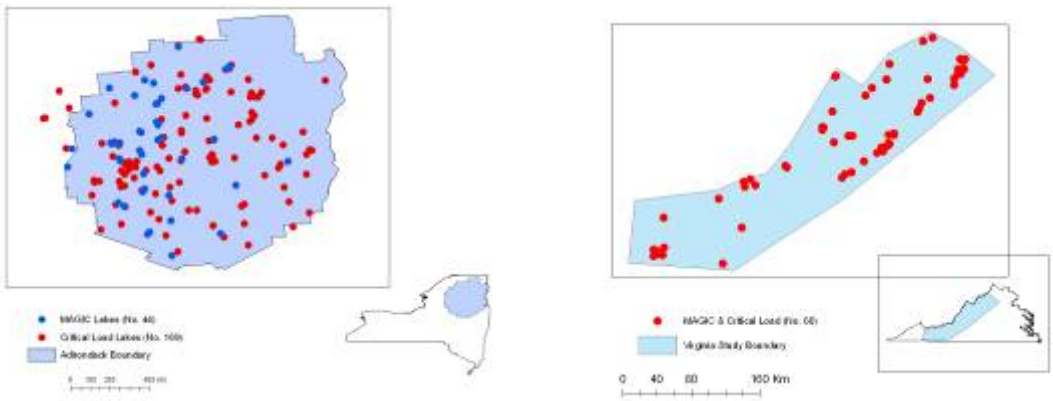


Figure 2-20 Locations of Lakes and Streams where Critical Loads were Calculated

In this case study, the focus is on the combined load of nitrogen and sulfur deposition below which the ANC level would still support healthy aquatic ecosystems. Critical loads were calculated for 169 lakes in the Adirondack region and 60 streams in Virginia (Figure 2-20). The Steady-State Water Chemistry (SSWC) model was used to calculate the critical load, relying on water chemistry data from the USEPA Temporal Intergraded Monitoring of Ecosystems (TIME) and Long-term Monitoring (LTM) programs and model assumptions well supported by the scientific literature. Research studies have shown that surface water with ANC values greater than 50 μeq/L tend to protect most fish (i.e., brook trout, others) and other aquatic organisms (Table 2-5). In this case, the critical load represents the combined deposition load of nitrogen and sulfur to which a lake or stream could be subjected and still have an ANC of 50 μeq/L. Critical loads of combined total nitrogen and sulfur are expressed in terms of ionic charge balance as milliequivalent per square meter per year ($meq/m^2/yr$).

Table 2-5 Aquatic Status Categories

CATEGORY LABEL	ANC LEVELS*	EXPECTED ECOLOGICAL EFFECTS
Acute Concern	<0 micro equivalent per Liter (μeq/L)	Complete loss of fish populations is expected. Planktonic communities have extremely low diversity and are dominated by acidophilic forms. The numbers of individuals in plankton species that are present are greatly reduced.
Severe Concern	0 – 20 μeq/L	Highly sensitive to episodic acidification. During episodes of high acid deposition, brook trout populations may experience lethal effects. Diversity and distribution of zooplankton communities decline sharply.
Elevated Concern	20 – 50 μeq/L	Fish species richness is greatly reduced (more than half of expected species are missing). On average, brook trout populations experience sub-lethal effects, including loss of health and reproduction (fitness). Diversity and distribution of zooplankton communities also decline.
Moderate Concern	50 – 100 μeq/L	Fish species richness begins to decline (sensitive species are lost from lakes). Brook trout populations are sensitive and variable, with possible sub-lethal effects. Diversity and distribution of zooplankton communities begin to decline as species that are sensitive to acid deposition are affected.
Low Concern	>100 μeq/L	Fish species richness may be unaffected. Reproducing brook trout populations are expected where habitat is suitable. Zooplankton communities are unaffected and exhibit expected diversity and range.

When the critical load is "exceeded," it means that the amount of combined nitrogen and sulfur atmospheric deposition is greater than the critical load for a particular lake or stream, preventing the water body from reaching or maintaining an ANC concentration of 50 μeq/L. Exceedances were calculated from deposition for years 2002 and 2020 with and without emissions from shipping. In year 2002, there was no difference in the percent of lakes or streams in both regions that exceeded the critical load for the case with and without ship emissions (Table 2-6). For the year 2020, when ship emissions are present, 33% of lakes in the Adirondack Mountains and 52% of streams in the Virginia Blue Ridge Mountains received greater acid deposition than could be neutralized. When ship emissions were removed from the modeling domain for the year 2020, 31- and 50% of lakes and streams, respectively, received greater acid deposition than could be neutralized a 2% improvement.

2.3.1.7.1 Regional Assessment

A regional estimate of the benefits of the reduction in international shipping emissions in 2020 can be derived from scaling up the results from 169 lakes to a larger population of lakes in the Adirondack Mountains. One hundred fifteen lakes of the 169 lakes modeled for critical loads are part of a subset of 1,842 lakes in the Adirondacks, which include all lakes from 0.5 to 2,000 ha in size and at least 0.5 meters in depth. Using weighting factors derived from the EMAP

probability survey and the critical load calculations from the 115 lakes, exceedance estimates were derived for the entire 1,842 lakes in the Adirondacks. Based on this approach, 66 fewer lakes in the Adirondack Mountains are predicted to receive nitrogen and sulfur deposition loads below the critical load and would be protected as a result of removing international shipping emissions in 2020.

Currently, no probability survey has been completed for the study area in Virginia. However, the 60 trout streams modeled are characteristic of first and second order streams on non-limestone bedrock in the Blue Ridge Mountains of Virginia. Because of the strong relationship between bedrock geology and ANC in this region, it is possible to consider the results in the context of similar trout streams in the Southern Appalachians that have the same bedrock geology and size. In addition, the 60 streams are a subset of 344 streams sampled by the Virginia Trout Stream Sensitivity Study, which can be applied to a population of 304 out of the original 344 streams. Using the 304 streams to which the analysis applies directly as the total, 6 additional streams in this group would be protected as a result of removing international shipping emissions in 2020. However, it is likely that many more of the ~12,000 trout streams in Virginia would benefit from reduced international shipping emissions given the extent of similar bedrock geology outside the study area.

Table 2-6 Percent of Modeled Lakes that Exceed the Critical Load for Years 2002 and 2020 with and without International Shipping Emissions. "Zero" Indicates without International Shipping Emissions

	2002	2002 ZERO	2020	2020 ZERO
Adirondack Mountains				
Exceeded Critical Load (%. Lakes)	45	45	33	31
Non-Exceeded Critical Load (%. Lakes)	55	55	73	71
Virginia Blue Ridge Mountains				
Exceeded Critical Load (%. Lakes)	82	82	52	50
Non-Exceeded Critical Load (%. Lakes)	18	18	48	50

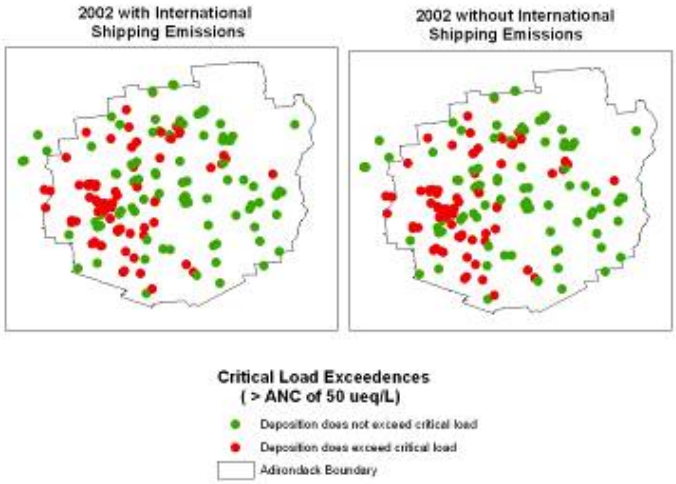


Figure 2-21 a. 2002

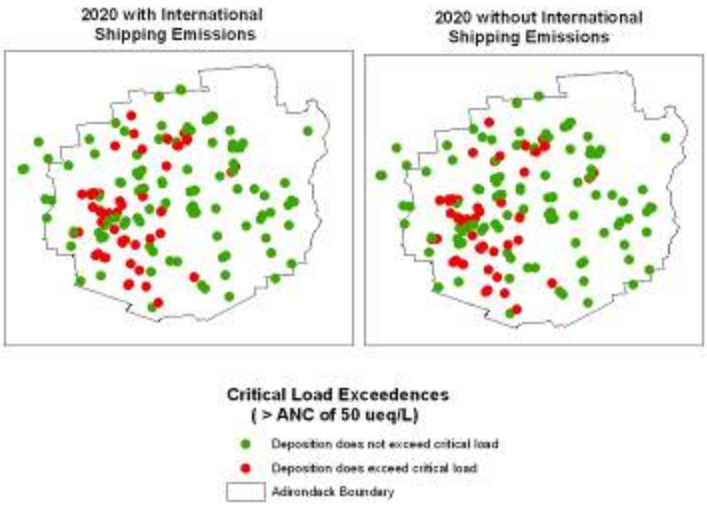


Figure 2-21 b. 2020; Critical Load Exceedance for ANC Concentration of 50 µeq/L. Green dots represent lakes in the Adirondack Mountains where current nitrogen and sulfur deposition is below their critical load and maintains an ANC concentration of 50 µeq/L. Red dots are lakes where current nitrogen and sulfur deposition exceeds their limit and the biota are likely impacted.

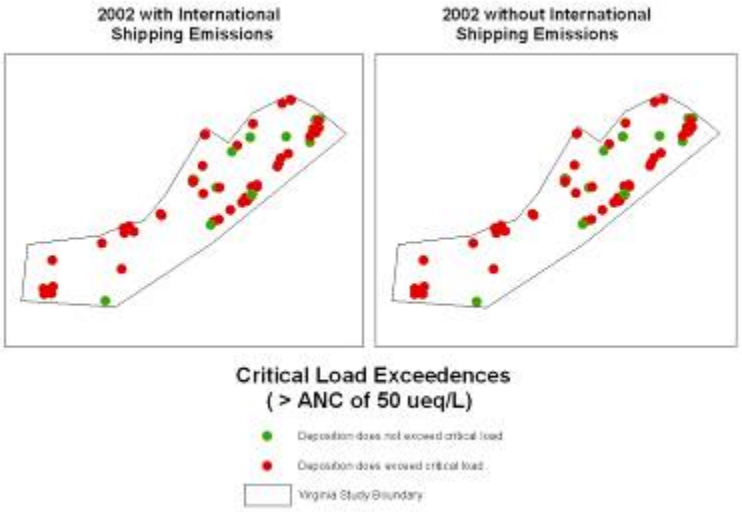


Figure 2-22 a. 2002

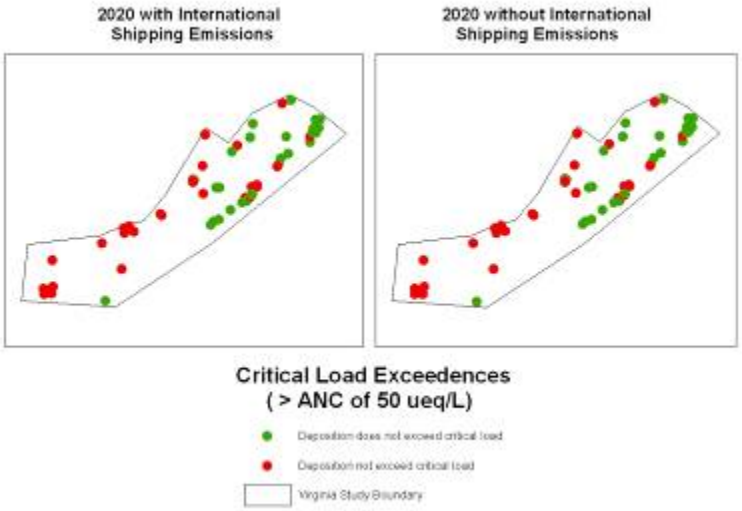


Figure 2-22 b. 2020; Critical Load Exceedances for ANC Concentration of 50 µeq/L. Green dots represent streams in the Virginia Blue Ridge Mountains where current nitrogen and sulfur deposition is below their critical load and maintains an ANC concentration of 50 µeq/L. Red dots are streams where current nitrogen and sulfur deposition exceeds their limit and the biota are likely impacted.

2.3.2 Deposition of Particulate Matter

Current international shipping emissions of $PM_{2.5}$ contain small amounts of metals:nickel, vanadium, cadmium, iron, lead, copper, zinc, aluminum.[278,279,280] Investigations of trace metals near roadways and industrial facilities indicate that a substantial burden of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel are shown to be directly

toxic to vegetation under field conditions.[281] 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.[282] This hypothesized 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 Northeast U.S.[283] 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. As the fallen leaves decompose, the heavy metals are transferred into the soil.[284,285]

Ships also emit air toxics, including polycyclic aromatic hydrocarbons (PAHs) -- a class of polycyclic organic matter (POM) that contain compounds which are known or suspected carcinogens. Since the majority of PAHs are adsorbed onto particles less than 1.0 μm in diameter, long range transport is possible. Particles of this size can remain airborne for days or even months and travel distances up to 10,000 km before being deposited on terrestrial or aquatic surfaces.[286,287,288,289,290] Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan in the Great Lakes, Chesapeake Bay which is surrounded by the States of Maryland and Virginia, Tampa Bay in the central part of the State of Florida and in other coastal areas of the U.S.[291] PAHs tend to accumulate in sediments and reach high enough concentrations in some coastal environments to pose an environmental health threat that includes cancer in fish populations, toxicity to organisms living in the sediment and risks to those (e.g., migratory birds) that consume these organisms.[292,293] PAHs tend to accumulate in sediments and bioaccumulate in freshwater, flora and fauna.

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.

2.3.3 Visibility Degradation

Emissions from international shipping activity contribute to poor visibility in the U.S. through their primary $PM_{2.5}$ and NO_X emissions (which contribute to the formation of secondary $PM_{2.5}$). These airborne particles degrade visibility by scattering and absorbing light. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

Modeling undertaken for this coordinated strategy shows that international shipping activities negatively impact visibility by contributing to urban haze in U.S. cities which are located near major deep sea ports and also as regional haze in national parks and wilderness areas throughout the U.S. The U.S. Government places special emphasis on protecting visibility in national parks and wilderness areas. Section 169 of the Clean Air Act requires the U.S. Government to address existing visibility impairment and future visibility impairment in the 156 national parks (see figure 2-23) exceeding 6,000 acres, and wilderness areas exceeding 5,000 acres, which are categorized as mandatory class I federal areas (62 FR 38680, July 18, 1997).

Based on modeling for this coordinated strategy, international shipping activities in 2002 contributed to visibility degradation at all of the 133 class I federal areas which have complete Interagency Monitoring of Protected Visual Environments (IMPROVE) ambient data for 2002 or are represented by IMPROVE monitors with complete data.[L] Absent further emission controls, by 2020, international shipping activities will have an even larger impact on visibility impairment in these class I federal areas. For example, in 2002, approximately 4% of visibility impairment in southern California's Agua Tibia Wilderness was due to shipping activity. U.S. modeling, conducted for this coordinated strategy, indicates that by 2020 approximately 12.5% of visibility impairment in Agua Tibia will be due to shipping. Likewise, in 2002, 2.7% of visibility impairment in southern Florida's Everglades National Park was due to international shipping, and this will double to 6% by 2020. Even in inland class I federal areas, shipping activity is contributing to visibility degradation. In 2020, about 2.5% of visibility degradation in the Grand Canyon National Park located in the state of Arizona will be from international shipping, while almost 6% of visibility degradation in the State of Washington's North Cascades National Park will be from shipping emissions.

2.3.3.1 Visibility Monitoring

In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., the U.S. EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network was originally established at 20 sites, but it has now been expanded to 110 sites that represent all but

[L] 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 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.

one of the 156 mandatory Federal Class I areas across the country (see figure 2-23). This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of Protected Visual Environments).

IMPROVE provides direct measurement of fine particles that contribute to visibility impairment. The IMPROVE network employs aerosol measurements at all sites, and optical and scene measurements at some of the sites. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon, soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency, with adjustment for the relative humidity. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. Optical measurements are used to directly measure light extinction or its components. Such measurements are taken principally with either a transmissometer, which measures total light extinction, or a nephelometer, which measures particle scattering (the largest human-caused component of total extinction). Scene characteristics are typically recorded three times daily with 35 millimeter photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Directly measured light extinction is used under the IMPROVE protocol to cross check that the aerosol-derived light extinction levels are reasonable in establishing current visibility conditions. Aerosol-derived light extinction is used to document spatial and temporal trends and to determine how proposed changes in atmospheric constituents would affect future visibility conditions.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. The rural East generally has higher levels of impairment than remote sites in the West, with the exception of urban-influenced sites such as San Gorgonio Wilderness (CA) and Point Reyes National Seashore (CA), which have annual average levels comparable to certain sites in the Northeast. Regional differences are illustrated by Figures 4-39a and 4-39b in the Air Quality Criteria Document for Particulate Matter, which show that, for Class I areas, visibility levels on the 20% haziest days in the West are about equal to levels on the 20% best days in the East.[294]

Higher visibility impairment levels in the East are due to generally higher concentrations of anthropogenic fine particles, particularly sulfates, and higher average relative humidity levels. In fact, sulfates account for 60-86% of the haziness in eastern sites.[295] Aerosol light extinction due to sulfate on the 20% haziest days is significantly larger in eastern class I areas as compared to western areas (Figures 4-40a and 4-40b in the Air Quality Criteria Document for Particulate Matter).[296] With the exception of remote sites in the northwestern U.S., visibility is typically worse in the summer months. This is particularly true in the Appalachian region, where average light extinction in the summer exceeds the annual average by 40%.[297]

2.3.3.2 Addressing Visibility in the U.S.

The U.S. EPA has two programmatic approaches to address visibility. First, to address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which would act in

conjunction with the establishment of a regional haze program. In setting this secondary standard, EPA concluded that $PM_{2.5}$ causes adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. Second, section 169 of the Clean Air Act provides additional authority to address existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas categorized as mandatory class I federal areas (62 FR 38680-81, July 18, 1997).[M] Figure 2-23 below identifies where each of these parks are located in the U.S. In July 1999 the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory class I federal areas. Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.[N] OGVs, powered by Category 3 engines, contribute to visibility concerns in these areas through their primary $PM_{2.5}$ emissions and their NO_X and SO_X emissions, which contribute to the formation of secondary $PM_{2.5}$.

Figure 2-23 Mandatory Class I Areas in the U.S.

[M] 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.

[N] As mentioned above, the EPA has recently proposed to amend the PM NAAQS (71 FR 2620, Jan. 17, 2006). The proposal would set the secondary NAAQS equal to the primary standards for both $PM_{2.5}$ and $PM_{10-2.5}$. EPA also is taking comment on whether to set a separate $PM_{2.5}$ standard, designed to address visibility (principally in urban areas), on potential levels for that standard within a range of 20 to 30 $\mu g/m^3$, and on averaging times for the standard within a range of four to eight daylight hours.

2.3.4 Ozone Impacts on Plants and Ecosystems

There are a number of environmental or public welfare effects associated with the presence of ozone in the ambient air.[298] In this section, we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

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".[299] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[300] 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.[301,302] If enough tissue becomes damaged from these effects, a plant's capacity to fix carbon to form carbohydrates, which are the primary form of energy used by plants is reduced,[303] while plant respiration increases. 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, leading to reduced growth and/or reproduction. 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.[304,305]

This ozone damage may or may not be accompanied by visible injury on leaves, and likewise, visible foliar injury may or may not be a symptom of the other types of plant damage described above. When visible injury is present, it is commonly manifested as chlorotic or necrotic spots, and/or increased leaf senescence (accelerated leaf aging). Because ozone damage can consist of visible injury to leaves, it can also reduce the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

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 ozone uptake through closure of stomata)[306,307,308] 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.[309]

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.[310,311] 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.[312,313]

Because plants are at the base 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.[314] 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.[315,316,317] 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 United States."[318] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[319,320,321]

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.[322] 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.

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition.[323] In the U.S., ozone in the lower atmosphere is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves.[324]

In the U.S. this indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. As part of its Phase 3 program, formerly known as Forest Health Monitoring, FIA examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. For this indicator, forest land does not include woodlots and urban trees. Sites are selected using a systematic sampling grid, based on a global sampling design.[325,326] At each site that has at least 30 individual plants of at least three ozone-sensitive species and enough open space to ensure that sensitive plants are not protected from ozone exposure by the forest canopy, FIA looks for damage on the foliage of ozone-sensitive forest plant species. Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest.

Monitoring of ozone injury to plants by the USDA Forest Service has expanded over the last 10 years from monitoring sites in 10 states in 1994 to nearly 1,000 monitoring sites in 41 states in 2002. The data underlying this indicator are based on averages of all observations collected in 2002, the latest year for which data are publicly available at the time the study was conducted, and are broken down by EPA Region. Ozone damage to forest plants is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury (visible foliar injury to highly sensitive or moderately sensitive plants, respectively), and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively.[327, 328]

2.3.4.1 Recent Ozone Data for the U.S.

There is considerable regional variation in ozone-related visible foliar injury to sensitive plants in the U.S. The U.S. EPA has developed an environmental indicator based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program which examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country (this indicator does not include woodlots and urban trees). Sites are selected using a systematic sampling grid, based on a global sampling design.[329, 330] Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest. The data underlying the indictor in Figure 2-24 are based on averages of all observations collected in 2002, the latest year for which data are publicly available at the time the study was conducted, and are broken down by U.S. EPA Regions. Ozone damage to forest plants is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury visible foliar injury to highly sensitive or moderately sensitive plants, respectively, and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively.[331]

The highest percentages of observed high and severe foliar injury, those which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Mid-Atlantic and Southeast regions. In EPA Region 3 (which comprises the States of Pennsylvania, West Virginia, Virginia, Delaware, Maryland and Washington D.C.), 12% of ozone-sensitive plants showed signs of high or severe foliar damage, and in Regions 2 (States of New York, New Jersey) and 4 (States of North Carolina, South Carolina, Kentucky, Tennessee, Georgia, Florida,

Alabama, and Mississippi), the values were 10% and 7%, respectively. The sum of high and severe ozone injury ranged from 2% to 4% in EPA Region 1 (the six New England States), Region 7 (States of Missouri, Iowa, Nebraska and Kansas), and Region 9 (States of California, Nevada, Hawaii and Arizona). The percentage of sites showing some ozone damage was about 45% in each of these EPA Regions.

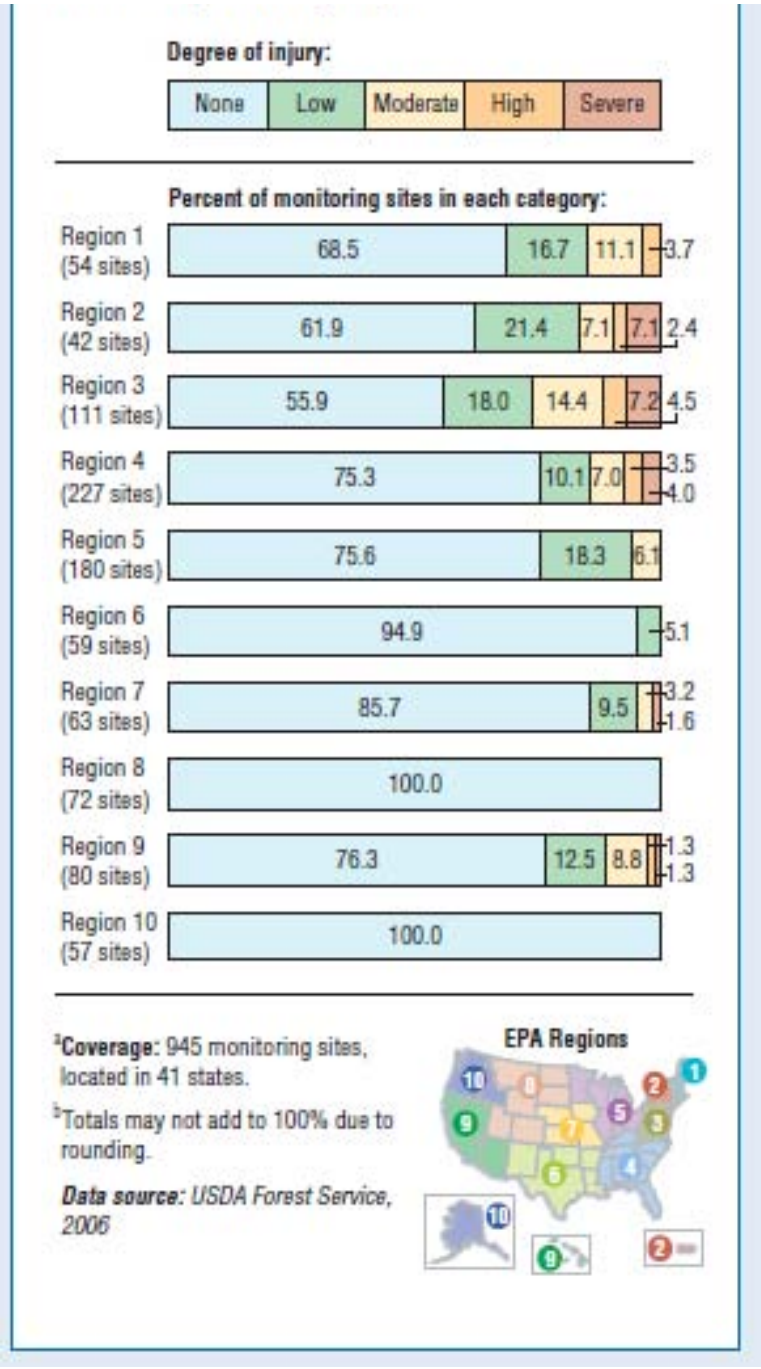


Figure 2-24 Ozone Injury to Forest Plants in U.S. by EPA Regions, 2002[ab]

2.3.4.1.1 Indicator Limitations

Field and laboratory studies were reviewed to identify the forest plant species in each region that are highly sensitive to ozone air pollution. Other forest plant species, or even genetic variants of the same species, may not be harmed at ozone levels that cause effects on the selected ozone-sensitive species.

Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among regions of the U.S.

Ozone damage to foliage is considerably reduced under conditions of low soil moisture, but most of the variability in the index (70%) was explained by ozone concentration.[332] Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury.[333]

Though FIA has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury. Even though the biosite data have been collected over multiple years, most biosites were not monitored over the entire period, so these data cannot provide more than a baseline for future trends.

2.3.4.1.2 Ozone Impacts on Forest Health

Air pollution can impact the environment and affect ecological systems, leading to changes in the biological community (both in the diversity of species and the health and vigor of individual species). As an example, many studies have shown that ground-level ozone reduces the health of plants including many commercial and ecologically important forest tree species throughout the United States.[334]

When ozone is present in the air, it can enter the leaves of plants, where it can cause significant cellular damage. Since photosynthesis occurs in cells within leaves, the ability of the plant to produce energy by photosynthesis can be compromised if enough damage occurs to these cells. If enough tissue becomes damaged, it can reduce carbon fixation and increase plant respiration, leading to reduced growth and/or reproduction in young and mature trees. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stressors (e.g., harsh weather). Because ozone damage can consist of visible injury to leaves, it also reduces the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

Assessing the impact of ground-level ozone on forests in the eastern United States involves understanding the risks to sensitive tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risks to particular plants from ground-level ozone, scientists have developed ozone-exposure/tree-response functions by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." Typically, seedlings are used because they are easy to manipulate and measure their growth loss from ozone pollution. The mechanisms of susceptibility to ozone within the leaves of seedlings and mature trees are identical, and the decreases predicted using

the seedlings should be related to the decrease in overall plant fitness for mature trees, but the magnitude of the effect may be higher or lower depending on the tree species. [335]

Some of the common tree species in the United States that are sensitive to ozone are black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera),* eastern white pine (*Pinus strobus).* Ozone-exposure/tree-response functions have been developed for each of these tree species, as well as for aspen (*Populus tremuliodes*), and ponderosa pine (*Pinus ponderosa*). Other common tree species, such as oak (*Quercus* spp.*)* and hickory (*Carya* spp.), are not nearly as sensitive to ozone. Consequently, with knowledge of the distribution of sensitive species and the level of ozone at particular locations, it is possible to estimate a "biomass loss" for each species across their range.

2.3.4.2 W126 Modeling and Projected Impact of Ship Emissions on U.S. Forests Biomass

To estimate the biomass loss for the tree species listed above across the eastern United States, the biomass loss for each of the five tree species was calculated using the three-month 12-hour W126 exposure metric at each location and its individual ozone-exposure/tree-response functions. The W126 exposure metric was calculated using monitored data from the AQS air quality monitoring sites. This analysis was done for 2020 with and without international shipping emissions to determine the benefit of lowering shipping emissions on these sensitive tree species in the eastern half of the U.S.

The biomass loss in the eastern U.S. attributable to international shipping appears to range from 0-6.5 % depending on the particular species. The most sensitive species in the U.S. to ozone-related biomass loss is black cherry; the area of its range with more than 10% biomass loss in 2020 decreased by 8.5% when emissions from ships were removed. Likewise, Table 2-7 indicates that yellow-poplar, eastern white pine, aspen, and ponderosa pine saw areas with more then 2% biomass loss reduced by 2.1% to 3.8% in 2020. The 2% level of biomass loss is important, because a scientific consensus workshop on ozone effects reported that a 2% annual biomass loss causes long term ecological harm due to the potential for compounding effects over multiple years as short-term negative effects on seedlings affect long-term forest health. [336,337] Figure 2-25 shows ship emissions' adverse impact on U.S. forest biomass loss in 2020.

Table 2-7 The Percent Improvement in Area of the Tree Species Range Between the "Base Case" and "Zero Out" Marine Emissions with Biomass Loss of Greater than 2, 4, 6, and 10% due to Ozone for Year 2020. Units are % Improvement of Area of Species Range.

Tree Species	Percent of Biomass Loss			
	2%	4%	6%	10%
Aspen *Populus tremuloides*	2.4	1.4	0.8	n/a
Black Cherry *Prunus serotina*	n/a	n.c..	2.9	8.5
Ponderosa Pine *Pinus ponderosa*	3.8	2.0	1.5	n/a
Tulip Poplar *Liriodendron tulipifera*	2.1	0.8	n.c.	n/a
E. White Pine *Pinus strobus*	2.8	1.1	0.4	n/a

n.c. - no change in the area
n/a – out of range

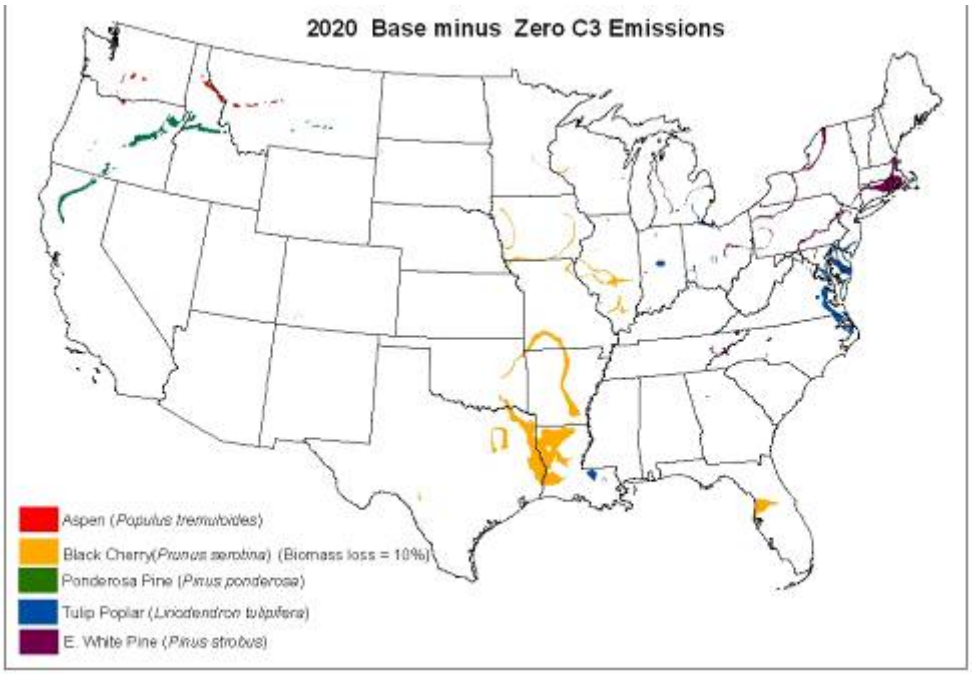


Figure 2-25 U.S. Geographic Areas where the Coordinated Strategy would Reduce Biomass Loss by More than 2%

2.3.4.2.1 Methodology

Outputs from the CMAQ modeling were used to calculate a longer-term ozone exposure metric known as "W126".[338] Previous EPA analyses have concluded that the cumulative, seasonal W126 index is the most appropriate index for relating vegetation response to ambient ozone exposures. The metric is a sigmoidally weighted 3-month sum of all hourly ozone

concentrations observed during the daily 12-hr period between 8 am to 8 pm. The three months are the maximum consecutive three months during the ozone season, defined for this modeling as May through September.

As in the ozone and $PM_{2.5}$ modeling, the CMAQ model was used in a relative sense to estimate how ambient W126 levels would change as a result of future growth and/or emissions reductions associated with our coordinated program. The resultant W126 outputs were fed into a separate model which calculated biomass loss from certain tree species as a result of prolonged exposure to ozone. The results of that analysis are discussed below. The CMAQ modeling estimated that ship emissions contributed to high levels of W126 in some coastal areas. This contribution was estimated to range from as much as 30- to 40% in parts of California and Florida. The average contribution from all ship emissions was 8% nationally.

2.4 Impacts of the Coordinated Strategy on Air Quality

The controls from the coordinated strategy (Section 3.4.3 of the DRIA) would significantly reduce emissions of NO_X, SO_X and PM from C3 vessels. Air quality modeling and monitoring data presented in this section indicate that a large number of people live in counties that are designated as nonattainment for either or both of the $PM_{2.5}$ or 8-hour ozone NAAQS. Figure 2-26 illustrates the widespread nature of the ozone and $PM_{2.5}$ nonattainment areas as well as the mandatory class I federal areas. Air quality modeling was performed for the coordinated strategy which illustrates the changes in ambient concentrations of $PM_{2.5}$ and ozone as well as changes in deposition of nitrogen and sulfur and levels of visibility which are expected to occur with the emission reductions from the coordinated strategy.

Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used to characterize the air quality impacts of the proposal, and the benefits modeling presented in Chapter 6, are slightly different than the coordinated strategy. For example, the 2020 air quality impacts are based on inventory estimates that were modeled using incorrect ECA boundary information off of the western coast of the U.S. A calculation error placed the western 200 nautical mile (nm) ECA boundary approximately 50 nm closer to shore. Additionally, the 2020 air quality control case does not reflect emission reductions related to global controls for areas that are beyond 200 nm but within the CMAQ air quality modeling domain. The impact of these differences is expected to be minimal. In total, while the inventory and air quality modeling discrepancies are modest, they result in a conservative estimate of the 2020 air quality impacts that are presented in this chapter.

The modeling for 2030 was based on inventories that reflected an ECA distance closer to shore than what we are proposing. The air quality modeling for 2030 therefore reflects the impacts associated with approximately 80% of the emission reductions achieved by the coordinated strategy. As a result, the 2030 air quality impacts presented in this chapter should be considered conservative estimates of the improvements in air quality associated with the proposal. For the final RIA, we plan to model the 2030 coordinated strategy to control ship emissions with a 200 nm boundary and global controls beyond.

Please refer to Chapter 3 for a comparison of the inventories used to support the air quality modeling and the inventories of the coordinated strategy.

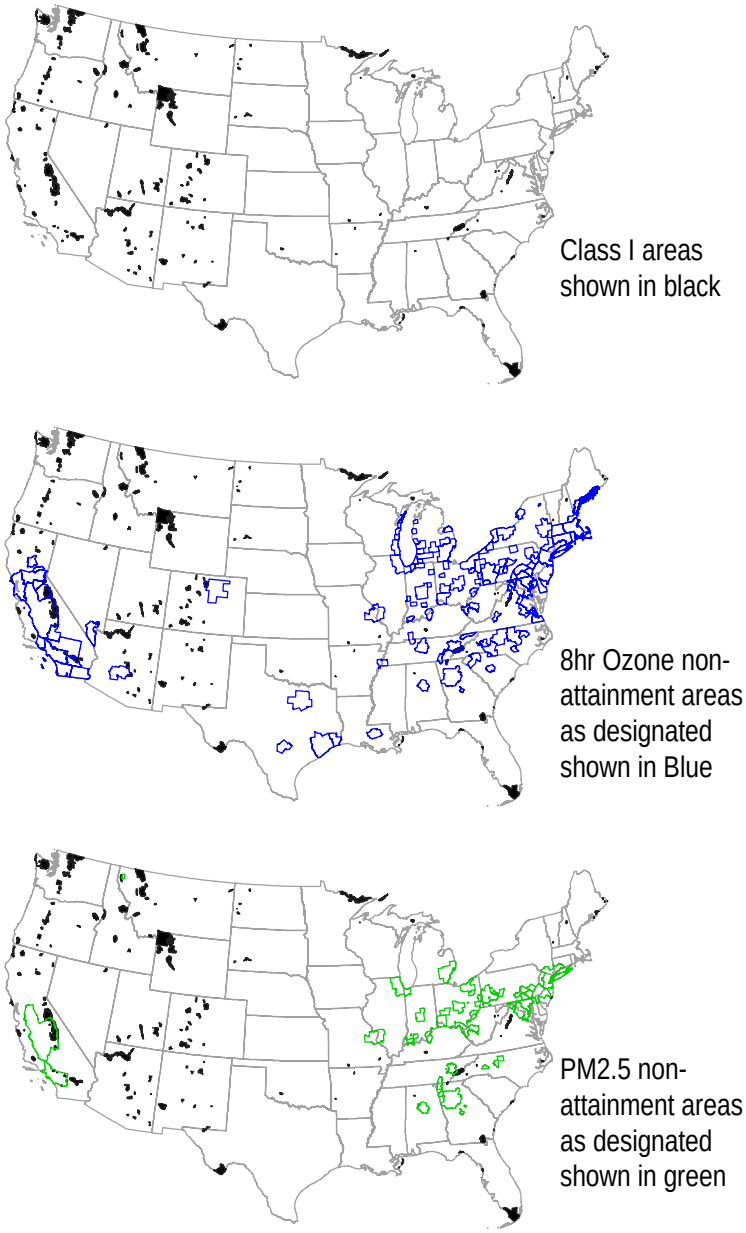


Figure 2-26 PM2.5 and 8-hour Ozone Nonattainment Areas and Mandatory Class I Federal Areas

2.4.1 Particulate Matter

The emission reductions from the coordinated strategy would assist PM nonattainment areas in reaching the standard by each area's respective attainment date and assist PM maintenance areas in maintaining the PM standards in the future. In this section we present information on current and model-projected future PM levels.

2.4.1.1 Current Levels of $PM_{2.5}$

As described in Section 2.2.1, PM causes adverse health effects, and the U.S. Government has set national standards to protect against those health effects. There are two U.S. National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$: an annual standard (15 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$). The most recent revisions to these standards were in 1997 and 2006. In 2005, the U.S. EPA designated nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 19844, April 14, 2005).[O] As of March 4, 2009 there are 39 1997 $PM_{2.5}$ nonattainment areas composed of 208 full or partial counties with a total population exceeding 88 million. Area designations for the 2006 24-hour $PM_{2.5}$ NAAQS are expected to be promulgated in 2009 and become effective 90 days after publication in the Federal Register.

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most 1997 $PM_{2.5}$ nonattainment areas are 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.[339] The 2006 24-hour $PM_{2.5}$ nonattainment areas will be required to attain the 2006 24-hour $PM_{2.5}$ NAAQS in the 2014 to 2019 time frame and then be required to maintain the 2006 24-hour $PM_{2.5}$ NAAQS thereafter.[340] The IMO, the U.S. Government and individual states and local areas have already put in place many $PM_{2.5}$ and $PM_{2.5}$ precursor emission reduction programs. However, C3 vessels are significant contributors to $PM_{2.5}$ in many areas and states will need additional reductions in a timely manner to help them meet their air quality goals. The fuel sulfur emission standards will become effective in 2010 and 2015, and the NO_X engine emission standards will become effective in 2016. Therefore the fuel and engine emission reductions associated with the coordinated strategy will assist $PM_{2.5}$ nonattainment areas in reaching the standard by each area's respective attainment date and/or assist in maintaining the PM standard in the future.

2.4.1.2 Projected Levels of $PM_{2.5}$

In conjunction with the coordinated strategy, we performed a series of 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 C3 fuel and engine controls, 2030 baseline projection, and 2030 baseline projection with C3 fuel and engine controls. Information on the air quality

[O] 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.

modeling methodology is contained in Section 2.4.5. In the following sections we describe projected $PM_{2.5}$ levels in the future, with and without the controls described in this proposed action.

2.4.1.2.1 Projected $PM_{2.5}$ Levels without the Coordinated Strategy

Even with the implementation of all current state and federal regulations, including the Small SI Engine Rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), 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), there are 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 annual $PM_{2.5}$ NAAQS in the future.

The baseline air quality modeling conducted for the coordinated strategy projects that in 2020, with all current controls in effect but excluding the reductions expected to occur as a result of the coordinated strategy, at least 13 counties, with a projected population of nearly 30 million people, may not attain the annual standard of 15 $\mu g/m^3$. Ten of these 13 projected nonattainment areas are in California, which has been shown to be strongly impacted by emissions from C3 vessels. These numbers do not account for additional areas that may have future air quality measurements above the 24-hour standard of 35 $\mu g/m^3$. The numbers also do not account for those areas that are within 10% of the $PM_{2.5}$ standard. These areas, although not violating the standard, will also benefit from the emissions reductions which will help ensure long term maintenance of the $PM_{2.5}$ NAAQS. For example, in 2020, an additional 13 million people are projected to live in 12 counties that have air quality measurements within 10% of the annual $PM_{2.5}$ NAAQS. This modeling supports the conclusion that there are a substantial number of counties across the U.S. projected to experience $PM_{2.5}$ concentrations at or above the $PM_{2.5}$ NAAQS into the future. Emission reductions from C3 vessels will be helpful for these counties in attaining and maintaining the $PM_{2.5}$ NAAQS.

2.4.1.2.2 Projected $PM_{2.5}$ Levels with the Coordinated Strategy

This section summarizes the results of our modeling of $PM_{2.5}$ air quality impacts in the future due to the reductions in C3 vessel emissions described in this proposed action. Specifically, we compare baseline scenarios to scenarios with controls. Our modeling indicates that the reductions from the coordinated strategy will provide nationwide improvements in ambient $PM_{2.5}$ concentrations and minimize the risk of exposures in future years. Since the emission reductions from this rule go into effect during the period when some areas are still working to attain the $PM_{2.5}$ NAAQS, the projected emission reductions will assist state and local agencies in their effort to attain the $PM_{2.5}$ standard and help others maintain the standard.

On a population-weighted basis, the average modeled future-year $PM_{2.5}$ design values would decrease by 0.51 $\mu g/m^3$ in 2020 and 0.98 $\mu g/m^3$ in 2030. In addition, those counties that are projected to be above the 2006 annual $PM_{2.5}$ standard in 2020 and 2030 would have even larger decreases from the emission controls associated with the coordinated strategy. On a population-weighted basis, the average modeled future-year $PM_{2.5}$ design values for counties

whose design values were greater than 15 $\mu g/m^3$ would decrease by 1.56 $\mu g/m^3$ in 2020 and 3.26 $\mu g/m^3$ in 2030. Table 2-8 shows the average change in future year $PM_{2.5}$ design values for: (1) all counties with 2002 baseline design values, (2) counties with baseline design values that exceeded the standard in 2000-2004 ("violating" counties), (3) counties that did not exceed the standard, but were within 10% of it in 2000-2004, (4) counties with future year design values that exceeded the standard, and (5) counties with future year design values that did not exceed the standard, but were within 10% of it in 2020 and 2030. Counties within 10% of the standard are 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 2030, indicating in five different ways the overall improvement in ozone air quality.

Table 2-8 Average Change in Projected Future Year $PM_{2.5}$ Design Value as a Result of the C3 Fuel and Engine Controls

Average[a]	Number of US Counties	Change in 2020 design value ($\mu g/m^3$)	Change in 2030 design value ($\mu g/m^3$)
All	556	-0.22	-0.41
All, population-weighted	556	-0.51	-0.98
Counties whose base year is violating the 2006 annual $PM_{2.5}$ standard	82	-0.28	-0.52
Counties whose base year is violating the 2006 annual $PM_{2.5}$ standard, population-weighted	82	-0.81	-1.68
Counties whose base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard	113	-0.20	-0.34
Counties whose base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard, population-weighted	113	-0.36	-0.60
Counties whose 2020 base year is violating the 2006 annual $PM_{2.5}$ standard	13	-0.99	-1.92
Counties whose 2020 base year is violating the 2006 annual $PM_{2.5}$ standard, population-weighted	13	-1.56	-3.26
Counties whose 2030 base year is violating the 2006 annual $PM_{2.5}$ standard	14	-1.06	-2.03
Counties whose 2030 base year is violating the 2006 annual $PM_{2.5}$ standard, population-weighted	14	-1.57	-3.27
Counties whose 2020 base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard	12	-0.35	-0.62
Counties whose 2020 base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard, population-weighted	12	-0.30	-0.54
Counties whose 2030 base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard	12	-0.29	-0.51
Counties whose 2030 base year is within 10 percent of the 2006 annual $PM_{2.5}$ standard, population-weighted	12	-0.17	-0.30

Note:
[a] Averages are over counties with 2002 modeled design values

Figure 2-27 illustrates the geographic impact of the C3 engine and fuel controls on annual $PM_{2.5}$ design values in 2020. The most significant decreases occur along all of the coastlines with the maximum decrease in a 2020 design value being 3.13 $\mu g/m^3$ in Miami, FL.

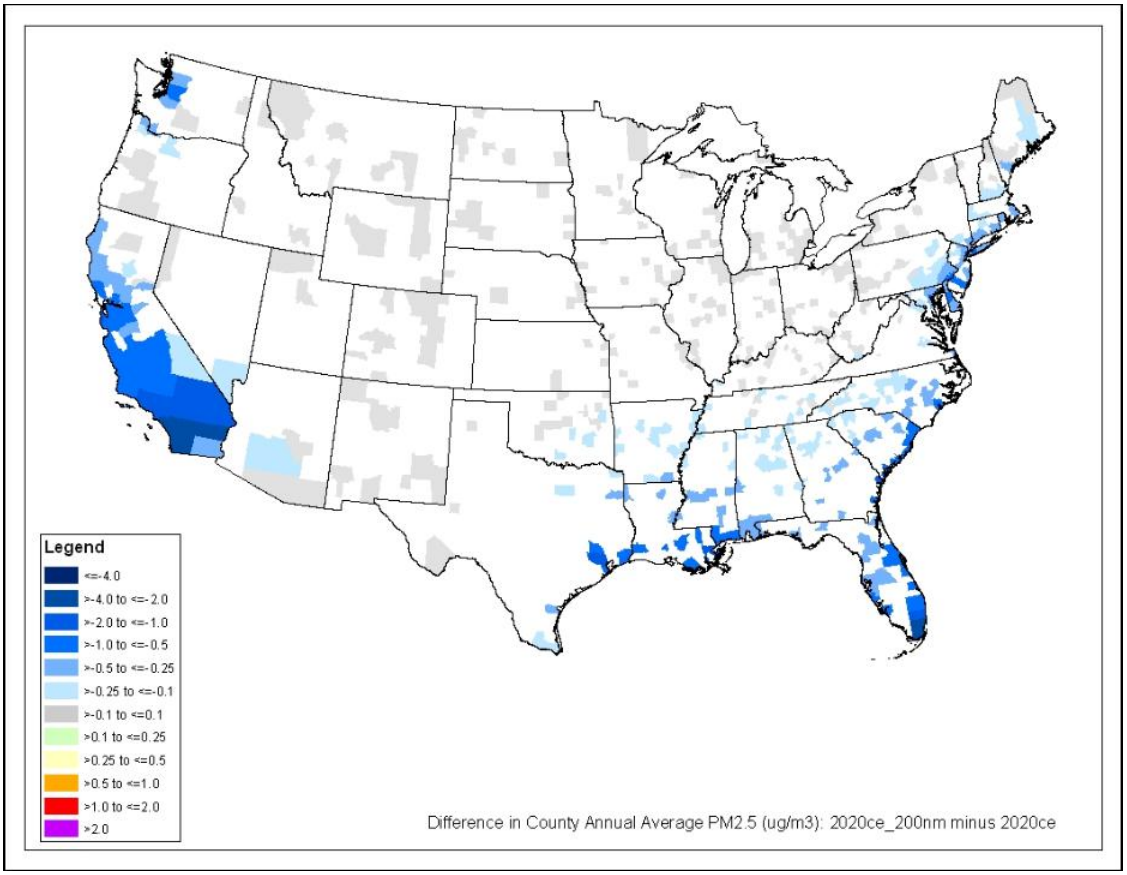


Figure 2-27 Impact of C3 Fuel and Engine Controls on Annual $PM_{2.5}$ Design Values (DV) in 2020 (units are µg/m^3)

Table 2-9 lists the counties with projected annual $PM_{2.5}$ design values that violate or are within 10% of the annual $PM_{2.5}$ standard in 2020 and 2030. 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 2-9. 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 2-9 Counties with 2020 or 2030 Projected Annual $PM_{2.5}$ Design Values in Violation or Within 10% of the Annual $PM_{2.5}$ Standard in the Base and Control Cases

STATE	COUNTY	2000-2004 AVERAGE ANNUAL $PM_{2.5}$ DV ($\mu/^3$)	2020 MODELING PROJECTIONS OF BASE ANNUAL $PM_{2.5}$ DV ($\mu g/m^3$)	2020 MODELING PROJECTIONS OF CONTROL ANNUAL $PM_{2.5}$ DV ($\mu g/m^3$)	2020 PROJECTED POPULATION[341]
Alabama	Jefferson Co	18.37	V	X	681,549
California	Fresno Co	20.03	V	V	1,066,878
California	Imperial Co	14.45	X	X	161,555
California	Kern Co	21.77	V	V	876,131
California	Kings Co	18.77	V	V	173,390
California	Los Angeles Co	23.17	V	V	10,376,013
California	Merced Co	16.48	V	X	277,863
California	Orange Co	18.27	V	V	3,900,599
California	Riverside Co	27.15	V	V	2,252,510
California	San Bernardino Co	24.63	V	V	2,424,764
California	San Diego Co	15.65	V	X	3,863,460
California	San Joaquin Co	14.84	X		743,469
California	Stanislaus Co	16.50	X	X	607,766
California	Tulare Co	21.33	V	V	477,296
California	Ventura Co	14.35	X		1,023,136
Georgia	Fulton Co	18.29	X	X	929,278
Illinois	Cook Co	17.07	X	X	5,669,479
Illinois	Madison Co	17.27	X	X	278,167
Kentucky	Jefferson Co	16.78	X	X	726,257
Michigan	Wayne Co	19.32	V	V	1,908,196
Montana	Lincoln Co	15.85	X	X	20,147
New York	New York Co	17.16	X	X	1,700,384
Ohio	Cuyahoga Co	18.37	X	X	1,326,680
Pennsylvania	Allegheny Co	21.00	V	V	1,242,587
West Virginia	Hancock Co	17.31	X		30,539

2.4.2 Ozone

The emission reductions from the coordinated strategy described in this proposal would also assist ozone nonattainment areas in reaching the standard by each area's respective attainment date as well as assist ozone maintenance areas in maintaining the ozone standards in the future. In this section, we present information on current and model-projected future ozone levels.

2.4.2.1 Current Levels of Ozone

As described in Section 2.2.2, ozone causes adverse health effects, and the U.S. Government has set national standards to protect against those health effects. The national

ambient air quality standard (NAAQS) for ozone is an 8-hour standard set at 0.075 ppm. The most recent revision to this standard was in 2008, the previous 8-hour ozone standard, set in 1997, had been 0.08 ppm. In 2004, the U.S. EPA designated nonattainment areas for the 1997 8-hour ozone NAAQS (69 FR 23858, April 30, 2004).[P] As of March 5, 2009, there are 57 1997 8-hour ozone nonattainment areas composed of 293 full or partial counties with a total population of almost 132 million.[342] Nonattainment designations for the 2008 8-hour ozone standard are expected to be final in March 2010.

States with ozone nonattainment areas are required to take action to bring those areas into compliance in the future. The attainment date assigned to an ozone nonattainment area is based on the area's classification. Most ozone nonattainment areas are required to attain the 1997 8-hour ozone NAAQS in the 2007 to 2013 time frame and then be required to maintain it thereafter.[Q] The attainment dates associated with the potential nonattainment areas based on the 2008 8-hour ozone NAAQS will likely be in the 2013 to 2021 timeframe, depending on the severity of the problem in each area. Table 2-10 provides an estimate, based on 2004-06 air quality data, of the counties with design values greater than the 2008 ozone NAAQS. We expect many of the ozone nonattainment areas will need to adopt additional emissions reduction programs to attain and maintain the ozone NAAQS. The expected NO_X reductions from these proposed standards would be useful to states as they seek to either attain or maintain the ozone NAAQS.

[P] 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.

[Q] 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 requested to be reclassified as an extreme nonattainment area which will make their attainment date June 15, 2024. The San Joaquin Valley Air Basin 8-hour ozone nonattainment area is designated as serious and will have to attain before June 15, 2013. The San Joaquin Valley Air Basin has requested to be reclassified as an extreme nonattainment area which will make their attainment date June 15, 2024.

Table 2-10 Counties with Design Values Greater Than the 2008 Ozone NAAQS Based on 2005-2007 Air Quality Data

	Number of Counties	Population[a]
1997 Ozone Standard: counties within the 57 areas currently designated as nonattainment	293	131,977,890
2008 Ozone Standard: additional counties that would not meet the 2008 NAAQS[b]	227	41,285,262
Total	520	173,263,152

Notes:
[a] Population numbers are from 2000 census data.
[b] Attainment designations for the 2008 ozone NAAQS have not yet been made. Nonattainment for the 2008 Ozone NAAQS will be based on three years of air quality data from later years. Also, the county numbers in the table include only the counties with monitors violating the 2008 Ozone NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

2.4.2.2 Projected Levels of Ozone

In conjunction with the coordinated strategy, we performed a series of air quality modeling simulations for the continental U.S. (described further in Section 3.4.3 of the DRIA). The model simulations were performed for several emissions scenarios including the following: 2002 baseline projection, 2020 baseline projection, 2020 baseline projection with C3 fuel and engine controls, 2030 baseline projection, and 2030 baseline projection with C3 fuel and engine controls. Information on the air quality modeling methodology is contained in Section 2.4.5. In the following sections, we describe our modeling of 8-hour ozone levels in the future with and without the controls described in this proposed action.

2.4.2.2.1 Projected Ozone Levels without the Coordinated Strategy

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), 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, 8-hour ozone levels are expected to improve in the future.

The baseline air quality modeling conducted for the coordinated strategy projects that in 2020, with all current controls in effect but excluding the reductions achieved through the coordinated strategy, up to 50 counties, with a population of almost 50 million people, may not attain the 8-hour standard of 0.075 ppm. These numbers do not account for those areas that are within 10% of the 2008 ozone standard. These areas, although not violating the standards, will also benefit from the additional reductions from this rule, ensuring long term maintenance of the ozone NAAQS. For example, in 2020, an additional 80 million people are projected to live in 135 counties that have air quality measurements within 10% of the 2008 ozone NAAQS. This modeling supports the conclusion that there are a substantial number of counties across the U.S. projected to experience 8-hour ozone concentrations at or above the ozone NAAQS into the future. Emission reductions from C3 vessels will be helpful for these counties in attaining and maintaining the ozone NAAQS.

2.4.2.2.2 Projected Ozone Levels with the Coordinated Strategy

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the reductions in C3 vessel emissions proposed in this action. Specifically, we compare baseline scenarios to scenarios with controls (Section 2.4.2.2 and 3.4.3 of the DRIA). Our modeling indicates that the reductions from this rule will provide nationwide improvements in ambient ozone concentrations and minimize the risk of exposures in future years. Since some of the 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.[343,344]

On a population-weighted basis, the average modeled future-year 8-hour ozone design values will decrease by 0.30 ppb in 2020 and 0.95 ppb in 2030. In addition, those counties that are projected to be above the 2008 ozone standard in 2020 and 2030 would have even larger decreases from these proposed controls. On a population-weighted basis, the average modeled future-year 8-hour ozone design values for counties whose design values were greater than 75 ppb would decrease by 0.46 ppb in 2020 and 1.58 ppb in 2030. Table 2-11 shows the average change in future year 8-hour ozone design values for: (1) all counties with 2002 baseline design values, (2) counties with baseline design values that exceeded the standard in 2000-2004 ("violating" counties), (3) counties that did not exceed the standard, but were within 10% of it in 2000-2004, (4) counties with future year design values that exceeded the standard, and (5) counties with future year design values that did not exceed the standard, but were within 10% of it in 2020 and 2030. Counties within 10% of the standard are 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 2030, indicating in five different ways the overall improvement in ozone air quality.

Table 2-11 Average Change in Projected Future Year 8-hour Ozone Design Value as a Result of the C3 Fuel and Engine Controls

Average[a]	Number of US Counties	Change in 2020 design value[b] (ppb)	Change in 2030 design value[b] (ppb)
All	661	-0.22	-0.66
All, population-weighted	661	-0.30	-0.95
Counties whose base year is violating the 2008 8-hour ozone standard	497	-0.21	-0.64
Counties whose base year is violating the 2008 8-hour ozone standard, population-weighted	497	-0.27	-0.85
Counties whose base year is within 10 percent of the 2008 8-hour ozone standard	99	-0.21	-0.64
Counties whose base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted	99	-0.29	-0.85
Counties whose 2020 base year is violating the 2008 8-hour ozone standard	50	-0.52	-1.61
Counties whose 2020 base year is violating the 2008 8-hour ozone standard, population-weighted	50	-0.46	-1.48
Counties whose 2030 base year is violating the 2008 8-hour ozone standard	33	-0.61	-1.92
Counties whose 2030 base year is violating the 2008 8-hour ozone standard, population-weighted	33	-0.49	-1.58
Counties whose 2020 base year is within 10 percent of the 2008 8-hour ozone standard	135	-0.30	-0.90
Counties whose 2020 base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted	135	-0.24	-0.75
Counties whose 2030 base year is within 10 percent of the 2008 8-hour ozone standard	105	-0.38	-1.14
Counties whose 2030 base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted	105	-0.27	-0.82

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.

Figure 2-28 illustrates the geographic impact of the C3 engine and fuel controls on 8-hour ozone design values in 2020. The most significant decreases occur along all of the coastlines with the maximum decrease in a 2020 design value being 2.0 ppb in Bristol, Massachusetts. As can be seen from Table 2-11 and Figure 2-28 the air quality modeling performed for the coordinated strategy indicates that the C3 engine standards provide improvements in ozone

levels for the vast majority of areas. However, there are two counties in Washington, Clallam County (0.7 ppb) and Clark County (0.2 ppb), and two counties in southern California, Orange County (3.0 ppb) and San Bernardino County (0.1 ppb), which will experience 8-hour ozone design value increases in 2030 due to the NO_X disbenefits which occur in these VOC-limited ozone nonattainment areas.

While the impact of the C3 engine and fuel controls would reduce ozone levels generally and provide national ozone-related health benefits, this is not always the case at the local level. The air quality modeling projects that in a few areas ozone levels will get higher because of the NO_X disbenefit phenomenon. 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 NO_X 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 NO_X 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.[345] It is important to note the following as well: there is a level of NO_X control where enough NO_X will have been reduced to result in decreases in ambient ozone concentrations, this modeling does not include future VOC or NO_X controls that local areas are planning, and reductions in NO_X are not only important to help reduce ozone but also to help reduce $PM_{2.5}$.

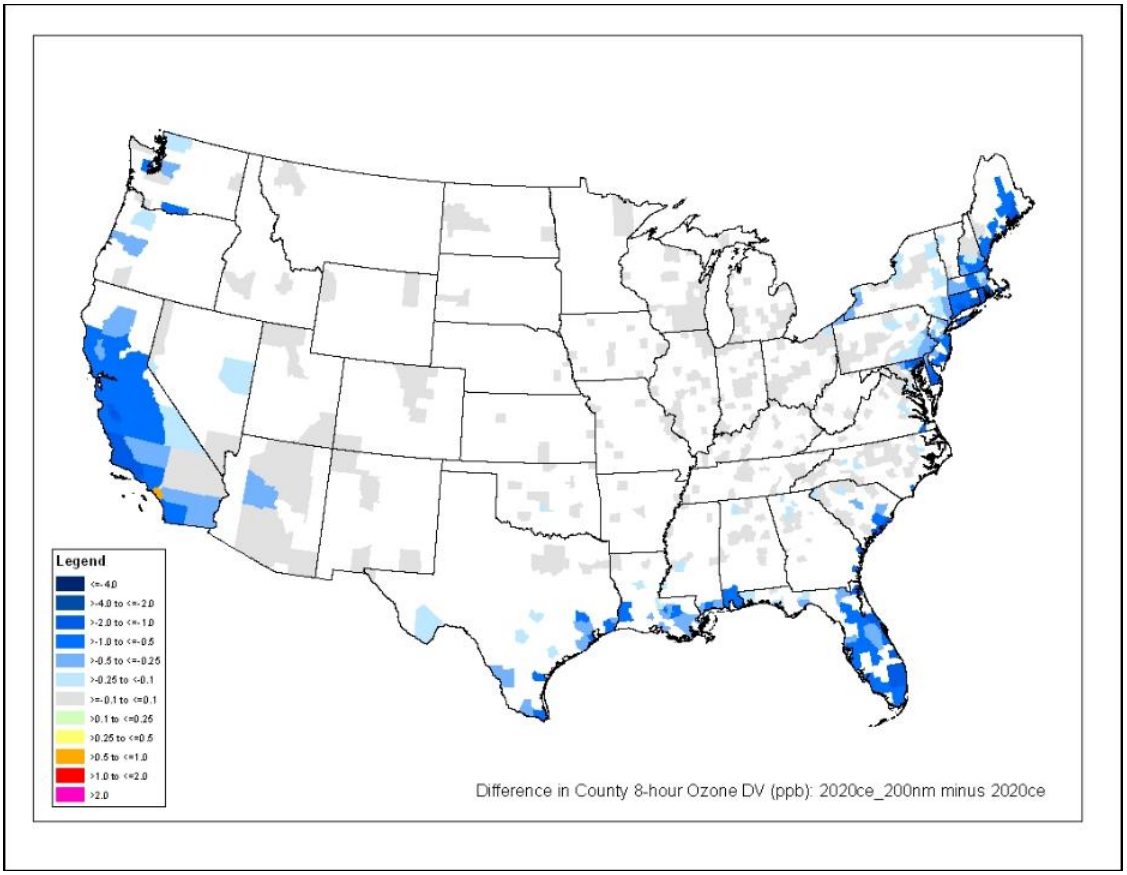


Figure 2-28 Impact of C3 Fuel and Engine Controls on 8-hour Ozone Design Values in 2020 (units are ppb)

2.4.3 Deposition of Nitrogen and Sulfur

2.4.3.1 Current Levels of Nitrogen and Sulfur Deposition

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 17 years although many areas continue to be negatively impacted by deposition. Deposition of inorganic nitrogen and sulfur species routinely measured in the U.S. between 2004 and 2006 were as high as 9.6 kg N/ha/yr and 21.3 kg S/ha/yr. Figures 2-29 and 2-30 show that annual total deposition (the sum of wet and dry deposition) decreased between 1989-1999 and 2004-2006 due to sulfur and NO_X controls on power plants, motor vehicles and fuels in the U.S. The data shows that reductions were more substantial for sulfur compounds than for nitrogen compounds. These numbers are generated by the U.S. national monitoring network and they likely underestimate nitrogen deposition because NH_3 is not measured. In the eastern U.S., where data are most abundant, total sulfur deposition decreased by about 36 % between 1990 and 2005 while total nitrogen deposition decreased by 19% over the same time frame.[346]

The EPA is concerned that both current ship emissions and projected future ship emissions will seriously erode environmental improvements that have been achieved in these ecologically sensitive areas. As the air quality modeling results in Section 2.4.3.2 show, both

nitrogen and sulfur deposition resulting from ship emissions impact a significant portion of ecologically sensitive areas in the U.S.

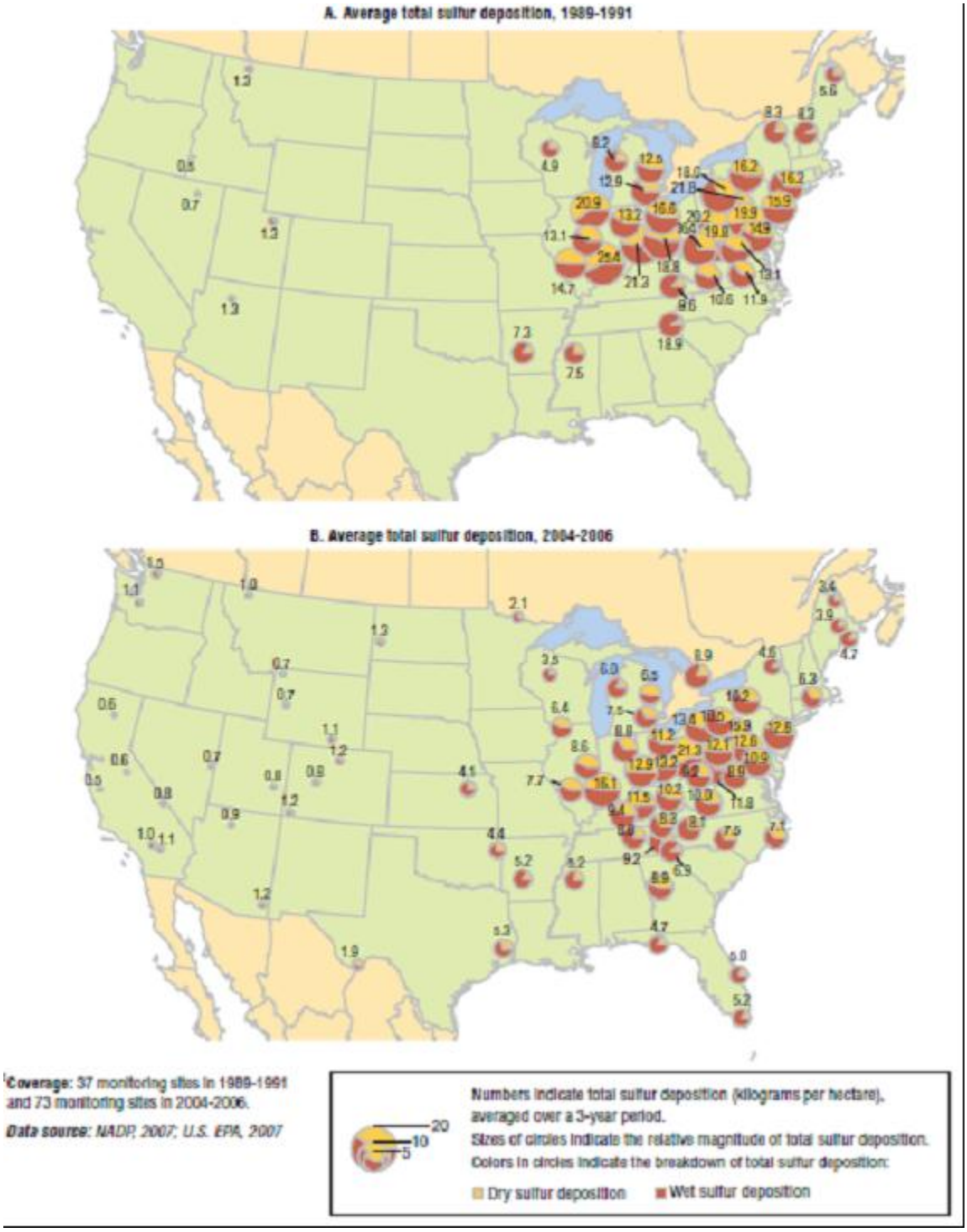


Figure 2-29 Total Sulfur Deposition in the Contiguous U.S., 1989-1991 and 2004 -2006

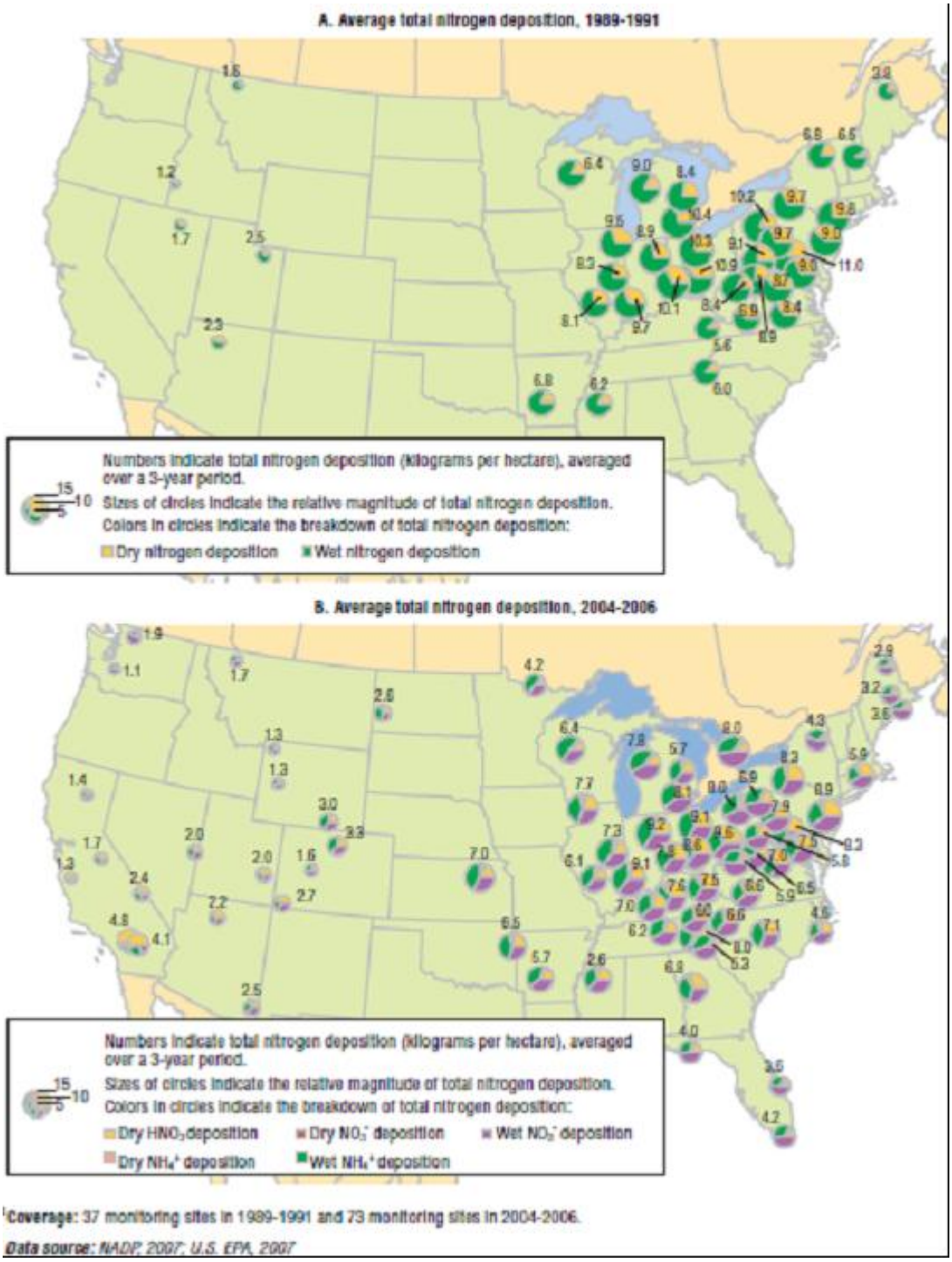


Figure 2-30 Total Nitrogen Deposition in the Contiguous U.S., 1989-1991 and 2004-2006

2.4.3.2 Projected Levels of Nitrogen and Sulfur Deposition

If the coordinated strategy were adopted, reductions in nitrogen deposition would result by 2020, benefiting many sensitive ecological areas throughout the U.S. Areas benefiting are described in detail in Section 2.3.1.1 and include sensitive forests, wetlands such as freshwater bogs and marshes, lakes and streams throughout the entire U.S. Figure 2-31 illustrates the nitrogen deposition reductions that would occur along U.S. coastlines in 2020 as well as reductions occurring within the interior of the U.S. Reductions would range from 3% to 7% along the entire Atlantic and Gulf Coasts while along the Pacific Coast nitrogen deposition reductions would be higher, ranging from 3% to 13%.

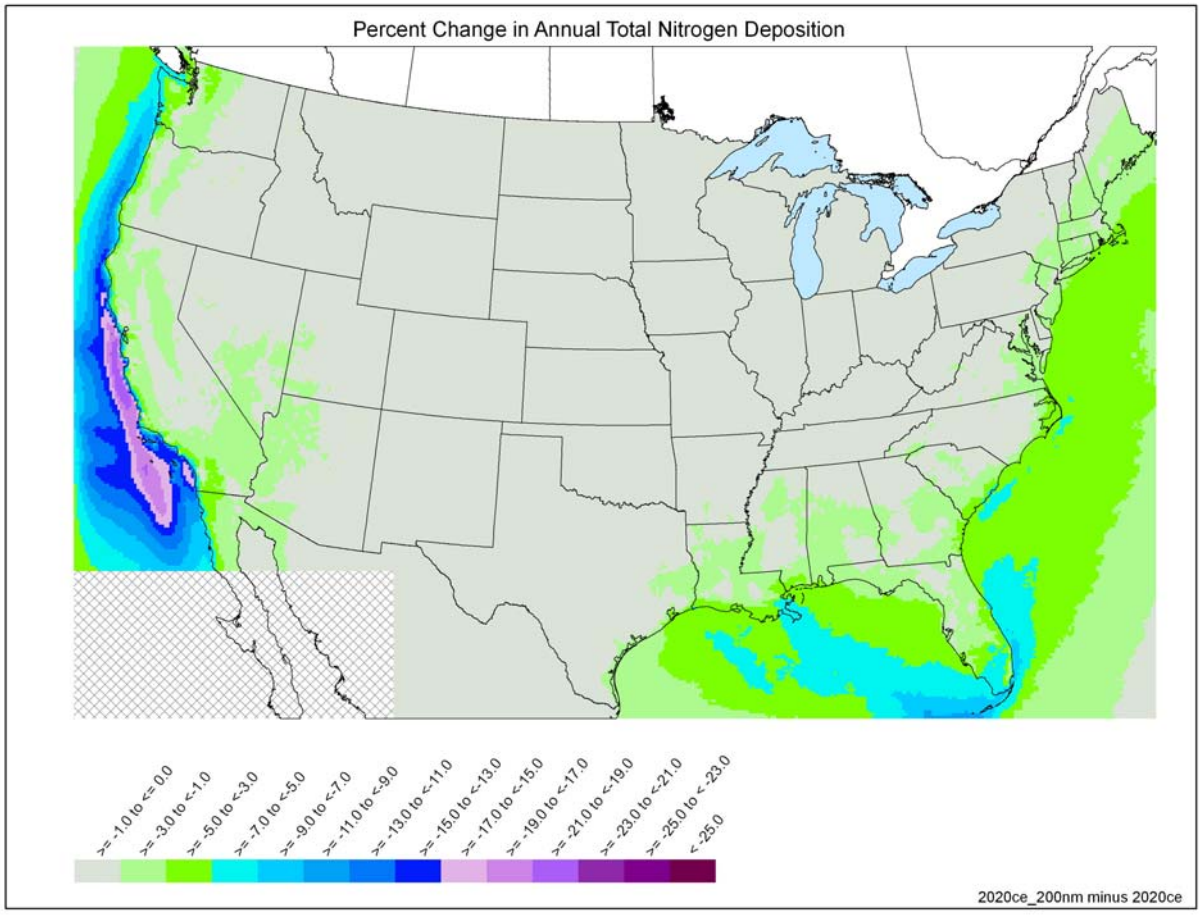


Figure 2-31 Percent Change in Annual Total Nitrogen over the U.S. Modeling Domain

With respect to sulfur deposition, adopting the coordinated strategy would result in reducing sulfur deposition levels in 2020; in some regions by more than 25%. Figure 2-32 illustrates the sulfur deposition reductions occurring throughout the U.S. In some individual U.S. watersheds, consisting of offshore islands or close to coastal areas, sulfur deposition levels would be reduced by up to 80%. More generally, the Northeast Atlantic Coastal region would experience sulfur deposition reductions from C3 vessels ranging from 7% to 25% while the Southeast Atlantic Coastal region would experience reductions ranging from 7% to more than 25%. Sulfur deposition would be reduced in the Gulf Coast region from 3% to more than 25%.

Along the West Coast of the U.S. sulfur deposition reductions exceeding 25% would occur in the entire Los Angeles Basin in the State of California. The Pacific Northwest would also see significant sulfur deposition reductions ranging from 4% to more than 25%. The Great Lakes would experience reductions of 1-3%. As importantly, sulfur deposition reductions due to the coordinated strategy would also impact the entire U.S. land mass with even interior sections of the U.S. experiencing reductions of 1%. Together, these reductions would assist the U.S. in its efforts to reduce acidification impacts associated with nitrogen and sulfur depositions in both terrestrial and aquatic ecosystems in coastal areas of the U.S. as well as within the interior of the U.S.

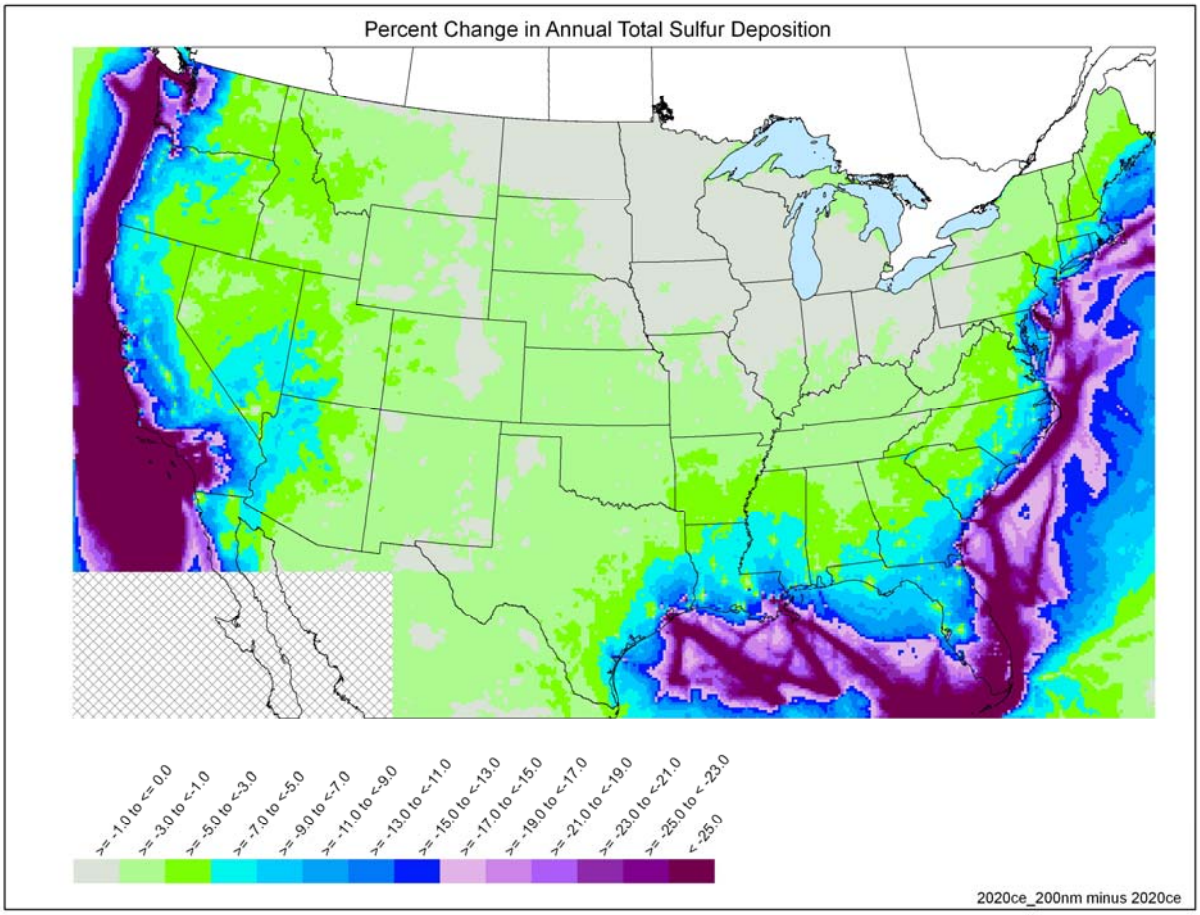


Figure 2-32 Percent Change in Annual Total Sulfur over the U.S. Modeling Domain

Appendix 3B presents the range as well as the average total nitrogen and total sulfur deposition changes in 2020 for CMAQ modeling scenarios over 18 specific U.S. subregions. In the case of the coordinated strategy, sulfur deposition levels were reduced by on average from 0 to 19% over these large drainage regions. In individual hydrological unit codes (HUCs) consisting of offshore islands or close to coastal areas, sulfur deposition levels in 2020 were improved by as much as 78% while nitrogen deposition levels were improved by as much as 13% in some coastal areas.

2.4.4 Visibility Degradation

2.4.4.1 Current Visibility Levels

Recently designated $PM_{2.5}$ nonattainment areas indicate that, as of December 2008, over 88 million people live in nonattainment areas for the 1997 $PM_{2.5}$ NAAQS. Thus, at least these populations would likely be experiencing visibility impairment, as well as many thousands of individuals who travel to these areas. In addition, while visibility trends have improved in mandatory class I federal areas, the most recent data show that these areas continue to suffer from visibility impairment. In eastern parks, average visual range has decreased from 90 miles to 15-25 miles. In the West, visual range has decreased from 140 miles to 35-90 miles. In summary, visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote mandatory class I federal areas.[347,348] The mandatory federal class I areas are listed in Figure 2-23 and in Table 2-12.

2.4.4.2 Projected Visibility Levels

Based on modeling for the coordinated strategy, international shipping activities in 2002 contributed to visibility degradation at all 133 mandatory class I federal areas monitored by the U.S. Government. Absent further emission controls, by 2020, international shipping activities will have an even larger impact on visibility impairment in these class I federal areas. The results suggest that controlling emissions from C3 vessels would result in improved visibility in all 133 class I federal areas, although areas would continue to have annual average deciview (DV) levels above background in 2020.

The results indicate that reductions in regional haze would occur in all 133 of the areas analyzed as a result of an ECA adoption. The model projects that for all mandatory class I federal areas combined, average visibility on the 20% worst days at these scenic locales would improve by 0.21 deciviews,[R] or 1.2%. The greatest improvement in visibilities would be seen in coastal areas. For instance, the Agua Tibia Wilderness area (near Los Angeles) would see a 9% improvement (2.17 DV) in 2020. National parks and national wilderness areas in other parts of the country would also see improvements as a result of the controls from the coordinated strategy. For example, the Cape Romain National Wildlife Refuge (South Carolina) would see a 5% improvement in visibility (1.16 DV); and Acadia National Park (Maine) would see a 4% improvement (0.76 DV) with a 200 nm ECA. Likewise, in 2002, about 3% of visibility impairment in southern Florida's Everglades National Park was due to international shipping (0.61 DV), and this will double to 6% (1.35 DV) by 2020. Even in inland class I federal areas, international shipping activity is contributing to visibility degradation. In 2020, about 2.5% (0.28 DV) of visibility degradation in the Grand Canyon National Park located in the state of Arizona will be from international shipping, while almost 6% (0.81 DV) of visibility degradation

[R] The level of visibility impairment in an area is based on the light-extinction coefficient and a unit less 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.

in the State of Washington's North Cascades National Park will be from international shipping emissions. Table 2-12 which follows contains the full visibility results from three 2020 scenarios over the 133 analyzed areas.

Table 2-12 Visibility Levels in Deciviews for Individual U.S. Class I Areas on the 20% Worst Days for Several Scenarios

CLASS 1 AREA (20% WORST DAYS)	STATE	BASELINE VISIBILITY	2020 BASE	200NM CONT-ROL	ZERO C3 EMISSIONS	NATURAL BACKGROUND
Sipsey Wilderness	AL	29.03	23.67	23.42	23.32	10.99
Caney Creek Wilderness	AR	26.36	22.20	22.01	21.88	11.58
Upper Buffalo Wilderness	AR	26.27	22.25	22.15	22.11	11.57
Chiricahua NM	AZ	13.43	13.15	13.07	13.00	7.21
Chiricahua Wilderness	AZ	13.43	13.17	13.09	13.02	7.21
Galiuro Wilderness	AZ	13.43	13.18	13.09	13.00	7.21
Grand Canyon NP	AZ	11.66	11.24	11.04	10.96	7.14
Mazatzal Wilderness	AZ	13.35	12.88	12.73	12.61	6.68
Petrified Forest NP	AZ	13.21	12.88	12.76	12.70	6.49
Pine Mountain Wilderness	AZ	13.35	12.74	12.59	12.48	6.68
Saguaro NM	AZ	14.83	14.39	14.31	14.22	6.46
Sierra Ancha Wilderness	AZ	13.67	13.33	13.21	13.10	6.59
Sycamore Canyon Wilderness	AZ	15.25	15.00	14.90	14.84	6.69
Agua Tibia Wilderness	CA	23.50	22.99	20.82	20.11	7.64
Caribou Wilderness	CA	14.15	13.73	13.51	13.43	7.31
Cucamonga Wilderness	CA	19.94	18.34	17.57	17.27	7.06
Desolation Wilderness	CA	12.63	12.29	12.11	12.07	6.12
Dome Land Wilderness	CA	19.43	18.59	18.23	18.14	7.46
Emigrant Wilderness	CA	17.63	17.35	17.14	17.08	7.64
Hoover Wilderness	CA	12.87	12.79	12.68	12.65	7.91
Joshua Tree NM	CA	19.62	17.95	17.30	17.21	7.19
Lassen Volcanic NP	CA	14.15	13.71	13.46	13.37	7.31
Lava Beds NM	CA	15.05	14.47	14.32	14.24	7.86

Mokelumne Wilderness	CA	12.63	12.40	12.21	12.16	6.12
Pinnacles NM	CA	18.46	17.86	17.11	16.89	7.99
Point Reyes NS	CA	22.81	22.38	21.71	21.54	15.77
Redwood NP	CA	18.45	18.26	17.81	17.48	13.91
San Gabriel Wilderness	CA	19.94	17.92	17.12	16.84	7.06
San Gorgonio Wilderness	CA	22.17	20.66	20.45	20.35	7.30
San Jacinto Wilderness	CA	22.17	20.25	19.86	19.55	7.30
South Warner Wilderness	CA	15.05	14.70	14.57	14.51	7.86
Thousand Lakes Wilderness	CA	14.15	13.68	13.42	13.33	7.31
Ventana Wilderness	CA	18.46	18.36	17.72	17.57	7.99
Yosemite NP	CA	17.63	17.32	17.13	17.08	7.64
Black Canyon of the Gunnison NM	CO	10.33	9.77	9.69	9.66	6.24
Eagles Nest Wilderness	CO	9.61	9.05	9.00	8.98	6.54
Flat Tops Wilderness	CO	9.61	9.25	9.20	9.18	6.54
Great Sand Dunes NM	CO	12.78	12.41	12.36	12.34	6.66
La Garita Wilderness	CO	10.33	9.91	9.84	9.81	6.24
Maroon Bells-Snowmass Wilderness	CO	9.61	9.23	9.19	9.16	6.54
Mesa Verde NP	CO	13.03	12.42	12.33	12.28	6.83
Mount Zirkel Wilderness	CO	10.52	10.02	9.99	9.98	6.44
Rawah Wilderness	CO	10.52	10.00	9.97	9.95	6.44
Rocky Mountain NP	CO	13.83	13.09	13.06	13.05	7.24
Weminuche Wilderness	CO	10.33	9.88	9.80	9.77	6.24
West Elk Wilderness	CO	9.61	9.20	9.15	9.12	6.54
Chassahowitzka	FL	26.09	22.37	21.97	21.75	11.21
Everglades NP	FL	22.30	21.75	21.14	20.40	12.15
St. Marks	FL	26.03	22.37	21.96	21.65	11.53
Cohutta Wilderness	GA	30.30	23.29	23.13	23.07	11.14
Okefenokee	GA	27.13	23.86	23.30	23.07	11.44

Wolf Island	GA	27.13	23.76	22.97	22.75	11.44
Craters of the Moon NM	ID	14.00	13.00	12.97	12.94	7.53
Sawtooth Wilderness	ID	13.78	13.66	13.63	13.61	6.43
Mammoth Cave NP	KY	31.37	25.43	25.33	25.30	11.08
Acadia NP	ME	22.89	20.55	19.79	19.62	12.43
Moosehorn	ME	21.72	19.02	18.55	18.38	12.01
Roosevelt Campobello International Park	ME	21.72	19.25	18.58	18.23	12.01
Isle Royale NP	MI	20.74	18.99	18.84	18.81	12.37
Seney	MI	24.16	21.54	21.49	21.47	12.65
Voyageurs NP	MN	19.27	17.55	17.52	17.51	12.06
Hercules-Glades Wilderness	MO	26.75	22.84	22.74	22.72	11.30
Anaconda-Pintler Wilderness	MT	13.41	13.14	13.10	13.07	7.43
Bob Marshall Wilderness	MT	14.48	14.13	14.11	14.09	7.74
Cabinet Mountains Wilderness	MT	14.09	13.55	13.50	13.47	7.53
Gates of the Mountains Wilderness	MT	11.29	10.90	10.87	10.85	6.45
Medicine Lake	MT	17.72	16.20	16.18	16.17	7.90
Mission Mountains Wilderness	MT	14.48	14.02	13.99	13.97	7.74
Scapegoat Wilderness	MT	14.48	14.15	14.12	14.11	7.74
Selway-Bitterroot Wilderness	MT	13.41	13.08	13.02	12.98	7.43
UL Bend	MT	15.14	14.65	14.63	14.62	8.16
Linville Gorge Wilderness	NC	28.77	22.63	22.43	22.34	11.22
Swanquarter	NC	25.49	21.79	21.11	20.99	11.94
Lostwood	ND	19.57	17.45	17.43	17.41	8.00
Theodore Roosevelt NP	ND	17.74	16.44	16.42	16.41	7.79
Great Gulf Wilderness	NH	22.82	19.53	19.34	19.29	11.99
Presidential Range-Dry River Wilderness	NH	22.82	19.53	19.33	19.28	11.99
Brigantine	NJ	29.01	25.27	24.46	24.31	12.24
Bandelier NM	NM	12.22	11.45	11.39	11.36	6.26

Bosque del Apache	NM	13.80	12.93	12.89	12.87	6.73
Gila Wilderness	NM	13.11	12.59	12.52	12.48	6.69
Pecos Wilderness	NM	10.41	10.00	9.93	9.90	6.44
Salt Creek	NM	18.03	16.70	16.66	16.63	6.81
San Pedro Parks Wilderness	NM	10.17	9.52	9.44	9.41	6.08
Wheeler Peak Wilderness	NM	10.41	9.91	9.85	9.82	6.44
White Mountain Wilderness	NM	13.70	12.87	12.82	12.79	6.86
Jarbidge Wilderness	NV	12.07	11.88	11.81	11.78	7.87
Wichita Mountains	OK	23.81	20.45	20.31	20.24	7.53
Crater Lake NP	OR	13.74	13.33	13.20	13.13	7.84
Diamond Peak Wilderness	OR	13.74	13.26	13.11	13.03	7.84
Eagle Cap Wilderness	OR	18.57	17.73	17.69	17.65	8.92
Gearhart Mountain Wilderness	OR	13.74	13.41	13.30	13.25	7.84
Hells Canyon Wilderness	OR	18.55	17.16	17.12	17.07	8.32
Kalmiopsis Wilderness	OR	15.51	15.24	14.85	14.66	9.44
Mount Hood Wilderness	OR	14.86	14.30	13.93	13.64	8.44
Mount Jefferson Wilderness	OR	15.33	14.90	14.62	14.46	8.79
Mount Washington Wilderness	OR	15.33	14.88	14.62	14.46	8.79
Mountain Lakes Wilderness	OR	13.74	13.28	13.14	13.07	7.84
Strawberry Mountain Wilderness	OR	18.57	17.71	17.66	17.62	8.92
Three Sisters Wilderness	OR	15.33	14.93	14.69	14.54	8.79
Cape Romain	SC	26.48	23.51	22.35	22.14	12.12
Badlands NP	SD	17.14	15.63	15.59	15.57	8.06
Wind Cave NP	SD	15.84	14.78	14.75	14.73	7.71
Great Smoky Mountains NP	TN	30.28	24.01	23.81	23.72	11.24
Joyce-Kilmer-Slickrock Wilderness	TN	30.28	23.56	23.35	23.26	11.24
Big Bend NP	T_X	17.30	16.25	16.11	16.01	7.16
Carlsbad Caverns NP	T_X	17.19	16.05	15.98	15.93	6.68

Guadalupe Mountains NP	T_X	17.19	16.03	15.95	15.90	6.68
Arches NP	UT	11.24	10.94	10.86	10.83	6.43
Bryce Canyon NP	UT	11.65	11.41	11.28	11.22	6.86
Canyonlands NP	UT	11.24	10.96	10.90	10.89	6.43
Zion NP	UT	13.24	12.91	12.80	12.73	6.99
James River Face Wilderness	VA	29.12	23.31	23.16	23.12	11.13
Shenandoah NP	VA	29.31	22.77	22.61	22.57	11.35
Lye Brook Wilderness	VT	24.45	21.02	20.77	20.72	11.73
Alpine Lake Wilderness	WA	17.84	16.85	16.56	16.26	8.43
Glacier Peak Wilderness	WA	13.96	13.85	13.53	13.19	8.01
Goat Rocks Wilderness	WA	12.76	12.23	11.95	11.70	8.36
Mount Adams Wilderness	WA	12.76	12.16	11.88	11.67	8.36
Mount Rainier NP	WA	18.24	17.47	17.02	16.66	8.55
North Cascades NP	WA	13.96	13.85	13.46	13.04	8.01
Olympic NP	WA	16.74	16.18	15.87	15.39	8.44
Pasayten Wilderness	WA	15.23	14.89	14.82	14.72	8.26
Dolly Sods Wilderness	WV	29.04	22.46	22.31	22.26	10.39
Otter Creek Wilderness	WV	29.04	22.45	22.30	22.26	10.39
Bridger Wilderness	WY	11.12	10.83	10.78	10.76	6.58
Fitzpatrick Wilderness	WY	11.12	10.87	10.81	10.79	6.58
Grand Teton NP	WY	11.76	11.37	11.32	11.30	6.51
North Absaroka Wilderness	WY	11.45	11.17	11.14	11.13	6.86
Red Rock Lakes	WY	11.76	11.45	11.40	11.38	6.51
Teton Wilderness	WY	11.76	11.43	11.38	11.36	6.51
Washakie Wilderness	WY	11.45	11.19	11.16	11.15	6.86
Yellowstone NP	WY	11.76	11.40	11.35	11.33	6.51

2.4.5 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 is included in the AQM TSD for the coordinated strategy.[349]

2.4.5.1 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, nitrogen and sulfur deposition, and visibility levels. The 2002-based CMAQ modeling platform was used as the tool for the air quality modeling of future baseline emissions and control scenarios for the coordinated strategy. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to changes in emissions, meteorology, and/or model formulation. The base year of data used to construct this platform includes emissions and meteorology for 2002. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

The CMAQ modeling system is a non-proprietary comprehensive three-dimensional, grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations and deposition, over regional and urban spatial scales for given input sets of meteorological conditions and emissions.[350,351,352] CMAQ is a publicly available, peer reviewed,[S] state-of-the-science model consisting of a number of science attributes that are critical for simulating the oxidant precursors and non-linear organic and inorganic chemical relationships associated with the formation of sulfate, nitrate, and organic aerosols. CMAQ also simulates the transport and removal of directly emitted particles which are speciated as elemental carbon, crustal material, nitrate, sulfate, and organic aerosols. The CMAQ model version 4.6 was most recently peer-reviewed in February of 2007 for the U.S. EPA as reported in the "Third Peer Review of the CMAQ Model."[353]**{** XE "Seigneur et al., 1999" **}** The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[354,355,356]

This 2002 multi-pollutant modeling platform used the latest publicly-released CMAQ version 4.6[T] with a few minor changes and new features made internally by the U.S. EPA CMAQ model developers, all of which reflects updates to earlier versions in a number of areas to improve the underlying science. The model enhancements in CMAQ v4.6.1 include: (1) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH; (2) an improved vertical asymmetric convective mixing module (ACM2) that allows in-cloud transport from a source layer to all other-in cloud layers (combined non-local and local

[S] Community Modeling & Analysis System (CMAS) – Reports from the CMAQ Review Process can be found at: http://www.cmascenter.org/r_and_d/cmaq_review_process.cfm?temp_id=99999 .

[T] CMAQ version 4.6 was released on September 30, 2006. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org.

closure scheme); (3) a heterogeneous reaction involving nitrate formation (gas-phase reactions involving N_2O_5 and H_2O); (4) the heterogeneous N_2O_5 reaction probability is now temperature- and humidity-dependent, (5) an updated version of the ISORROPIA aerosol thermodynamics module including improved representation of aerosol liquid water content and correction in activity coefficients for temperature other than 298K, and (6) an updated gas-phase chemistry mechanism, Carbon Bond 05 (CB05) and associated Euler Backward Iterative (EBI) solver, with extensions to model explicit concentrations of air toxic species.

2.4.5.2 Model Domain and Configuration

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 2-33. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

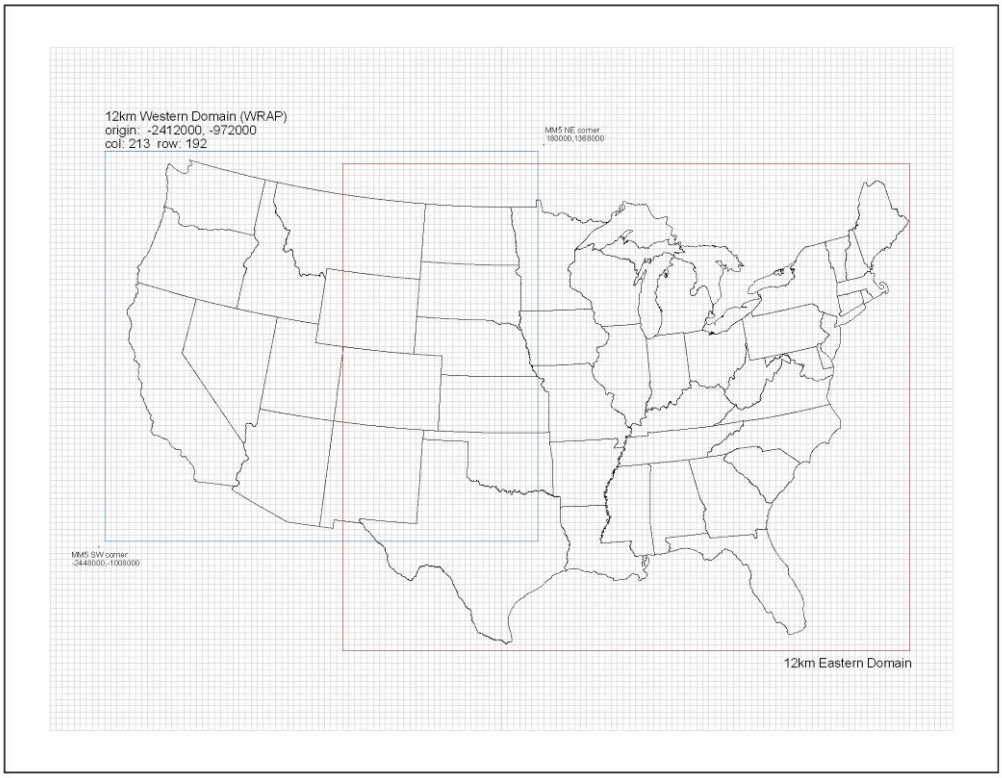


Figure 2-33 Map of the CMAQ Modeling Domain

2.4.5.3 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[357] 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.[358] 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.[359]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[360] 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 analyzed for the coordinated strategy are summarized in Chapter 3 of this DRIA.

2.4.5.4 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 2002 state/local monitoring 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.[U] 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.[V] Overall, the performance for the 2002 modeling platform is within the range or close to that of these other applications. The performance of the CMAQ modeling was evaluated over a 2002 base case. The model was

[U] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANE-VU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and Western Regional Air Partnership (WRAP).

[V] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

able to reproduce historical concentrations of ozone and $PM_{2.5}$ over the land with low amounts of bias and error. While we are not able to evaluate the model's performance over the ocean, there is no evidence to suggest that model performance is unsatisfactory over the ocean. A more detailed summary of the 2002 CMAQ model performance evaluation is available within the AQM TSD.

2.4.5.5 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, nitrogen and sulfur deposition levels and visibility estimates for each of the following emissions scenarios:

2002 base year

2020 base line projection

2020 base line projection with coordinated strategy emission reductions

2030 base line projection

2030 base line projection with coordinated strategy emission reductions

It should be noted that the emission control scenarios used in the air quality and benefits modeling are slightly different than the coordinated strategy. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of this DRIA 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, nitrogen and sulfur deposition levels, 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).

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 U.S. 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)".[361] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Small SI Engine Rule modeling AQM TSD.[362] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[363]

2.4.5.6 Deposition Modeling Methodology

The CMAQ model provides estimates of the amount of nitrogen and sulfur deposition in each of the simulated scenarios. Additionally, we conducted analyses using a separate methodology in which the CMAQ outputs were used to estimate the impacts on deposition levels in a manner similar to how the model is used for ozone and fine particulate matter. In this methodology, CMAQ outputs of annual wet deposition from the 2002 base year model run are used in conjunction with annual wet deposition predictions from the control or future case scenarios to calculate relative reduction factors (RRFs) for wet deposition. Separate wet deposition RRFs are calculated for reduced nitrogen, oxidized nitrogen, and sulfur. These RRFs are multiplied by the corresponding measured annual wet deposition of reduced nitrogen, oxidized nitrogen, and sulfur from the National Atmospheric Deposition Program (NADP) network. The result is a projection of the NADP wet deposition for the control or future case scenarios. The projected wet deposition for each of the three species is added to the CMAQ-predicted dry deposition for each of these species to produce total reduced nitrogen, total oxidized nitrogen, and total sulfur deposition for the control/future case scenario. The reduced and oxidized nitrogen depositions are summed to calculate total nitrogen deposition.

This analysis was completed for each individual 8-digit hydrological unit code (HUC) within the U.S. modeling domain. Each 8-digit HUC represents a local drainage basin. There were 2,108 8-digit HUCs considered as part of this analysis. This assessment corroborated the absolute deposition modeling results.

2.4.5.7 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.[W]

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.[364]

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 of this DRIA).

For visibility calculations, we are continuing to use the IMPROVE program species definitions and visibility formulas which are recommended in the modeling guidance.[365] 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).

[W] 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".

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CHAPTER 3: EMISSION INVENTORY

CHAPTER 3 Emission Inventory

3.1 Introduction

Ships (i.e., ocean-going vessels) are significant contributors to the total United States (U.S.) mobile source emission inventory. The U.S. ship inventory reported here focuses on Category 3 (C3) vessels, which use C3 engines for propulsion. C3 engines are defined as having displacement above 30 liters per cylinder (L/cyl). The resulting inventory includes emissions from both propulsion and auxiliary engines used on these vessels, as well as those on gas and steam turbine vessels.

Most of the vessels operating in U.S. ports that have propulsion engines less than 30 liters per cylinder are domestic and are already subject to strict national standards affecting NO_X, PM, and fuel sulfur content. As such, the inventory does not include any ships, foreign or domestic, powered by Category 1 or Category 2 (i.e., <30 L/cyl) engines. In addition, as discussed in Sections 3.3.2.5 and 3.3.3.2, this inventory is primarily based on activity data for ships that carry foreign cargo. Category 3 vessels carrying domestic cargo that operate only between U.S. ports are only partially accounted for in this inventory.[1] Emissions due to military vessels are also excluded.

The regional and national inventories for C3 vessels presented in this chapter are sums of independently constructed port and interport emissions inventories. Port inventories were developed for 89 deep water and 28 Great Lake ports in the U.S.[2] While there are more than 117 ports in the U.S., these are the top U.S. ports in terms of cargo tonnage. Port-specific emissions were calculated with a "bottom-up" approach, using data for vessel calls, emission factors, and activity for each port. Interport emissions were obtained using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM).[3,4] STEEM also uses a "bottom-up" approach, estimating emissions from C3 vessels using historical North American shipping activity, ship characteristics, and activity-based emission factors. STEEM was used to quantify and geographically (i.e., spatially) represent interport vessel traffic and emissions for vessels traveling within 200 nautical miles (nm) of the U.S.

The detailed port inventories were spatially merged into the STEEM gridded inventory to create a comprehensive inventory for Category 3 vessels. For the 117 ports, this involved removing the near-port portion of the STEEM inventory and replacing it with the detailed port inventories. For the remaining U.S. ports for which detailed port inventories are not available, the near-port portion of the STEEM inventory was simply retained. This was done for a base year of 2002. Inventories for 2020 were then projected using regional growth rates[5,6] and adjustment factors to account for the International Maritime Organization (IMO) Tier 1 and Tier 2 NO_X standards and NO_X retrofit program.[2] Inventories incorporating additional Tier 3 NO_X and fuel sulfur controls within the proposed Emission Control Area (ECA) were also developed for 2020 and 2030.

This chapter details the methodologies used to create the baseline and future year inventories and presents the resulting inventories for the U.S. Section 3.2 describes the modeling domain and geographic regions used in this analysis. Section 3.3 describes the methodology and

results for the 2002 base year inventory. Section 3.4 follows with a discussion of the growth rates and methodology used to create the 2020 and 2030 baseline and control inventories. Section 3.5 presents the estimated contribution of Category 3 vessels to U.S. national and local inventories. Section 3.6 follows with estimates of the projected emission reductions due to the proposed control program. Section 3.7 concludes the chapter by describing the changes in the inventories between the baseline scenarios used for the air quality modeling and the updated baseline scenarios in this proposed rule.

The inventory estimates reported in this chapter include emissions out to 200 nm from the U.S. coastline, including Alaska and Hawaii, but not extending into the Exclusive Economic Zone (EEZ) of neighboring countries. Inventories are presented for the following pollutants: oxides of nitrogen (NO_X), particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2). The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling.

3.2 Modeling Domain and Geographic Regions

The inventories described in this chapter reflect ship operations that occur within the area that extends 200 nautical miles (nm) from the official U.S. baseline, which is recognized as the low-water line along the coast as marked on the official U.S. nautical charts in accordance with the articles of the Law of the Sea. This boundary is roughly equivalent to the border of the U.S Exclusive Economic Zone. The U.S. region was then clipped to the boundaries of the U.S. Exclusive Economic Zone. The boundary was divided into regions using geographic information system (GIS) shapefiles obtained from the National Oceanic and Atmospheric Administration, Office of Coast Survey.[7] The accuracy of the NOAA shapefiles was verified with images obtained from the U.S. Geological Survey. The confirmed NOAA shapefiles were then combined with a shapefile of the U.S. international border from the National Atlas.[8]

The resulting region was further subdivided for this analysis to create regions that were compatible with the geographic scope of the regional growth rates, which are used to project emission inventories for the years 2020 and 2030, as described later in this document.

- The Pacific Coast region was split into separate North Pacific and South Pacific regions along a horizontal line originating from the Washington/Oregon border (Latitude 46° 15' North).

- The East Coast and Gulf of Mexico regions were divided along a vertical line roughly drawn through Key Largo (Longitude 80° 26' West).

- The Alaska region was divided into separate Alaska Southeast and Alaska West regions along a straight line intersecting the cities of Naknek and Kodiak. The Alaska Southeast region includes most of the State's population, and the Alaska West region includes the emissions from ships on a great circle route along the Aleutian Islands between Asia and the U.S. West Coast.

- For the Great Lakes domain, a similar approach was used to create shapefiles containing all the ports and inland waterways in the near port inventory and extending out into the lakes to the international border with Canada. The modeling domain spanned from Lake Superior on the west to the point eastward in the State of New York where the St. Lawrence River parts from U.S. soil.

- The Hawaiian domain was subdivided so that a distance of 200 nm beyond the southeastern islands of Hawaii, Maui, Oahu, Molokai, Niihau, Kauai, Lanai, and Kahoolawe was contained in Hawaii East. The remainder of the Hawaiian Region was then designated Hawaii West.

This methodology resulted in nine separate regional modeling domains that are identified below and shown in Figure 3-1. U.S. territories are not included in this analysis.

- South Pacific (SP)
- North Pacific (NP)
- East Coast (EC)
- Gulf Coast (GC)
- Alaska Southeast (AE)
- Alaska West (AW)
- Hawaii East (HE)
- Hawaii West (HW)
- Great Lakes (GL)

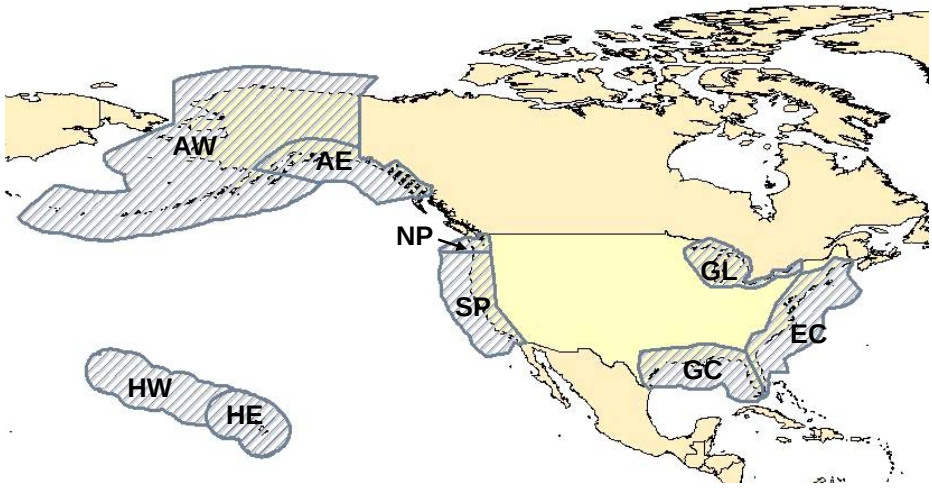


Figure 3-1 Regional Modeling Domains

3.3 Development of 2002 Baseline Inventory

This section describes the methodology and inputs, and presents the resulting inventories for the 2002 baseline calendar year. The first section describes the general methodology. The second section describes the methodology, inputs, and results for near port emissions. The third section describes the methodology and inputs for emissions when operating away from port (also referred to as "interport" emissions). The fourth section describes the method for merging the interport and near port portions of the inventory. Resulting total emissions for the U.S., as well as for nine geographic regions within the U.S., are then presented.

3.3.1 Outline of Methodology

The total inventory was created by summing emissions estimates for ships while at port (near port inventories) and while underway (interport inventories). Near port inventories for calendar year 2002 were developed for 117 U.S. commercial ports that engage in foreign trade. Based on an ICF International analysis,[9] these 117 commercial ports encompass nearly all U.S. C3 vessel calls.[10]

The outer boundaries of the ports are defined as 25 nm from the terminus of the reduced speed zone for deep water ports and 7 nm from the terminus of the reduced speed zone for Great Lake ports. Port emissions are calculated for different modes of operation and then summed. Emissions for each mode are calculated using port-specific information for vessel calls, vessel characteristics, and activity, as well as other inputs that vary instead by vessel or engine type (e.g., emission factors).

The interport inventory was estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[3,4] The model geographically characterizes emissions from ships traveling along shipping lanes to and from individual ports, in addition to the emissions from vessels transiting near the ports. The shipping lanes were identified from actual ship positioning reports. The model then uses detailed information about ship destinations, ship attributes (e.g., vessel speed and engine horsepower), and emission factors to produce spatially allocated (i.e., gridded) emission estimates for ships engaged in foreign commerce.

The 117 near port inventories are an improvement upon STEEM's near port results in several ways. First, the precision associated with STEEM's use of ship positioning data may be less accurate in some locations, especially as the lanes approach shorelines where ships would need to follow more prescribed paths. Second, the STEEM model includes a maneuvering operational mode (i.e., reduced speed) that is generally assumed to occur for the first and last 20 kilometers of each trip when a ship is leaving or entering a port. In reality, the distance when a ship is traveling at reduced speeds varies by port. Also, the distance a ship traverses at reduced speeds often consists of two operational modes: a reduced speed zone (RSZ) as a ship enters or leaves the port area and actual maneuvering at a very low speed near the dock. Third, the STEEM model assumes that the maneuvering distance occurs at an engine load of 20 percent, which represents a vessel speed of approximately 60 percent of cruise speed. This is considerably faster than ships would maneuver near the docks. The single maneuvering speed assumed by STEEM also does not reflect the fact that the reduced speed zone, and therefore emissions, may vary by port. Fourth, and finally, the STEEM model does not include the

emissions from auxiliary engines during hotelling operations at the port. The near-port inventories correct these issues.

The regional emission inventories produced by the current STEEM interport model are most accurate for vessels while cruising in ocean or Great Lakes shipping lanes, and the near port inventories, which use more detailed local port information, are significantly more accurate near the ports. Therefore, the inventories in this analysis are derived by merging together: (1) the near port inventories, which extend 25 nautical miles and 7 nautical miles from the terminus of the RSZ for deep water ports and Great Lake ports, respectively, and (2) the remaining interport portion of the STEEM inventory, which extends from the endpoint of the near port inventories to the 200 nautical mile boundary or international border with Canada, as appropriate. Near some ports, a portion of the underlying STEEM emissions were retained if it was determined that the STEEM emissions included ships traversing the area near a port, but not actually entering or exiting the port.

3.3.2 Near Port Emissions

Near port inventories for calendar year 2002 were developed for ocean-going vessels at 89 deep water and 28 Great Lake ports in the U.S. The inventories include emissions from both propulsion and auxiliary engines on these vessels.

This section first describes the selection of the ports for analysis and then provides the methodology used to develop the near port inventories. This is followed by a description of the key inputs. Total emissions by port and pollutant for 2002 are then presented. The work summarized here was conducted by ICF International under contract to EPA.[2] The ICF documentation provides more detailed information.[2]

3.3.2.1 Selection of Individual Ports to be Analyzed

All 150 deep sea and Great Lake ports in the Principal Ports of the United States dataset[11] were used as a starting point. Thirty ports which had no foreign traffic were eliminated because there is no information in the U.S. Army Corps of Engineers (USACE) entrances and clearances data about domestic traffic. (See Section 3.3.2.5 for a further discussion of domestic traffic and how it is accounted for in this study). In addition, two U.S. Territory ports in Puerto Rico were removed as these were outside the area of interest for this study. Several California ports were added to the principle ports list because ARB provided the necessary data and estimates for those ports. This is discussed in Section 3.3.2.4.1. Also, a conglomerate port in the Puget Sound area was added as discussed in Section 3.3.2.4.2. The final list of 117 deep sea and Great Lake ports, along with their coordinates, is given in the Appendix, Table 3-102.

3.3.2.2 Port Methodology

Near port emissions for each port are calculated for four modes of operation: (1) hotelling, (2) maneuvering, (3) reduced speed zone (RSZ), and (4) cruise. Hotelling, or dwelling, occurs while the vessel is docked or anchored near a dock, and only the auxiliary engine(s) are being used to provide power to meet the ship's energy needs. Maneuvering occurs within a very short distance of the docks. The RSZ varies from port to port, though generally the

RSZ would begin and end when the pilots board or disembark, and typically occurs when the near port shipping lanes reach unconstrained ocean shipping lanes. The cruise mode emissions in the near ports analysis extend 25 nautical miles beyond the end of the RSZ lanes for deep water ports and 7 nautical miles for Great Lake ports.

Emissions are calculated separately for propulsion and auxiliary engines. The basic equation used is as follows:

Equation 3-1

$$Emissions_{mode[eng]} = (calls) \times (P_{[eng]}) \times (hrs/call_{mode}) \times (LF_{mode[eng]}) \times (EF_{[eng]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{mode\ [eng]}$ = Metric tonnes emitted by mode and engine type
Calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[eng]}$ = Total engine power by engine type, in kilowatts
$hrs/call_{mode}$ = Hours per call by mode
$LF_{mode\ [eng]}$ = Load factor by mode and engine type (unitless)
$EF_{[eng]}$ = Emission factor by engine type for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Main engine load factors are calculated directly from the propeller curve based upon the cube of actual speed divided by maximum speed (at 100% maximum continuous rating [MCR]). In addition, cruise mode activity is based on cruise distance and speed inputs. The following sections provide the specific equations used to calculate propulsion and auxiliary emissions for each activity mode.

3.3.2.2.1 Cruise

Cruise emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate cruise mode emissions for the main engines is:

Equation 3-2

$$Emissions_{cruise[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{cruise}) \times (LF_{cruise[main]}) \times (EF_{[main]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{cruise\ [main]}$ = Metric tonnes emitted from main engines in cruise mode
Calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{cruise}$ = Hours per call for cruise mode
$LF_{cruise\ [main]}$ = Load factor for main engines in cruise mode (unitless)
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

In addition, the time in cruise is calculated as follows:

Equation 3-3

$$Hrs/call_{cruise} = Cruise\ Distance[nmiles]/Cruise\ Speed[knots] \times 2\ trips/call$$

Where:
Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance

Main engine load factors are calculated directly from the propeller curve based upon the cube of actual speed divided by maximum speed (at 100% maximum continuous rating [MCR]):

Equation 3-4

$$LoadFactor_{cruise[main]} = \left(Cruise\ Speed[knots]/Maximum\ Speed[knots]\right)^3$$

Since cruise speed is estimated at 94 percent of maximum speed[12], the load factor for main engines at cruise is 0.83.

Substituting Equation 3-3 for time in cruise into Equation 3-2, and using the load factor of 0.83, the equation used to calculate cruise mode emissions for the main engines becomes the following:

Equation 3-5 Cruise Mode Emissions for Main Engines

$$Emissions_{cruise[main]} = (calls) \times (P_{[main]}) \times (Cruise\ Distance/Cruise\ Speed) \times (2\ trips/call) \times 0.83 \times (EF_{[main]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{cruise\ [main]}$ = Metric tonnes emitted from main engines in cruise mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance
0.83 = Load factor for main engines in cruise mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

The equation used to calculate cruise mode emissions for the auxiliary engines is:

Equation 3-6 Cruise Mode Emissions for Auxiliary Engines

$$Emissions_{cruise[aux]} = (calls) \times (P_{[aux]}) \times (Cruise\ Distance/Cruise\ Speed) \times (2\ trips/call) \times (LF_{cruise[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{cruise[aux]}$ = Metric tonnes emitted from auxiliary engines in cruise mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
Cruise distance = one way distance (25 nautical miles for deep sea ports, and 7 nautical miles for Great Lake ports)
Cruise speed = vessel service speed, in knots
2 trips/call = Used to calculate round trip cruise distance
$LF_{cruise\ [aux]}$ = Load factor for auxiliary engines in cruise mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

The inputs of calls, cruise distance, and vessel speed are the same for main and auxiliary engines. Relative to the main engines, auxiliary engines have separate inputs for engine power, load factor, and emission factors. The activity-related inputs, such as engine power, vessel speed, and calls, can be unique to each ship calling on a port, if ship-specific information is available. For this analysis, as discussed in Section 3.3.2.3.1.1, these inputs were developed by port for bins that varied by ship type, engine type, and dead weight tonnage (DWT) range.

3.3.2.2.2 Reduced Speed Zone

RSZ emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate RSZ mode emissions for the main engines is:

Equation 3-7

$$Emissions_{RSZ[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{RSZ}) \times (LF_{RSZ[main]}) \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[main]}$ = Metric tonnes emitted from main engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{RSZ}$ = Hours per call for RSZ mode
$LF_{RSZ\ [main]}$ = Load factor for main engines in RSZ mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

In addition, the time in RSZ mode is calculated as follows:

Equation 3-8

$$Hrs/call_{RSZ} = RSZ\ Distance[nmiles] / RSZ\ Speed[knots] \times 2\,trips/call$$

Load factor during the RSZ mode is calculated as follows:

Equation 3-9

$$LoadFactor_{RSZ[main]} = \left(RSZ\ Speed / Maximum\ Speed\right)^3$$

In addition:

Equation 3-10

$$Maximum\ Speed = Cruise\ Speed / 0.94$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Substituting

Equation 3-10 into Equation 3-9, the equation to calculate load factor becomes:

Equation 3-11

$$LoadFactor_{RSZ[main]} = \left(RSZ\ Speed \times 0.94 / Cruise\ Speed\right)^3$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Load factors below 2 percent were set to 2 percent as a minimum.

Substituting Equation 3-8 for time in mode and Equation 3-11 for load factor into Equation 3-7 , the expression used to calculate RSZ mode emissions for the main engines becomes:

Equation 3-12 RSZ Mode Emissions for Main Engines

$$Emissions_{RSZ[aux]} = (calls) \times (P_{[aux]}) \times (RSZ\ Distance / RSZ\ Speed) \times (2\ trips/call) \times \left(RSZ\ Speed \times 0.94 / Cruise\ Speed\right)^3 \times (EF_{[aux]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[main]}$ = Metric tonnes emitted from main engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
RSZ distance = one way distance, in nautical miles (specific to each port)
RSZ speed = speed, in knots (specific to each port)
2 trips/call = Used to calculate round trip RSZ distance
Cruise speed = vessel service speed, in knots
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to tons
0.94 = Fraction of cruise speed to maximum speed

Emission factors are considered to be relatively constant down to about 20 percent load. Below that threshold, emission factors tend to increase significantly as the load decreases. During the RSZ mode, load factors can fall below 20 percent. Low load multiplicative

adjustment factors were developed and applied when the load falls below 20 percent (0.20). If the load factor is 0.20 or greater, the low load adjustment factor is set to 1.0.

The equation used to calculate RSZ mode emissions for the auxiliary engines is:

Equation 3-13 RSZ Mode Emissions for Auxiliary Engines

$$Emissions_{RSZ[aux]} = (calls) \times (P_{[aux]}) \times (RSZ\ Distance / RSZ\ Speed) \times (2\ trips/call) \times (LF_{RSZ[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{RSZ[aux]}$ = Metric tonnes emitted from auxiliary engines in RSZ mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
RSZ distance = one way distance, in nautical miles (specific to each port)
RSZ speed = speed, in knots (specific to each port)
2 trips/call = Used to calculate round trip cruise distance
$LF_{RSZ\ [aux]}$ = Load factor for auxiliary engines in RSZ mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Unlike main engines, there is no need for a low load adjustment factor for auxiliary engines, because of the way they are generally operated. When only low loads are needed, one or more engines are shut off, allowing the remaining engines to maintain operation at a more efficient level.

The inputs of calls, RSZ distance, and RSZ speed are the same for main and auxiliary engines. Relative to the main engines, auxiliary engines have separate inputs for engine power, load factor, and emission factors. The RSZ distances vary by port rather than vessel or engine type. Some RSZ speeds vary by ship type, while others vary by DWT. Mostly, however, RSZ speed is constant for all ships entering the harbor area. All Great Lake ports have reduced speed zone distances of three nautical miles occurring at halfway between cruise speed and maneuvering speed.

3.3.2.2.3 Maneuvering

Maneuvering emissions are calculated for both propulsion (main) and auxiliary engines. The basic equation used to calculate maneuvering mode emissions for the main engines is:

Equation 3-14

$$Emissions_{man[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{man}) \times (LF_{man[main]}) \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[main]}$ = Metric tonnes emitted from main engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode

$LF_{man\ [main]}$ = Load factor for main engines in maneuvering mode, unitless
$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Maneuvering time-in-mode is estimated based on the distance a ship travels from the breakwater or port entrance to the pier/wharf/dock (PWD). Maneuvering times also include shifts from one PWD to another or from one port within a greater port area to another. Average maneuvering speeds vary from 3 to 8 knots depending on direction and ship type. For consistency, maneuvering speeds were assumed to be the dead slow setting of approximately 5.8 knots.

Load factor during maneuvering is calculated as follows:

Equation 3-15

$$LoadFactor_{man[main]} = \left(ManSpeed[knots] / MaximumSpeed[knots]\right)^3$$

In addition:

Equation 3-16

$$MaximumSpeed = CruiseSpeed[knots] / 0.94$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Also, the maneuvering speed is 5.8 knots. Substituting Equation 3-16 into Equation 3-15, and using a maneuvering speed of 5.8 knots, the equation to calculate load factor becomes:

Equation 3-17

$$LoadFactor_{man[main]} = \left(5.45 / CruiseSpeed\right)^3$$

Load factors below 2 percent were set to 2 percent as a minimum.

Substituting Equation 3-17 for load factor into Equation 3-14, the expression used to calculate maneuvering mode emissions for the main engines becomes:

Equation 3-18 Maneuvering Mode Emissions for Main Engines

$$Emissions_{man[main]} = (calls) \times (P_{[main]}) \times (hrs/call_{man}) \times (5.45/CruiseSpeed)^3 \times (EF_{[main]}) \times (Adj) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[main]}$ = Metric tonnes emitted from main engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[main]}$ = Total main engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode
Cruise speed = Vessel service speed, in knots

$EF_{[main]}$ = Emission factor for main engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
Adj = Low load adjustment factor, unitless (used when the load factor is below 0.20)
10^{-6} = Conversion factor from grams to metric tonnes

Since the load factor during maneuvering usually falls below 20 percent, low load adjustment factors are also applied accordingly. Maneuvering times are not readily available for all 117 ports. For this analysis, maneuvering times and load factors available for a subset of the ports were used to calculate maneuvering emissions for the remaining ports. This is discussed in more detail in Section 3.3.2.3.8.

The equation used to calculate maneuvering mode emissions for the auxiliary engines is:

Equation 3-19 Maneuvering Mode Emissions for Auxiliary Engines

$$Emissions_{man[aux]} = (calls) \times (P_{[aux]}) \times (hrs/call_{man}) \times (LF_{man[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{man[aux]}$ = Metric tonnes emitted from auxiliary engines in maneuvering mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
$hrs/call_{man}$ = Hours per call for maneuvering mode
$LF_{man\ [aux]}$ = Load factor for auxiliary engines in maneuvering mode, unitless (these vary by ship type and activity mode)
$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Low load adjustment factors are not applied for auxiliary engines.

3.3.2.2.4 Hotelling

Hotelling emissions are calculated for auxiliary engines only, as main engines are not operational during this mode. The equation used to calculate hotelling mode emissions for the auxiliary engines is:

Equation 3-20 Hotelling Mode Emissions for Auxiliary Engines

$$Emissions_{hotel[aux]} = (calls) \times (P_{[aux]}) \times (hrs/call_{hotel}) \times (LF_{hotel[aux]}) \times (EF_{[aux]}) \times (10^{-6}\ tonnes/g)$$

Where:
$Emissions_{hotel[aux]}$ = Metric tonnes emitted from auxiliary engines in hotelling mode
calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)
$P_{[aux]}$ = Total auxiliary engine power, in kilowatts
$hrs/call_{hotel}$ = Hours per call for hotelling mode
$LF_{hotel\ [aux]}$ = Load factor for auxiliary engines in hotelling mode, unitless (these vary by ship type and activity mode)

$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)
10^{-6} = Conversion factor from grams to metric tonnes

Hotelling times are not readily available for all 117 ports. For this analysis, hotelling times available for a subset of the ports were used to calculate hotelling emissions for the remaining ports. This is discussed in more detail in Section 3.3.2.3.8.

3.3.2.3 Inputs for Port Emission Calculations

From a review of the equations described in Section 3.3.2.2, the following inputs are required to calculate emissions for the four modes of operation (cruise, RSZ, maneuvering, and hotelling):

- Number of calls
- Main engine power
- Cruise (vessel service) speed
- Cruise distance
- RSZ distance for each port
- RSZ speed for each port
- Auxiliary engine power
- Auxiliary load factors
- Main and auxiliary emission factors
- Low load adjustment factors for main engines
- Maneuvering time-in-mode (hours/call)
- Hotelling time-in-mode (hours/call)

Note that load factors for main engines are not listed explicitly, since they are calculated as a function of mode and/or cruise speed. This section describes the inputs in more detail, as well as the sources for each input.

3.3.2.3.1 Calls and Ship Characteristics (Propulsion Engine Power and Cruise Speed)

For this analysis, U.S. Army Corps of Engineers (USACE) entrance and clearance data for 2002,[13] together with Lloyd's data for ship characteristics,[14] were used to calculate average ship characteristics and calls by ship type for each port. Information for number of calls, propulsion engine power, and cruise speed were obtained from these data.

3.3.2.3.1.1 Bins by Ship Type, Engine Type, and DWT Range

The records from the USACE entrances and clearances data base were matched with Lloyd's data on ship characteristics for each port. Calls by vessels that have either Category 1 or 2 propulsion engines were eliminated from the data set. The data was then binned by ship type, engine type and dead weight tonnage (DWT) range. The number of entrances and clearances in each bin are counted, summed together and divided by two to determine the number of calls (i.e., one entrance and one clearance was considered a call). For Great Lake ports, there is a larger frequency of ships either entering the port loaded and leaving unloaded (light) or entering the

port light and leaving loaded. In these cases, there would only be one record (the loaded trip into or out of the port) that would be present in the data. For Great Lake ports, clearances were matched with entrances by ship name. If there was not a reasonable match, the orphan entrance or clearance was treated as a call.

Propulsion power and vessel cruise speed are also averaged for each bin. While each port is analyzed separately, the various bins and national average ship characteristics are given in Table 3-1 for deep sea ports and Table 3-2 for Great Lake ports. Auxiliary engine power was computed from the average propulsion power using the auxiliary power to propulsion power ratios discussed in Section 3.3.2.3.4.

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
AUTO CARRIER	MSD	< 10,000	35	6,527	1,736	16.0	6,211
		10,000 – 20,000	224	10,499	2,793	18.2	13,003
		20,000 – 30,000	28	6,620	1,761	13.0	22,268
	MSD Total		286	9,640	2,564	17.4	13,063
	SSD	<10,000	84	7,927	2,109	17.7	8,845
		10,000 – 20,000	2,316	10,899	2,899	18.7	14,959
		20,000 – 30,000	621	13,239	3,522	19.5	24,860
	SSD Total		3,020	11,298	3,005	18.8	16,826
AUTO CARRIER Total			3,306	11,155	2,967	18.7	16,500
BARGE CARRIER	MSD	< 25,000	1	4,461	1,200	13.3	4,393
	MSD Total		1	4,461	1,200	13.3	4,393
	SSD	< 25,000	1	3,916	1,053	14.0	11,783
		35,000 – 45,000	20	19,463	5,236	18.0	44,799
		45,000 – 90,000	19	25,041	6,736	20.0	48,093
	SSD Total		40	21,724	5,844	18.9	45,538
	ST	35,000 – 45,000	5	24,196	6,509	21.7	41,294
	ST Total		5	24,196	6,509	21.7	41,294
BARGE CARRIER Total			45	21,779	5,859	19.1	44,657
BULK CARRIER	MSD	< 25,000	213	4,867	1,080	14.0	15,819
		25,000 – 35,000	6	8,948	1,986	14.0	29,984
		35,000 – 45,000	44	9,148	2,031	15.2	39,128
		45,000 – 90,000	51	9,705	2,155	14.3	71,242
		> 90,000	1	16,109	3,576	15.8	105,550
	MSD Total		314	6,360	1,412	14.2	28,621

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
BULK CARRIER	SSD	< 25,000	1,194	5,650	1,254	14.2	19,913
		25,000 – 35,000	2,192	7,191	1,596	14.6	29,323
		35,000 – 45,000	1,742	8,515	1,890	14.7	39,875
		45,000 – 90,000	3,733	9,484	2,105	14.4	62,573
		> 90,000	352	14,071	3,124	14.5	112,396
	SSD Total		9,212	8,434	1,872	14.5	46,746
	ST	< 25,000	72	6,290	1,396	15.0	18,314
		25,000 – 35,000	3	8,948	1,986	15.0	33,373
	ST Total		75	6,379	1,416	15.0	18,819
BULK CARRIER Total			9,600	8,350	1,854	14.5	45,936
CONTAINER SHIP	MSD	< 25,000	1,005	6,846	1,506	17.2	8,638
		25,000 – 35,000	53	22,304	4,907	20.6	28,500
		35,000 – 45,000	59	26,102	5,742	22.3	39,932
		45,000 – 90,000	248	37,650	8,283	24.0	56,264
	MSD Total		1,365	13,878	3,053	18.8	19,419
	SSD	< 25,000	2,054	12,381	2,724	19.1	18,776
		25,000 – 35,000	2,360	19,247	4,234	20.5	31,205
		35,000 – 45,000	2,443	24,755	5,446	21.8	40,765
		45,000 – 90,000	6,209	36,151	7,953	23.3	58,604
		> 90,000	98	57,325	12,612	25.0	105,231
	SSD Total		13,163	27,454	6,040	21.9	44,513
	ST	< 25,000	46	20,396	4,487	20.8	19,963
		25,000 – 35,000	89	21,066	4,635	21.0	30,804
		35,000 – 45,000	41	23,562	5,184	21.0	40,949
	ST Total		176	21,472	4,724	21.0	30,334
CONTAINER SHIP Total			14,703	26,122	5,747	21.6	42,014
GENERAL CARGO	MSD	< 25,000	2,937	5,080	1,316	15.1	8,268
		25,000 – 35,000	38	9,458	2,450	15.4	30,746
		35,000 – 45,000	1	13,728	3,556	14.3	40,910
		45,000 – 90,000	9	11,932	3,090	16.0	50,250
	MSD Total		2,984	5,159	1,336	15.1	8,688
	SSD	< 25,000	2,357	6,726	1,742	15.4	14,409
		25,000 – 35,000	500	7,575	1,962	14.9	29,713
		35,000 – 45,000	1,122	9,269	2,401	15.2	41,568
		45,000 – 90,000	405	9,336	2,418	15.1	47,712
		> 90,000	6	10,628	2,753	14.5	134,981
	SSD Total		4,389	7,718	1,999	15.3	26,326
	ST	< 25,000	18	17,897	4,635	21.0	22,548
	ST Total		18	17,897	4,635	21.0	22,548
GENERAL CARGO Total			7,391	6,709	1,738	15.2	19,196

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
MISCELLANEOUS	MSD	All	51	9,405	2,530	12.7	6,083
	MSD Total		51	9,405	2,530	12.7	6,083
	MSD-ED	All	6	16,968	4,565	12.7	15,795
	MSD-ED Total		6	16,968	4,565	12.7	15,795
	SSD	All	7	4,659	1,253	14.2	8,840
	SSD Total		7	4,659	1,253	14.2	8,840
	ST	All	1	12,871	3,462	21.0	16,605
	ST Total		1	12,871	3,462	21.0	16,605
MISCELLANEOUS Total			64	9,564	2,573	13.0	7,311
PASSENGER	MSD	<10,000	1,011	22,024	6,123	20.2	5,976
		10,000 - 20,000	24	96,945	26,951	28.5	15,521
	MSD Total		1,035	23,762	6,606	20.4	6,197
	MSD-ED	<10,000	1,964	39,095	10,868	20.9	7,345
		10,000 - 20,000	228	53,236	14,800	22.0	10,924
	MSD-ED Total		2,192	40,566	11,277	21.1	7,717
	SSD	<10,000	189	23,595	6,559	20.1	6,235
	SSD Total		189	23,595	6,559	20.1	6,235
	GT-ED	10,000 - 20,000	143	44,428	12,351	24.0	11,511
	GT-ED Total		143	44,428	12,351	24.0	11,511
	ST	<10,000	13	16,858	4,687	21.2	6,981
		10,000 - 20,000	52	29,982	8,335	18.0	13,960
	ST Total		65	27,357	7,605	18.6	12,564
PASSENGER Total			3,623	34,800	9,674	20.9	7,443
REEFER	MSD	<10,000	122	4,829	1,961	16.3	5,646
		10,000 - 20,000	60	12,506	5,077	20.0	11,632
	MSD Total		182	7,360	2,988	17.5	7,619
	SSD	<10,000	464	6,539	2,655	18.0	7,267
		10,000 - 20,000	801	12,711	5,161	20.8	13,138
	SSD Total		1,265	10,449	4,242	19.7	10,986
REEFER Total			1,447	10,060	4,084	19.5	10,562
RORO	MSD	<10,000	892	7,840	2,031	15.5	6,641
		10,000 - 20,000	286	9,312	2,412	17.0	11,338
		> 30,000	31	22,386	5,798	21.0	31,508
	MSD Total		1,208	8,561	2,217	16.0	8,389
	SSD	<10,000	132	7,240	1,875	15.0	4,695
		10,000 - 20,000	208	9,062	2,347	16.9	14,293
		20,000 - 30,000	31	12,781	3,310	18.9	22,146
		> 30,000	555	20,362	5,274	18.9	42,867
	SSD Total		925	15,702	4,067	17.9	30,321
	GT	> 30,000	1	47,076	12,193	24.0	36,827
	GT Total		1	47,076	12,193	24.0	36,827
	ST	10,000 – 20,000	2	22,373	5,795	25.0	16,144
		20,000 – 30,000	1	22,373	5,795	25.0	22,501
	ST Total		3	22,373	5,795	25.0	18,687
RORO Total			2,137	11,687	3,027	16.8	17,910

Table 3-1 Bins and Average Ship Characteristics for Deep Sea Ports (continued)

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
TANKER	MSD	<30,000	650	4,888	1,031	14.3	11,415
		30,000 - 60,000	181	10,533	2,222	15.3	42,153
		60,000 - 90,000	148	9,782	2,064	14.7	74,245
		90,000 - 120,000	3	15,139	3,194	14.1	113,957
	MSD Total		981	6,697	1,413	14.6	26,847
	SSD	<30,000	3,050	6,303	1,330	14.6	17,145
		30,000 - 60,000	3,752	9,021	1,903	14.9	41,677
		60,000 - 90,000	1,766	10,310	2,175	14.6	74,595
		90,000 - 120,000	2,835	12,318	2,599	14.6	101,116
		120,000 - 150,000	258	15,840	3,342	14.7	144,405
		> 150,000	487	16,888	3,563	15.2	166,394
	SSD Total		12,147	9,755	2,058	14.7	61,353
	GT-ED	30,000 - 60,000	13	7,592	1,602	14.5	39,839
	GT-ED Total		13	7,592	1,602	14.5	39,839
	ST	< 30,000	2	13,534	2,856	18.0	27,235
		30,000 - 60,000	87	15,818	3,338	17.9	43,982
		60,000 - 90,000	73	26,848	5,665	18.9	70,108
		90,000 - 120,000	4	17,660	3,726	16.3	91,868
		120,000 - 150,000	3	19,125	4,035	16.0	122,409
		> 150,000	2	20,785	4,386	14.3	190,111
	ST Total		170	20,678	4,363	18.2	58,616
TANKER Total			13,310	9,667	2,040	14.8	58,754
TUG	MSD	All	48	7,579	2,039	14.5	626
	MSD Total		48	7,579	2,039	14.5	626
TUG Total			48	7,579	2,039	14.5	626
Grand Total			55,672	15,212	3,593	17.4	38,083

Note:

[a] Engine Types: MSD = medium speed engine; SSD = slow speed engine; ST = steam turbine; GT = gas turbine

Table 3-2 Bins and Average Ship Characteristics for Great Lake Ports

Ship Type	Main Engine [a]	DWT Range	Calls	Engine Power (kW)		Cruise Speed (kts)	DWT
				Main	Auxiliary		
BULK CARRIER	MSD	10,000 - 20,000	9	4,413	980	15.3	11,693
		20,000 - 30,000	4	8,826	1,959	14.0	28,481
		30,000 - 40,000	11	6,001	1,332	13.5	32,713
	MSD Total		24	5,876	1,305	14.2	24,125
	SSD	10,000 - 20,000	18	4,844	1,075	13.6	14,392
		20,000 - 30,000	208	6,995	1,553	14.6	27,486
		30,000 - 40,000	223	8,284	1,839	14.1	34,172
	SSD Total		449	7,549	1,676	14.3	30,282
	ST	20,000 - 30,000	23	6,910	1,534	15.5	26,513
	ST Total		23	6,910	1,534	15.5	26,513
BULK CARRIER Total			496	7,438	1,651	14.4	29,809
SELF UNLOADING BULK CARRIER	MSD	10,000 - 20,000	5	3,114	691	10.5	12,513
		20,000 - 30,000	12	6,436	1,429	15.0	28,591
		30,000 - 40,000	771	6,881	1,528	13.2	33,531
		> 40,000	67	12,140	2,695	13.5	65,089
	MSD Total		855	7,265	1,613	13.3	35,812
	SSD	20,000 - 30,000	275	6,659	1,478	15.0	26,504
		30,000 - 40,000	122	7,574	1,681	14.9	34,476
	SSD Total		397	6,940	1,541	14.9	28,954
	ST	< 10,000	26	3,236	718	12.3	4,538
		10,000 - 20,000	93	4,750	1,055	13.6	16,830
		20,000 - 30,000	79	6,679	1,483	16.6	28,847
	ST Total		198	5,321	1,181	14.6	20,011
SELF UNLOADING BULK CARRIER Total			1,450	6,910	1,534	13.9	31,776
GENERAL CARGO	MSD	< 10,000	87	4,436	847	15.1	6,755
		10,000 - 20,000	6	5,939	1,134	16.5	12,497
	MSD Total		93	4,533	866	15.2	7,125
	SSD	< 10,000	3	4,763	910	16.4	6,708
		10,000 - 20,000	7	6,280	1,199	14.1	16,993
		20,000 - 30,000	1	7,099	1,356	16.0	24,432
		30,000 - 40,000	6	8,827	1,686	15.0	30,900
	SSD Total		17	6,959	1,329	14.9	20,524
GENERAL CARGO Total			110	4,908	937	15.1	9,196
INTEGRATED TUG-BARGE	MSD	All	24	5,364	1,443	13.8	672
	MSD Total		24	5,364	1,443	13.8	672
INTEGRATED TUG-BARGE Total			24	5,364	1,443	13.8	672
TANKER	MSD	10,000 - 20,000	42	3,972	838	13.5	10,475
	MSD Total		42	3,972	838	13.5	10,475
	SSD	10,000 - 20,000	5	5,160	1,089	14.3	13,735
	SSD Total		5	5,160	1,089	14.3	13,735
TANKER Total			47	4,098	865	13.6	10,822
Grand Total			2,127	6,850	1,515	14.1	29,336

Note:

[a] Engine Types: MSD = medium speed engine; SSD = slow speed engine; ST = steam turbine

3.3.2.3.1.2 Removal of Category 1 and 2 Ships

Since these inventories were intended to cover ships with Category 3 propulsion engines only, the ships with Category 1 and 2 propulsion engines were eliminated. This was accomplished by matching all ship calls with information from Lloyd's Data, which is produced by Lloyd's Register-Fairplay Ltd.[14] Over 99.9 percent of the calls in the entrances and clearances data were directly matched with Lloyd's data. The remaining 0.1 percent was estimated based upon ships of similar type and size.

Engine category was determined from engine make and model. Engine bore and stroke were found in the Marine Engine 2005 Guide[15] and displacement per cylinder was calculated. Ships with Category 1 or 2 propulsion engines were eliminated from the data.

Many passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes. Both were included in the current inventory.

3.3.2.3.1.3 Treatment of Electric-Drive Ships

Many passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes. Both were included in the current inventory.

Lloyds clearly calls out these types of engines in their database and that information was used to distinguish them from direct and geared drive systems. Generally the power Lloyds lists is the total power. To separate out propulsion from auxiliary power for purposes of calculating emissions, the total power listed in the Lloyds data was divided by 1 plus the ratio of auxiliary to propulsion power (given in Table 3-3) to obtain the propulsion power portion of the total. The remaining portion was considered auxiliary engine power. In addition, no low load adjustment factor was applied to diesel and gas turbine electric engines for loads below 20 percent MCR because several engines are used to generate power, and some can be shut down to allow others to operate at a more efficient setting.

3.3.2.3.2 Cruise Distance

Cruise mode emissions are calculated assuming a 25 nautical mile distance into and out of the port for deep sea ports and 7 nautical miles into and out of the port for Great Lake ports outside of the reduced speed and maneuvering zones.

3.3.2.3.3 RSZ Distances and Speeds by Port

Reduced speed zone (RSZ) distance and speed were determined for each port. For deep sea ports, the RSZ distances were developed from shipping lane information contained in the U.S. Army Corps of Engineers National Waterway Network.[16] The NWN is a geographic database of navigable waterways in and around the U.S. The database defines waterways as links or line segments that, for the purposes of this study, represent actual shipping lanes (i.e., channels, intracoastal waterways, sea lanes, and rivers). The geographic locations of the waterways that were directly associated with each of the 117 ports were viewed using geographic

information system computer software. The sea-side endpoint for the RSZ was selected as the point along the line segment that was judged to be far enough into the ocean where ship movements were unconstrained by the coastline or other vessel traffic. These RSZ sea-side endpoints typically coincided with estimates provided by the pilots for the major ports as reported in earlier work. The resulting RSZ distance was then measured for each deep sea port. The final RSZ distances and endpoints for each port are listed in the Appendix, Table 3-103. The RSZ for each Great Lake port was fixed at three nautical miles, as previously discussed in Section 3.3.2.2.2.

The RSZ speeds were primarily taken from previous studies by ICF[17,18] or from an ENVIRON report[19] based upon discussions with pilots. A few of the RSZ speeds were also modified based upon newer information obtained from conversations with pilots. The final RSZ speeds for each port are listed in the Appendix, Table 3-103. The RSZ speeds for the Great Lake ports vary by vessel type and are the average of the vessel service speed and the maneuvering speed.

3.3.2.3.4 Auxiliary Engine Power and Load Factors

Since hotelling emissions are a large part of port inventories, it is important to distinguish propulsion engine emissions from auxiliary engine emissions. In the methodology used in this analysis, auxiliary engine maximum continuous rating power and load factors were calculated separately from propulsion engines and different emission factors (EFs) applied. All auxiliary engines were treated as Category 2 medium-speed diesel (MSD) engines for purposes of this analysis.

Auxiliary engine power is not contained in the USACE database and is only sparsely populated in the Lloyd's database; as a result, it must be estimated. The approach taken was to derive ratios of average auxiliary engine power to propulsion power based on survey data. The California Air Resources Board (ARB) conducted an Oceangoing Ship Survey of 327 ships in January 2005 that was principally used for this analysis.[20] Average auxiliary engine power to propulsion power ratios were estimated by ship type and are presented in Table 3-3. These ratios by ship type were applied to the propulsion power data to derive auxiliary power for the ship types at each port.

Table 3-3 Auxiliary Engine Power Ratios (ARB Survey, except as noted)

Ship Type	Average Propulsion Engine (kW)	Average Auxiliary Engines				Auxiliary to Propulsion Ratio
		Number	Power Each (kW)	Total Power (kW)	Engine Speed	
Auto Carrier	10,700	2.9	983	2,850	Medium	0.266
Bulk Carrier	8,000	2.9	612	1,776	Medium	0.222
Container Ship	30,900	3.6	1,889	6,800	Medium	0.220
Passenger Ship[a]	39,600	4.7	2,340	11,000	Medium	0.278
General Cargo	9,300	2.9	612	1,776	Medium	0.191
Miscellaneous[b]	6,250	2.9	580	1,680	Medium	0.269
RORO	11,000	2.9	983	2,850	Medium	0.259
Reefer	9,600	4.0	975	3,900	Medium	0.406
Tanker	9,400	2.7	735	1,985	Medium	0.211

Notes:

[a] Many passenger ships typically use a different engine configuration known as diesel-electric. These vessels use large generator sets for both propulsion and ship-board electricity. The figures for passenger ships above are estimates taken from the Starcrest Vessel Boarding Program.

[b] Miscellaneous ship types were not provided in the ARB methodology, so values from the Starcrest Vessel Boarding Program were used.

Load factors for auxiliary engines vary by ship type and operating mode. It was previously thought that power generation was provided by propulsion engines in all modes but hotelling. Starcrest's Vessel Boarding Program[12] showed that auxiliary engines are on all of the time, except when using shoreside power during hotelling. Table 3-4 shows the auxiliary engine load factors by ship type determined by Starcrest, through interviews conducted with ship captains, chief engineers, and pilots during its vessel boarding programs. Auxiliary load factors were used in conjunction with total auxiliary power. Auxiliary load factors listed in Table 3-4 are used together with the total auxiliary engine power (determined from total propulsion power and the ratios from Table 3-3) to calculate auxiliary engine emissions.

Table 3-4 Auxiliary Engine Load Factor Assumptions

Ship-Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0.13	0.30	0.67	0.24
Bulk Carrier	0.17	0.27	0.45	0.22
Container Ship	0.13	0.25	0.50	0.17
Passenger Ship	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
Miscellaneous	0.17	0.27	0.45	0.22
RORO	0.15	0.30	0.45	0.30
Reefer	0.20	0.34	0.67	0.34
Tanker	0.13	0.27	0.45	0.67

3.3.2.3.5 Fuel Types and Fuel Sulfur Levels

There are primarily three types of fuel used by marine engines: residual marine (RM), marine diesel oil (MDO), and marine gas oil (MGO), with varying levels of fuel sulfur.[5] MDO and MGO are generally described as distillate fuels. For this analysis, RM and MDO fuels are assumed to be used. Since PM and SO_2 emission factors are dependent on the fuel sulfur level, calculation of port inventories requires information about the fuel sulfur levels associated with each fuel type, as well as which fuel types are used by propulsion and auxiliary engines.

An ARB survey[20] found that almost all ships used RM in their main propulsion engines, and that only 29 percent of all ships (except passenger ships) used distillate in their auxiliary engines, with the remaining 71 percent using RM. However, only 8 percent of passenger ships used distillate in their auxiliary engines, while the other 92 percent used RM. We used the results of this survey as reasonable approximations for calculations of emission factors. However, their accuracy for years other than those of the ARB survey may be affected by fuel prices, since as fuel prices increase, more ships will use RM in their auxiliary engines.

Based on the ARB survey, average fuel sulfur level for residual marine was set to 2.5 percent for the west coast and 2.7 percent for the rest of the country. A sulfur content of 1.5 percent was used for MDO.[21] While a more realistic value for MDO used in the U.S. appears to be 0.4 percent, given the small proportion of distillate fuel used by ships relative to RM, the difference should not be significant. Sulfur levels in other areas of the world can be significantly higher for RM. Table 3-5 provides the assumed mix of fuel types used for propulsion and auxiliary engines by ship type.

Table 3-5 Estimated Mix of Fuel Types Used by Ships

Ship Type	Fuel Used	
	Propulsion	Auxiliary
Passenger	100% RM	92% RM/8% MDO
Other	100% RM	71% RM/29% MDO

3.3.2.3.6 Propulsion and Auxiliary Engine Emission Factors

An analysis of emission data was prepared and published in 2002 by Entec.[21] The resulting Entec emission factors include individual factors for three speeds of diesel engines (slow-speed diesel (SSD), medium-speed diesel (MSD), and high-speed diesel (HSD)), steam turbines (ST), gas turbines (GT), and two types of fuel used here (RM and MDO). Table 3-6 lists the propulsion engine emission factors for NO_X and HC that were used for the 2002 port inventory development. The CO, PM, SO_2 and CO_2 emission factors shown in the table come from other data sources as explained below.

Table 3-6 Emission Factors for OGV Main Engines using RM, g/kWh

Engine	All Ports				West Coast Ports			Other Ports		
	NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	SO_2
SSD	18.1	1.40	0.60	620.62	1.4	1.3	9.53	1.4	1.3	10.29
MSD	14.0	1.10	0.50	668.36	1.4	1.3	10.26	1.4	1.3	11.09
ST	2.1	0.20	0.10	970.71	1.4	1.3	14.91	1.5	1.4	16.10
GT	6.1	0.20	0.10	970.71	1.4	1.3	14.91	1.5	1.4	16.10

CO emission factors were developed from information provided in the Entec appendices because they are not explicitly stated in the text. . HC and CO emission factors were confirmed with a recent EPA review.[22]

PM_{10} values were determined by EPA based on existing engine test data in consultation with ARB.[23] GT PM_{10} emission factors were not part of the EPA analysis but assumed here to be equivalent to ST PM_{10} emission factors. Test data shows PM_{10} emission rates as dependent upon fuel sulfur levels, with base PM_{10} emission rates of 0.23 g/kw-hr with distillate fuel (0.24% sulfur) and 1.35 g/kw-hr with residual fuel (2.46% sulfur).[24] The equation used to generate emission factors based on sulfur content is shown below.

Equation 3-21 Calculation of PM_{10} Emission Factors Based on Fuel Sulfur Levels

$$PM_{EF} = PM_{Nom} + [(S_{Act} - S_{Nom}) \times BSFC \times FSC \times MWR \times 0.0001]$$

Where:

PM_{EF} = PM emission factor adjusted for fuel sulfur

PM_{Nom}= PM emission rate at nominal fuel sulfur level

= 0.23 g/kW-hr for distillate fuel, 1.35 g/kW-hr for residual fuel
S_{Act}= Actual fuel sulfur level (weight percent)
S_{Nom}= nominal fuel sulfur level (weight percent)
= 0.24 for distillate fuel, 2.46 for residual fuel
BSFC= fuel consumption in g/kW-hr
= 200 g/kW-hr used for this analysis
FSC= percentage of sulfur in fuel that is converted to direct sulfate PM
= 2.247% used for this analysis
MWR= molecular weight ratio of sulfate PM to sulfur
= 224/32 = 7 used for this analysis

The PM_{10} to $PM_{2.5}$ conversion factor used here is 0.92. While the NONROAD model uses 0.97 for such conversion based upon low sulfur fuels, a reasonable value seems to be closer to 0.92 because higher sulfur fuels in medium and slow speed engines would tend to produce larger particulates than high speed engines on low sulfur fuels.

SO_2 emission factors were based upon a fuel sulfur to SO_2 conversion formula which was supplied by ENVIRON.[25] Emission factors for SO_2 emissions were calculated using the formula assuming that 97.753 percent of the fuel sulfur was converted to SO_2.[26] The brake specific fuel consumption (BSFC)[A] that was used for SSDs was 195 g/kWh, while the BSFC that was used for MSDs was 210 g/kWh based upon Lloyds 1995. The BSFC that was used for STs and GTs was 305 g/kWh based upon Entec.[21]

Equation 3-22 Calculation of SO_2 Emission Factors, g/kWh

SO_2 EF = BSFC x 2 x 0.97753 x Fuel Sulfur Fraction

CO_2 emission factors were calculated from the BSFC assuming a fuel carbon content of 86.7 percent by weight[21] and a ratio of molecular weights of CO_2 and C at 3.667.

Equation 3-23 Calculation of CO_2 Emission Factors, g/kWh

CO_2 EF = BSFC x 3.667 x 0.867

Fuel consumption was calculated from CO_2 emissions based on a 1:3.183 ratio. 3.183 tons of CO_2 emissions are assumed produced from one metric ton of fuel.

The most current set of auxiliary engine emission factors comes from Entec except as noted below. Table 3-7 provides these auxiliary engine emission factors.

Table 3-7 Auxiliary Engine Emission Factors by Fuel Type, g/kWh

		All Ports				West Coast Ports			Other Ports		
Engine	**Fuel**	**NO_X**	**CO**	**HC**	**CO_2**	**PM_{10}**	**$PM_{2.5}$**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**	**SO_2**
MSD	RM	14.70	1.10	0.40	668.36	1.4	1.3	10.26	1.4	1.3	11.09
	MDO	13.90	1.10	0.40	668.36	0.6	0.55	6.16	0.6	0.55	6.16

[A] Brake specific fuel consumption is sometimes called specific fuel oil consumption (SFOC).

It should be noted that Entec used 2.7 percent fuel sulfur content for RM, and 1.0 percent for MDO which is consistent with the RM assumptions made in this analysis for other than West Coast ports. For MDO, there is a slight discrepancy between the 1.0 percent used by Entec versus the 1.5 percent estimate used for this analysis. SO_2 emission factors were calculated based upon the assumed sulfur levels and the methodology suggested by ENVIRON[25] while PM emissions were determined by EPA based on existing engine test data in consultation with ARB.[23]

Using the ratios of RM versus MDO use determined by the ARB study[20] as given in Table 3-5 together with the emission factors shown in Table 3-7, the auxiliary engine emission factor averages by ship type are listed in Table 3-8. As discussed above, this fuel sulfur level may be too high for the U.S. However, we do not believe this emission factor has a significant effect on the total emission inventory estimates.

If the fuel sulfur level for MDO is correctly adjusted from 1.5 percent to 1.0 percent, the effect on SO_2 emissions is still less than 7 percent, due to the high percentage of RM fuel used in auxiliary engines. The difference for PM is within the round off error of the emission factor.

Table 3-8 Auxiliary Engine Emission Factors by Ship Type, g/kWh

	All Ports				West Coast Ports			Other Ports		
Ship Type	**NO_X**	**CO**	**HC**	**CO_2**	**PM_{10}**	**$PM_{2.5}$**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**	**SO_2**
Passenger	14.64	1.10	0.40	668.36	1.3	1.2	9.93	1.4	1.3	10.70
Others	14.47	1.10	0.40	668.36	1.1	1.0	9.07	1.2	1.1	9.66

3.3.2.3.7 Low Load Adjustment Factors for Propulsion Engines

Emission factors are considered to be constant down to about 20 percent load. Below that threshold, emission factors tend to increase as the load decreases. This trend results because diesel engines are less efficient at low loads and the BSFC tends to increase. Thus, while mass emissions (grams per hour) decrease with low loads, the engine power tends to decrease more quickly, thereby increasing the emission factor (grams per engine power) as load decreases. Energy and Environmental Analysis Inc. (EEA) demonstrated this effect in a study prepared for EPA in 2000.[27] In the EEA report, various equations have been developed for the various emissions. The low-load emission factor adjustment factors were developed based upon the concept that the BSFC increases as load decreases below about 20 percent load. For fuel consumption, EEA developed the following equation:

Equation 3-24

$$\text{Fuel Consumption (g/kWh)} = 14.1205\ (1/\text{Fractional Load}) + 205.7169$$

In addition, based upon test data, they developed algorithms to calculate emission factors at reduced load. These equations are noted below:

Equation 3-25

Emission Rate (g/kWh) = a (Fractional Load)$^{-x}$ + b

For SO_2 emissions, however, EEA developed a slightly different equation:

Equation 3-26

Emission Rate (g/kWh) = a (Fuel Consumption x Fuel Sulfur Fraction) + b

The coefficients for the above equations are given in Table 3-9 below.

Table 3-9 Emission Factor Algorithm Coefficients for OGV Main Engines using RM

Coefficient	NO_X	HC	CO	PM	SO_2	CO_2
a	0.1255	0.0667	0.8378	0.0059	2.3735	44.1
x	1.5	1.5	1.0	1.5	n/a	1.0
b	10.4496	0.3859	0.1548	0.2551	-0.4792	648.6

The underlying database used to calculate these coefficients includes primarily tests on engines rated below 10,000 kW, using diesel fuel. This introduces uncertainty regarding the use of these coefficients for Category 3 engines using residual fuel; however, these are the best estimates currently available.

Using these algorithms, fuel consumption and emission factors versus load were calculated. By normalizing these emission factors to 20% load, the low-load multiplicative adjustment factors presented in Table 3-10 are calculated. SO_2 adjustment factors were calculated using 2.7% sulfur. The SO_2 multiplicative adjustment factors at 2.5 percent sulfur are not significantly different.

Table 3-10 Calculated Low Load Multiplicative Adjustment Factors

Load (%)	NO_X	HC	CO	PM	SO_2	CO_2
1	11.47	59.28	19.32	19.17	5.99	5.82
2	4.63	21.18	9.68	7.29	3.36	3.28
3	2.92	11.68	6.46	4.33	2.49	2.44
4	2.21	7.71	4.86	3.09	2.05	2.01
5	1.83	5.61	3.89	2.44	1.79	1.76
6	1.60	4.35	3.25	2.04	1.61	1.59
7	1.45	3.52	2.79	1.79	1.49	1.47
8	1.35	2.95	2.45	1.61	1.39	1.38
9	1.27	2.52	2.18	1.48	1.32	1.31
10	1.22	2.20	1.96	1.38	1.26	1.25
11	1.17	1.96	1.79	1.30	1.21	1.21
12	1.14	1.76	1.64	1.24	1.18	1.17
13	1.11	1.60	1.52	1.19	1.14	1.14
14	1.08	1.47	1.41	1.15	1.11	1.11
15	1.06	1.36	1.32	1.11	1.09	1.08
16	1.05	1.26	1.24	1.08	1.07	1.06
17	1.03	1.18	1.17	1.06	1.05	1.04
18	1.02	1.11	1.11	1.04	1.03	1.03
19	1.01	1.05	1.05	1.02	1.01	1.01
20	1.00	1.00	1.00	1.00	1.00	1.00

There is no need for a low load adjustment factor for auxiliary engines, because they are generally operated in banks. When only low loads are needed, one or more engines are shut off, allowing the remaining engines to operate at an efficient level.

3.3.2.3.8 Use of Detailed Typical Port Data for Other Inputs

There is currently not enough information to readily calculate time-in-mode (hours/call) for all 117 ports during the maneuvering and hotelling modes of operation. As a result, it was necessary to review and select available detailed emission inventories that have been estimated for selected ports to date. These ports are referred to as typical ports. The typical port information for maneuvering and hotelling time-in-mode (as well as maneuvering load factors for the propulsion engines) was then used for the typical ports and also assigned to the other modeled ports. A modeled port is the port in which emissions are to be estimated. The methodology that was used to select the typical ports and match these ports to the other modeled ports is briefly described in this section, and more fully described in the ICF documentation.[2]

3.3.2.3.8.1 Selection of Typical Ports

In 1999, EPA published two guidance documents[17,18] to calculate marine vessel activity at ports. These documents contained detailed port inventories of eight deep sea ports, two Great

Lake ports and two inland river ports. The detailed inventories were developed by obtaining ship call data from Marine Exchanges/Port Authorities (MEPA) at the various ports for 1996 and matching the various ship calls to data from Lloyds Maritime Information Services to provide ship characteristics. The ports for which detailed inventories were developed are shown in Table 3-11 for deep sea ports and Table 3-12 for Great Lake ports along with the level of detail of shifts for each port. Most ports provided the ship name, Lloyd's number, the vessel type, the date and time the vessel entered and left the port, and the vessel flag. Inland river ports were developed from U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics Center data.

Table 3-11 Deep Sea MEPA Vessel Movement and Shifting Details

MEPA Area and Ports	MEPA Data Includes
Lower Mississippi River including the ports of New Orleans, South Louisiana, Plaquemines, and Baton Rouge	Information on the first and last pier/wharf/dock (PWD) for the vessel (gives information for at most one shift per vessel). No information on intermediate PWDs, the time of arrival at the first destination PWD, or the time of departure from the River.
Consolidated Port of New York and New Jersey and other ports on the Hudson and Elizabeth Rivers	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
Delaware River Ports including the ports of Philadelphia, Camden, Wilmington and others	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
Puget Sound Area Ports including the ports of Seattle, Tacoma, Olympia, Bellingham, Anacortes, and Grays Harbor	All PWDs or anchorages for shifting are named. Arrival and departure dates and times are noted for all movements, allowing calculation of maneuvering and hotelling both for individual shifts and the overall call on port.
The Port of Corpus Christi, TX	Only has information on destination PWD and date and time in and out of the port area. No shifting details.
The Port of Coos Bay, OR	Only has information on destination PWD and date and time in and out of the port area. No shifting details.
Patapsco River Ports including the port of Baltimore Harbor, MD	All PWDs or anchorages for shifting are named. Shifting arrival and departure times are not given. Hotelling time is based upon the entrance and clearance times and dates, subtracting out maneuvering times. Maneuvering times were calculated based upon the distance the ship traveled at a given maneuvering speed.
The Port of Tampa, FL	All PWDs or anchorages for shifting are named. Arrival and departure dates and times are noted for all movements, allowing calculation of maneuvering and hotelling both for individual shifts and the overall call.

Table 3-12 Great Lake MEPA movements and shifts

MEPA Area and Ports	MEPA Data Includes
Port of Cleveland, OH	Information on the first and last PWD for the vessel (gives information for at most one shift per vessel). No information on intermediate PWDs..
Port of Burns Harbor, IN	No shifting details, No PWDs listed..

Since 1999, several new detailed emissions inventories have been developed and were reviewed for use as additional or replacement typical ports: These included:

- Port of Los Angeles[12,28]
- Puget Sound Ports[29]
- Port of New York/New Jersey[30]
- Port of Houston/Galveston[31]
- Port of Beaumont/Port Arthur[32]
- Port of Corpus Christi[33]
- Port of Portland[34]
- Ports of Cleveland, OH and Duluth-Superior, MN&WI[35]

Based on the review of these newer studies, some of the previous typical ports were replaced with newer data and an additional typical port was added. Data developed for Cleveland and Duluth-Superior for LADCO was used in lieu of the previous typical port data for Cleveland and Burns Harbor because it provided more detailed information and better engine category definitions. The Port of Houston/Galveston inventory provided enough data to add an additional typical port. All three port inventories were adjusted to reflect the current methodology used in this study.

The information provided in the current inventory for Puget Sound Ports[29] was used to calculate RSZ speeds, load factors, and times for all Puget Sound ports. As described in Section 3.3.2.4.2, an additional modeled port was also added to account for the considerable amount of Jones Act tanker ship activity in the Puget Sound area that is not contained in the original inventory.

The newer Port of New York/New Jersey inventory provided a check against estimates made using the 1996 data. All other new inventory information was found to lack sufficient detail to prepare the detailed typical port inventories needed for this project.

The final list of nine deep sea and two Great Lake typical ports used in this analysis and their data year is as follows:

- Lower Mississippi River Ports [1996]

- Consolidated Ports of New York and New Jersey and Hudson River [1996]
- Delaware River Ports [1996]
- Puget Sound Area Ports [1996]
- Corpus Christi, TX [1996]
- Houston/Galveston Area Ports [1997]
- Ports on the Patapsco River [1996]
- Port of Coos Bay, OR [1996]
- Port of Tampa, FL [1996]
- Port of Cleveland, OH on Lake Erie [2005]
- Duluth-Superior, MN & WI on Lake Michigan [2005]

The maneuvering and hotelling time-in-modes, as well as the maneuvering load factors for these typical ports, were binned by ship type, engine type, and DWT type, using the same bins described in Section 3.3.2.3.1.1.

3.3.2.3.8.2 Matching Typical Ports to Modeled Ports

The next step in the process was to match the ports to be modeled with the typical port which was most like it. Three criteria were used for matching a given port to a typical port: regional differences,[B] maximum vessel draft, and the ship types that call on a specific port. One container port, for instance, may have much smaller bulk cargo and reefer ships number of calls on that port than another. Using these three criteria and the eleven typical ports that are suitable for port matching, the 89 deep sea ports and 28 Great Lake ports were matched to the typical ports. For a typical port, the modeled and typical port is the same (i.e., the port simply represents itself). For California ports, we used data provided by ARB as discussed in Section 3.3.2.4. The matched ports for the deep sea ports are provided in Table 3-13.

Table 3-13 Matched Ports for the Deep Sea Ports

Modeled Port Name	Typical Like Port
Anacortes, WA	Puget Sound
Barbers Point, HI	Puget Sound
Everett, WA	Puget Sound
Grays Harbor, WA	Puget Sound
Honolulu, HI	Puget Sound
Kalama, WA	Puget Sound
Longview, WA	Puget Sound
Olympia, WA	Puget Sound

[B] The region in which a port was located was used to group top ports as it was considered a primary influence on the characteristics (size and installed power) of the vessels calling at those ports.

Modeled Port Name	Typical Like Port
Port Angeles, WA	Puget Sound
Portland, OR	Puget Sound
Seattle, WA	Puget Sound
Tacoma, WA	Puget Sound
Vancouver, WA	Puget Sound
Valdez, AK	Puget Sound
Other Puget Sound	Puget Sound
Anchorage, AK	Coos Bay
Coos Bay, OR	Coos Bay
Hilo, HI	Coos Bay
Kahului, HI	Coos Bay
Nawiliwili, HI	Coos Bay
Nikishka, AK	Coos Bay
Beaumont, TX	Houston
Freeport, TX	Houston
Galveston, TX	Houston
Houston, TX	Houston
Port Arthur, TX	Houston
Texas City, TX	Houston
Corpus Christi, TX	Corpus Christi
Lake Charles, LA	Corpus Christi
Mobile, AL	Corpus Christi
Brownsville, TX	Tampa
Gulfport, MS	Tampa
Manatee, FL	Tampa
Matagorda Ship	Tampa
Panama City, FL	Tampa
Pascagoula, MS	Tampa
Pensacola, FL	Tampa
Tampa, FL	Tampa
Everglades, FL	Tampa
New Orleans, LA	Lower Mississippi
Baton Rouge, LA	Lower Mississippi
South Louisiana, LA	Lower Mississippi
Plaquemines, LA	Lower Mississippi
Albany, NY	New York/New Jersey
New York/New Jersey	New York/New Jersey
Portland, ME	New York/New Jersey
Georgetown, SC	Delaware River
Hopewell, VA	Delaware River
Marcus Hook, PA	Delaware River

Modeled Port Name	Typical Like Port
Morehead City, NC	Delaware River
Paulsboro, NJ	Delaware River
Chester, PA	Delaware River
Fall River, MA	Delaware River
New Castle, DE	Delaware River
Penn Manor, PA	Delaware River
Providence, RI	Delaware River
Brunswick, GA	Delaware River
Canaveral, FL	Delaware River
Charleston, SC	Delaware River
New Haven, CT	Delaware River
Palm Beach, FL	Delaware River
Bridgeport, CT	Delaware River
Camden, NJ	Delaware River
Philadelphia, PA	Delaware River
Wilmington, DE	Delaware River
Wilmington, NC	Delaware River
Richmond, VA	Delaware River
Jacksonville, FL	Delaware River
Miami, FL	Delaware River
Searsport, ME	Delaware River
Boston, MA	Delaware River
New Bedford/Fairhaven, MA	Delaware River
Baltimore, MD	Patapsco River
Newport News, VA	Patapsco River
Savannah, GA	Patapsco River
Catalina, CA	ARB Supplied
Carquinez, CA	ARB Supplied
El Segundo, CA	ARB Supplied
Eureka, CA	ARB Supplied
Hueneme, CA	ARB Supplied
Long Beach, CA	ARB Supplied
Los Angeles, CA	ARB Supplied
Oakland, CA	ARB Supplied
Redwood City, CA	ARB Supplied
Richmond, CA	ARB Supplied
Sacramento, CA	ARB Supplied
San Diego, CA	ARB Supplied
San Francisco, CA	ARB Supplied
Stockton, CA	ARB Supplied

Great Lake ports were matched to either Cleveland or Duluth as shown in Table 3-14.

Table 3-14 Great Lake Match Ports

Port Name	Typical Like Port
Alpena, MI	Cleveland
Buffalo, NY	Cleveland
Burns Waterway, IN	Cleveland
Calcite, MI	Cleveland
Cleveland, OH	Cleveland
Dolomite, MI	Cleveland
Erie, PA	Cleveland
Escanaba, MI	Cleveland
Fairport, OH	Cleveland
Gary, IN	Cleveland
Lorain, OH	Cleveland
Marblehead, OH	Cleveland
Milwaukee, WI	Cleveland
Muskegon, MI	Cleveland
Presque Isle, MI	Cleveland
St Clair, MI	Cleveland
Stoneport, MI	Cleveland
Two Harbors, MN	Cleveland
Ashtabula, OH	Duluth-Superior
Chicago, IL	Duluth-Superior
Conneaut, OH	Duluth-Superior
Detroit, MI	Duluth-Superior
Duluth-Superior, MN&WI	Duluth-Superior
Indiana, IN	Duluth-Superior
Inland Harbor, MI	Duluth-Superior
Manistee, MI	Duluth-Superior
Sandusky, OH	Duluth-Superior
Toledo, OH	Duluth-Superior

Once a modeled port was matched to a typical port, the maneuvering and hotelling time-in-mode values, as well as the maneuvering load factors by bin for the typical ports, were used directly for the modeled ports, with no adjustments. The other inputs used for both the typical and modeled ports are as described in Section 3.3.2.3.

3.3.2.3.8.3 Bin Mismatches

In some cases, the specific DWT range bin at the modeled port was not in the typical like port data. In those cases, the next nearest DWT range bin was used for the calculations. In a few cases, the engine type for a given ship type might not be in the typical like port data. In these

cases, the closest engine type at the typical like port was used. Also in a few cases, a specific ship type in the modeled port data was not in the typical like port data. In this case, the nearest like ship type at the typical port was chosen to calculate emissions at the modeled port.

3.3.2.4 Stand Alone Ports

In a few cases, the USACE entrances and clearances data was not used to calculate emissions at the modeled port. These include the California ports for which we received data from ARB, the Port of Valdez, Alaska, and a conglomerate port within the Puget Sound area, as described below.

3.3.2.4.1 California Ports

The California Air Resources Board (ARB) supplied inventories for 14 California ports for 2002. The data received from ARB for the California ports were modified to provide consistent PM and SO_2 emissions to those calculated in this report. In addition, cruise and RSZ emissions were calculated directly based upon average ship power provided in the ARB methodology document[36] and number of calls, because ARB did not calculate cruise emissions, and transit (RSZ) emissions were allocated to counties instead of ports. ARB provided transit distances for each port to calculate the RSZ emissions. Ship propulsion and auxiliary engine power were calculated based upon the methodology in Section 3.3.2.3.1.3 for use in computing cruise and RSZ emissions. For maneuvering and hotelling emissions, the ARB values were used and adjusted as discussed below. The data supplied by ARB included domestic traffic as well as foreign cargo traffic.

For PM emission calculations, ARB used an emission factor of 1.5 g/kWh to calculate total PM emissions and factors of 0.96 and 0.937 to convert total PM to PM_{10} and $PM_{2.5}$ respectively. Since an emission factor of 1.4 g/kWh was used in our calculations for PM_{10} and an emission factor of 1.3 g/kWh for $PM_{2.5}$, ARB PM_{10} and $PM_{2.5}$ emissions were multiplied by factors of 0.972 and 0.925, respectively to get consistent PM_{10} and $PM_{2.5}$ emissions for propulsion engines.

For auxiliary engines, ARB used the same emission factors as above, while we used PM_{10} and $PM_{2.5}$ emission factors of 1.3 and 1.2 g/kWh, respectively for passenger ships and 1.1 and 1.0 g/kWh, respectively for all other ships. In the ARB inventory, all passenger ships are treated as electric drive and all emissions are allocated to auxiliary engines. ARB auxiliary engine emissions were thus multiplied by factors of 0.903 and 0.854 respectively for passenger ships and 0.764 and 0.711 respectively for other ships to provide consistent PM emission calculations.

SO_2 emissions were also different between the ARB and these analyses. ARB used a composite[C] propulsion engine SO_2 emission factor of 10.55 g/kWh while we used a composite SO_2 emission factor of 9.57 g/kWh. Thus, ARB SO_2 propulsion emissions were multiplied by a

[C] Based upon ARB assuming 95 percent of the engines were SSD and 5 percent were MSD. The composite SO_2 EF of 9.57 g/kW-hr was calculated using this weighting, along with the SSD and MSD SO_2 EFs for the West Coast ports reported in Table 3-6.

factor of 0.907 to be consistent with our emission calculations. For auxiliary engines, ARB used SO_2 emission factors of 11.48 and 9.34 g/kWh, respectively for passenger and other ships, while we use emission factors of 9.93 and 9.07 g/kWh, respectively. Thus, ARB auxiliary SO_2 emissions were multiplied by factors of 0.865 and 0.971, respectively for passenger and other ships to provide consistent SO_2 emissions.

3.3.2.4.2 Port in Puget Sound

In the newest Puget Sound inventory[29], it was found that a considerable amount of tanker ships stop at Cherry Point, Ferndale, March Point and other areas which are not within the top 89 U.S. deep sea ports analyzed in this analysis. In addition, since they are ships carrying U.S. cargo (oil from Alaska) from one U.S. port to another, they are not documented in the USACE entrances and clearances data. To compensate for this anomaly, an additional port was added which encompassed these tanker ships stopping within the Puget Sound area but not at one of the Puget Sound ports analyzed in this analysis. Ship calls in the 1996 typical port data to ports other than those in the top 89 U.S. deep sea ports were analyzed separately. There were 363 ship calls by tankers to those areas in 1996. In the inventory report for 2005, there were 468 calls. For 2002, it was estimated there were 432 calls. The same ship types and ship characteristics were used as in the 1996 data, but the number of calls was proportionally increased to 432 calls to represent these ships. The location of the "Other Puget Sound" port was approximately at Cherry Point near Aberdeen.

3.3.2.4.3 Port of Valdez

In a recent Alaska port inventory,[37] it was found that significant Category 3 domestic tanker traffic enters and leaves the Port of Valdez on destination to West Coast ports. Since the USACE entrances and clearances data did not contain any tanker calls at Valdez in 2002, the recent Alaska inventory data was used to calculate emissions at that port. In this case, the number of calls and ship characteristics for 2002 were taken directly from the Alaska inventory and used in determining emissions for the modeled port with the Puget Sound area typical port being used as the like port.

3.3.2.5 Domestic Traffic

One of the concerns with using USACE entrances and clearances data is that it only contains foreign cargo movements moved by either a foreign flag vessel or a U.S. flag vessel. The Maritime Administration (MARAD) maintains the Foreign Traffic Vessel Entrances and Clearances database, which contains statistics on U.S. foreign maritime trade. Data are compiled during the regular processing of statistics on foreign imports and exports. The database contains information on the type of vessel, commodities, weight, customs districts and ports, and origins and destinations of goods. Thus domestic traffic, i.e., U.S. ships delivering cargo from one U.S. port to another U.S. port, is covered under the Jones Act and is not accounted for in the database. However, U.S. flagged ships carrying cargo from a foreign port to a U.S. port or from a U.S. port to a foreign port are accounted for in the USACE entrances and clearances database, as these are considered foreign cargo movements.

Under the Jones Act, domestic cargo movements from one U.S. port to another U.S. port must be carried by a U.S. flag ship. The Jones Act also requires ships traveling between United States ports to be constructed by United States companies and owned by a United States company or citizen. Members of the ships' crews must be United States citizens or legal aliens. Because of the use of USACE data, in the present baseline and future year inventories, only limited Jones Act ships were counted. These ships included those servicing California ports, those serving the Port of Valdez and those serving other Puget Sound ports. At all other ports, Jones Act ships were not counted.

ICF conducted an analysis to estimate the amount of Category 3 Jones Act ships calling at the 117 U.S. ports. This was done by analyzing marine exchange data obtained from port authorities for eleven typical ports and using this information to estimate the Jones Act ship contribution for the remaining ports. Based on this limited analysis, Jones Act ships are estimated to account for 9.2% of the total installed power calling on U.S. ports. Approximately 30% of these ships, largely in the Alaska and Pacific regions, have been included in the 2002 baseline inventory. Based on this analysis, Jones Act ships excluded from this inventory constitute roughly 6.5% of total installed power.[38] This results in an underestimation of the port ship inventory and therefore the benefits of the coordinated program reported in this chapter are also underestimated.

3.3.2.6 2002 Near Port Inventories

This section presents a summary of the baseline near port inventories for 2002. Individual port inventories are presented separately for deep sea ports and Great Lake ports because of the difference in ship types between the two. This is followed by totals for the summed port inventories, provided by engine type (propulsion and auxiliary), mode of operation, and ship type.

3.3.2.6.1 Deep Sea Ports

Emission inventories for the 89 deep sea ports are presented here. Total emissions (propulsion and auxiliary) by ports are given in Table 3-15. Auxiliary only emissions by ports are given in Table 3-16. Emissions by mode are given in Table 3-17 for cruise, Table 3-18 for reduced speed zone, Table 3-19 for maneuvering, and Table 3-20 for hotelling. Emissions by ship type by port are given in Table 3-21 through Table 3-31. Ports that are missing from those lists had no emissions related to that ship type during 2002.

For deep sea ports, auxiliary emissions are responsible for roughly 47% of the NO_X and PM emissions, primarily due to emissions during the hotelling mode. Container and Tanker ships combined are responsible for approximately half the total emissions, followed by Passenger ships and Bulk Carrier ships.

3.3.2.6.2 Great Lake Ports

Emissions inventories for 28 Great Lake ports were developed and are presented here. Great Lake ships include self-unloading bulk carriers (Bulk Carrier, SU) which tend to operate

within the Great Lakes only. Other ships travel down the St. Lawrence River from the open ocean. Integrated tug-barges (ITB) are also used on the Great Lakes.

Total emissions by port for Great Lakes Ports are shown in Table 3-32. Auxiliary engine emissions for Great Lake ports are shown in Table 3-33. Emissions by mode for Great Lake ports are shown in Table 3-34 for cruise, Table 3-35 for reduced speed zone, Table 3-36 for maneuvering, and Table 3-37 for hotelling. Emissions by ship type are shown in Table 3-38 through Table 3-42.

Table 3-15 Total Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	403	32	29	14	32	225	15,462
Barbers Point, HI	472	122	10	9	4	10	71	5,034
Everett, WA	186	82	7	6	3	7	46	3,125
Grays Harbor, WA	360	50	4	4	2	4	30	2,066
Honolulu, HI	8,037	1,268	116	102	47	102	800	54,385
Kalama, WA	1,190	359	30	26	13	30	210	14,555
Longview, WA	1,619	413	34	30	15	35	239	16,495
Olympia, WA	97	56	4	4	2	4	31	2,047
Port Angeles, WA	556	151	13	11	5	12	89	6,042
Portland, OR	11,198	2,307	206	182	117	223	1,320	90,558
Seattle, WA	26,292	6,669	573	513	265	551	3,789	253,190
Tacoma, WA	19,130	5,742	477	428	217	464	3,211	215,754
Vancouver, WA	1,946	446	37	33	17	39	259	17,821
Valdez, AK	6,676	343	37	33	11	27	299	20,789
Other Puget Sound	5,678	2,111	219	197	71	169	1,745	118,629
Anchorage, AK	537	221	18	16	7	17	133	8,236
Coos Bay, OR	399	46	4	3	2	4	27	1,810
Hilo, HI	4,514	929	77	70	27	72	626	44,368
Kahului, HI	2,323	474	39	35	14	37	312	22,094
Nawiliwili, HI	591	122	10	9	4	9	83	5,884
Nikishka, AK	1,110	270	26	24	8	21	209	13,794
Beaumont, TX	12,699	2,106	261	240	91	189	1,972	83,736
Freeport, TX	7,411	714	92	85	25	54	716	28,422
Galveston, TX	6,572	1,014	118	102	35	69	873	43,643
Houston, TX	47,147	4,625	546	491	158	347	4,136	183,952
Port Arthur, TX	3,531	436	52	47	17	37	388	17,342
Texas City, TX	7,382	970	127	117	33	74	986	38,575
Corpus Christi, TX	11,452	1,758	143	132	59	401	1,090	70,240
Lake Charles, LA	6,382	850	80	74	35	239	594	38,409
Mobile, AL	8,200	1,144	95	88	39	303	724	46,155
Brownsville, TX	1,213	175	14	13	6	14	108	7,057
Gulfport, MS	3,556	607	51	46	20	48	414	26,382
Manatee, FL	2,903	667	56	49	22	53	450	28,904
Matagorda Ship	2,504	389	32	28	14	33	239	15,827
Panama City, FL	662	70	6	5	2	6	44	2,789
Pascagoula, MS	3,566	518	44	40	17	42	344	22,223
Pensacola, FL	351	40	3	3	1	3	27	1,726
Tampa, FL	10,941	1,507	129	109	50	121	988	63,033
Everglades, FL	38,304	4,287	402	372	134	334	3,123	198,127
New Orleans, LA	27,575	6,603	556	513	221	536	4,245	272,794
Baton Rouge, LA	4,627	1,985	160	148	63	155	1,223	78,568
South Louisiana, LA	18,366	6,428	519	479	203	502	3,976	257,346
Plaquemines, LA	4,230	1,045	85	78	33	82	658	43,258
Albany, NY	396	103	9	8	4	9	65	4,167
New York/New Jersey	86,980	7,364	622	575	274	621	4,620	296,780
Portland, ME	3,968	722	60	55	23	57	466	30,836
Georgetown, SC	609	89	7	7	3	7	152	3,668
Hopewell, VA	185	45	4	3	2	4	211	1,764

Table 3-15 Total Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	965	79	73	30	76	2,462	40,563
Morehead City, NC	967	121	10	9	4	10	94	5,196
Paulsboro, NJ	3,272	668	55	50	22	54	2,103	26,676
Chester, PA	1,467	196	16	15	7	16	411	7,648
Fall River, MA	290	35	3	3	1	3	52	1,748
New Castle, DE	765	199	16	15	6	16	394	8,257
Penn Manor, PA	721	174	14	13	6	14	656	6,878
Providence, RI	1,097	198	16	15	6	16	334	8,222
Brunswick, GA	5,184	670	54	50	22	53	1,297	26,273
Canaveral, FL	17,801	3,060	281	261	89	233	2,279	139,768
Charleston, SC	46,233	3,809	311	288	133	310	4,519	150,424
New Haven, CT	1,801	287	23	22	9	22	207	12,116
Palm Beach, FL	2,277	219	19	18	7	17	162	9,869
Bridgeport, CT	1,452	247	20	19	8	19	164	10,692
Camden, NJ	4,209	994	82	76	34	83	1,625	41,540
Philadelphia, PA	7,644	1,684	140	129	55	140	3,363	70,523
Wilmington, DE	4,444	627	52	48	23	54	1,011	25,319
Wilmington, NC	4,888	641	53	49	22	52	956	26,264
Richmond, VA	596	86	7	7	3	8	206	3,333
Jacksonville, FL	13,908	1,507	125	116	51	122	1,652	62,457
Miami, FL	57,415	7,155	650	602	218	551	5,340	322,880
Searsport, ME	543	110	9	8	3	9	124	4,769
Boston, MA	13,290	1,647	146	135	53	131	1,572	74,625
New Bedford/Fairhaven, MA	181	39	3	3	1	3	33	1,700
Baltimore, MD	25,197	6,412	519	481	212	502	3,918	244,560
Newport News, VA	5,529	505	41	38	17	41	316	19,760
Savannah, GA	37,523	3,594	289	267	126	291	2,174	137,046
Catalina, CA	928	78	7	7	2	6	53	3,639
Carquinez, CA	3,442	537	39	36	17	42	309	20,535
El Segundo, CA	1,685	192	14	13	6	15	108	7,095
Eureka, CA	409	82	6	5	2	6	51	3,486
Hueneme, CA	3,334	319	22	21	10	280	190	12,820
Long Beach, CA	56,935	5,303	389	357	166	417	3,141	213,005
Los Angeles, CA	50,489	4,793	352	324	150	378	2,839	192,430
Oakland, CA	48,762	3,022	222	205	100	239	1,638	110,003
Redwood City, CA	456	107	8	7	3	8	64	4,317
Richmond, CA	3,956	484	35	33	15	37	277	18,361
Sacramento, CA	455	138	10	9	4	11	81	5,417
San Diego, CA	8,255	840	68	63	25	65	536	36,609
San Francisco, CA	6,260	684	53	49	21	53	419	28,356
Stockton, CA	1,210	332	24	22	10	26	192	12,830
Total Port Emissions	863,191	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
Total Port Emissions (short tons)		***134,047***	***11,608***	***10,616***	***4,572***	***11,723***	***103,515***	***5,507,005***

Table 3-16 Auxiliary Engine Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	115	147	11	10	4	11	92	6,798
Barbers Point, HI	101	77	6	5	2	6	48	3,568
Everett, WA	40	21	2	1	1	2	13	977
Grays Harbor, WA	73	25	2	2	1	2	16	1,176
Honolulu, HI	2,043	793	67	61	22	60	522	36,366
Kalama, WA	260	172	13	12	5	13	108	7,930
Longview, WA	346	183	14	13	5	14	115	8,445
Olympia, WA	21	9	1	1	0	1	6	410
Port Angeles, WA	111	42	3	3	1	3	26	1,922
Portland, OR	2,560	924	70	64	26	70	580	42,675
Seattle, WA	5,947	1,472	116	106	41	112	939	67,795
Tacoma, WA	4,305	1,279	97	88	35	97	802	59,093
Vancouver, WA	427	182	14	13	5	14	114	8,402
Valdez, AK	1,411	256	20	18	7	19	161	11,836
Other Puget Sound	1,198	951	72	66	26	72	596	43,927
Anchorage, AK	158	99	8	7	3	8	63	3,683
Coos Bay, OR	78	21	2	2	1	2	14	949
Hilo, HI	1,251	815	64	58	23	64	529	38,048
Kahului, HI	642	412	32	29	12	32	267	19,178
Nawiliwili, HI	164	108	8	8	3	8	70	5,023
Nikishka, AK	235	132	10	9	4	10	83	5,623
Beaumont, TX	2,415	873	149	135	31	63	1,188	40,334
Freeport, TX	1,342	321	58	53	11	24	461	14,819
Galveston, TX	1,645	674	89	75	24	42	660	31,135
Houston, TX	8,410	1,827	305	268	64	129	2,352	84,373
Port Arthur, TX	640	173	29	25	6	12	220	8,002
Texas City, TX	1,414	418	78	71	15	31	626	19,301
Corpus Christi, TX	2,486	770	64	59	21	59	514	35,563
Lake Charles, LA	1,347	457	38	35	13	35	305	21,105
Mobile, AL	1,816	423	35	32	12	32	282	19,529
Brownsville, TX	260	84	7	6	2	6	56	3,899
Gulfport, MS	878	415	34	30	11	31	292	19,017
Manatee, FL	902	491	41	35	13	37	343	22,448
Matagorda Ship	535	202	17	14	6	15	131	9,318
Panama City, FL	130	28	2	2	1	2	19	1,315
Pascagoula, MS	795	277	23	20	8	21	187	12,772
Pensacola, FL	87	20	2	1	1	1	14	906
Tampa, FL	2,639	777	67	51	21	59	534	35,735
Everglades, FL	9,813	3,032	277	256	84	230	2,158	140,039
New Orleans, LA	6,376	3,426	295	271	95	260	2,343	158,234
Baton Rouge, LA	988	813	67	62	22	62	543	37,544
South Louisiana, LA	3,988	2,969	246	226	82	226	1,982	137,151
Plaquemines, LA	919	607	50	46	17	46	406	28,058
Albany, NY	85	46	4	3	1	3	31	2,111
New York/New Jersey	20,036	3,467	294	270	96	263	2,343	159,839
Portland, ME	883	477	40	37	13	36	320	22,034
Georgetown, SC	129	42	3	3	1	3	28	1,960
Hopewell, VA	40	16	1	1	0	1	11	757

Table 3-16 Auxiliary Engine Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	583	617	51	47	17	47	412	28,518
Morehead City, NC	203	74	6	6	2	6	49	3,421
Paulsboro, NJ	701	294	25	23	8	22	198	13,584
Chester, PA	318	63	5	5	2	5	42	2,897
Fall River, MA	61	17	2	2	1	2	15	1,035
New Castle, DE	164	120	10	9	3	9	80	5,532
Penn Manor, PA	159	69	6	5	2	5	46	3,204
Providence, RI	236	118	10	9	3	9	79	5,436
Brunswick, GA	1,302	263	22	20	7	20	176	12,160
Canaveral, FL	4,916	2,486	225	209	68	187	1,804	113,582
Charleston, SC	10,277	1,630	136	124	45	124	1,093	75,271
New Haven, CT	379	188	16	14	5	14	125	8,664
Palm Beach, FL	506	132	11	10	4	10	89	6,082
Bridgeport, CT	522	187	15	14	5	14	125	8,625
Camden, NJ	1,286	579	48	44	16	44	387	26,754
Philadelphia, PA	1,803	976	81	74	27	74	652	45,081
Wilmington, DE	1,155	303	25	23	8	23	202	13,982
Wilmington, NC	1,045	333	28	25	9	25	223	15,397
Richmond, VA	130	26	2	2	1	2	18	1,216
Jacksonville, FL	3,242	776	64	59	21	59	516	35,693
Miami, FL	14,504	5,171	462	428	142	389	3,711	236,659
Searsport, ME	116	73	6	6	2	6	49	3,380
Boston, MA	3,100	1,105	94	87	30	84	759	50,846
New Bedford/Fairhaven, MA	53	28	2	2	1	2	19	1,280
Baltimore, MD	5,924	1,632	137	126	45	52	1,111	75,309
Newport News, VA	1,216	170	14	13	5	13	122	8,063
Savannah, GA	8,297	1,035	83	76	29	79	691	47,804
Catalina, CA	257	45	4	4	1	3	28	2,043
Carquinez, CA	772	193	13	11	5	15	128	8,706
El Segundo, CA	355	47	3	3	1	4	32	2,117
Eureka, CA	88	59	4	4	2	5	38	2,661
Hueneme, CA	1,010	177	11	10	5	47	115	7,955
Long Beach, CA	13,007	2,632	178	162	72	205	1,704	119,333
Los Angeles, CA	11,535	2,356	160	145	65	184	1,525	106,855
Oakland, CA	10,759	860	57	52	24	67	551	39,102
Redwood City, CA	101	59	4	3	2	5	39	2,665
Richmond, CA	866	164	11	10	5	13	109	7,403
Sacramento, CA	95	61	4	4	2	5	40	2,754
San Diego, CA	2,164	483	37	34	13	37	311	21,942
San Francisco, CA	1,480	345	25	23	9	27	224	15,630
Stockton, CA	259	125	8	7	3	10	82	5,673
Total Auxiliary Emissions	197,430	57,317	5,052	4,597	1,615	4,306	41,232	2,635,436
Total Auxiliary Emissions (short tons)		***63,181***	***5,569***	***5,067***	***1,781***	***4,746***	***45,450***	***2,905,071***

Table 3-17 Cruise Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	50	4	4	2	4	29	1,871
Barbers Point, HI	472	28	2	2	1	2	16	1,039
Everett, WA	186	9	1	1	0	1	6	385
Grays Harbor, WA	360	15	1	1	1	1	10	627
Honolulu, HI	8,037	300	28	26	10	23	206	13,469
Kalama, WA	1,190	72	6	6	2	6	45	2,949
Longview, WA	1,619	89	8	7	3	7	55	3,597
Olympia, WA	97	5	0	0	0	0	3	184
Port Angeles, WA	556	27	2	2	1	2	17	1,134
Portland, OR	11,198	424	40	37	15	33	291	19,040
Seattle, WA	26,292	775	74	69	27	59	544	35,599
Tacoma, WA	19,130	622	59	55	22	49	428	28,010
Vancouver, WA	1,946	88	8	7	3	7	56	3,650
Valdez, AK	6,676	45	8	8	2	4	75	4,904
Other Puget Sound	5,678	197	24	22	7	15	202	13,218
Anchorage, AK	537	22	2	2	1	2	14	934
Coos Bay, OR	399	21	2	2	1	2	12	758
Hilo, HI	4,514	108	14	13	4	9	109	7,278
Kahului, HI	2,323	58	7	6	2	5	51	3,382
Nawiliwili, HI	591	14	2	2	1	1	15	984
Nikishka, AK	1,110	32	4	4	1	3	34	2,220
Beaumont, TX	12,699	665	52	48	22	51	384	23,253
Freeport, TX	7,411	362	28	26	12	28	209	12,624
Galveston, TX	6,572	283	23	22	9	22	175	10,741
Houston, TX	47,147	2,180	173	161	72	169	1,290	78,115
Port Arthur, TX	3,531	184	15	13	6	14	108	6,521
Texas City, TX	7,382	386	30	28	13	30	224	13,579
Corpus Christi, TX	11,452	584	46	43	19	45	341	20,702
Lake Charles, LA	6,382	266	25	23	9	21	195	11,811
Mobile, AL	8,200	402	33	30	13	31	247	14,961
Brownsville, TX	1,213	69	5	5	2	5	40	2,453
Gulfport, MS	3,556	148	13	12	5	12	95	5,765
Manatee, FL	2,903	132	11	10	4	10	82	4,991
Matagorda Ship	2,504	143	11	10	5	11	83	5,021
Panama City, FL	662	35	3	3	1	3	20	1,240
Pascagoula, MS	3,566	181	15	14	6	15	118	7,155
Pensacola, FL	351	16	1	1	1	1	10	635
Tampa, FL	10,941	539	45	42	18	42	341	20,705
Everglades, FL	38,304	1,348	131	121	45	104	1,038	62,951
New Orleans, LA	27,575	1,249	102	94	41	97	761	46,164
Baton Rouge, LA	4,627	238	19	17	8	18	139	8,439
South Louisiana, LA	18,366	961	75	70	32	74	557	33,789
Plaquemines, LA	4,230	221	17	16	7	17	128	7,766
Albany, NY	396	20	2	2	1	2	12	734
New York/New Jersey	86,980	3,266	261	242	108	253	1,940	117,641
Portland, ME	3,968	195	16	15	6	15	118	7,131
Georgetown, SC	609	31	3	2	1	2	19	1,153
Hopewell, VA	185	10	1	1	0	1	6	356

Table 3-17 Cruise Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	143	11	10	5	11	82	4,974
Morehead City, NC	967	44	4	3	1	3	28	1,687
Paulsboro, NJ	3,272	166	13	12	5	13	97	5,887
Chester, PA	1,467	63	5	5	2	5	37	2,261
Fall River, MA	290	13	1	1	0	1	9	540
New Castle, DE	765	41	3	3	1	3	23	1,415
Penn Manor, PA	721	38	3	3	1	3	22	1,351
Providence, RI	1,097	58	4	4	2	4	33	2,007
Brunswick, GA	5,184	222	17	16	7	17	129	7,816
Canaveral, FL	17,801	665	54	50	22	52	501	30,423
Charleston, SC	46,233	1,702	133	123	56	132	986	59,738
New Haven, CT	1,801	92	7	7	3	7	54	3,259
Palm Beach, FL	2,277	83	8	7	3	6	60	3,623
Bridgeport, CT	1,452	58	4	4	2	5	34	2,073
Camden, NJ	4,209	191	15	14	6	15	113	6,874
Philadelphia, PA	7,644	326	26	24	11	25	194	11,761
Wilmington, DE	4,444	178	14	13	6	14	104	6,283
Wilmington, NC	4,888	213	17	16	7	16	125	7,597
Richmond, VA	596	25	2	2	1	2	15	891
Jacksonville, FL	13,908	571	46	43	19	44	349	21,139
Miami, FL	57,415	2,068	173	161	70	161	1,497	90,831
Searsport, ME	543	27	2	2	1	2	17	1,018
Boston, MA	13,290	465	41	38	16	36	340	20,603
New Bedford/Fairhaven, MA	181	8	1	1	0	1	5	331
Baltimore, MD	25,197	1,013	81	75	34	78	600	36,410
Newport News, VA	5,529	214	17	16	7	17	125	7,560
Savannah, GA	37,523	1,400	110	102	46	108	815	49,371
Catalina, CA	928	36	4	3	1	3	26	1,700
Carquinez, CA	3,442	171	13	12	6	13	92	6,025
El Segundo, CA	1,685	87	7	6	3	7	47	3,068
Eureka, CA	409	19	2	1	1	1	11	699
Hueneme, CA	3,334	137	11	10	5	11	74	4,862
Long Beach, CA	56,935	2,093	168	156	69	162	1,165	76,254
Los Angeles, CA	50,489	1,856	149	138	62	144	1,033	67,622
Oakland, CA	48,762	1,676	131	122	55	130	900	58,866
Redwood City, CA	456	24	2	2	1	2	13	851
Richmond, CA	3,956	197	15	14	7	15	106	6,936
Sacramento, CA	455	23	2	2	1	2	13	821
San Diego, CA	8,255	336	30	28	11	26	217	14,243
San Francisco, CA	6,260	273	23	21	9	21	162	10,632
Stockton, CA	1,210	63	5	5	2	5	34	2,216
Total Cruise Emissions	863,191	34,193	2,826	2,623	1,141	2,651	21,186	1,314,146
Total Cruise Emissions (short tons)		***37,691***	***3,115***	***2,891***	***1,258***	***2,922***	***23,353***	***1,448,598***

Table 3-18 Reduced Speed Zone Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	191	15	14	6	15	103	6,773
Barbers Point, HI	472	3	0	0	0	0	2	125
Everett, WA	186	49	4	4	2	4	27	1,785
Grays Harbor, WA	360	3	0	0	0	0	2	109
Honolulu, HI	8,037	75	7	6	3	6	48	3,223
Kalama, WA	1,190	101	8	7	4	9	57	3,800
Longview, WA	1,619	125	10	9	5	11	70	4,645
Olympia, WA	97	43	3	3	1	3	23	1,509
Port Angeles, WA	556	77	6	6	3	6	45	2,924
Portland, OR	11,198	969	86	79	58	108	539	36,288
Seattle, WA	26,292	4,289	349	323	151	347	2,402	157,988
Tacoma, WA	19,130	3,685	290	269	121	285	2,023	133,271
Vancouver, WA	1,946	175	14	13	7	16	100	6,661
Valdez, AK	6,676	33	5	5	1	3	46	3,044
Other Puget Sound	5,678	963	112	104	32	75	942	61,929
Anchorage, AK	537	121	10	9	4	10	71	3,721
Coos Bay, OR	399	5	0	0	0	1	3	123
Hilo, HI	4,514	27	2	2	1	2	18	339
Kahului, HI	2,323	14	1	1	0	1	9	156
Nawiliwili, HI	591	4	0	0	0	0	2	47
Nikishka, AK	1,110	117	12	12	4	9	99	5,979
Beaumont, TX	12,699	771	81	75	45	88	574	29,868
Freeport, TX	7,411	28	2	2	1	2	18	1,016
Galveston, TX	6,572	101	10	9	4	8	73	3,958
Houston, TX	47,147	656	57	53	22	50	429	24,233
Port Arthur, TX	3,531	97	10	9	6	11	71	3,760
Texas City, TX	7,382	181	16	14	6	14	117	6,581
Corpus Christi, TX	11,452	419	33	31	14	293	250	15,432
Lake Charles, LA	6,382	175	20	19	13	185	124	7,805
Mobile, AL	8,200	352	29	27	12	239	219	13,537
Brownsville, TX	1,213	23	2	1	1	2	12	879
Gulfport, MS	3,556	50	4	3	2	5	27	2,070
Manatee, FL	2,903	78	7	4	3	7	36	3,183
Matagorda Ship	2,504	55	5	3	3	6	27	2,117
Panama City, FL	662	7	1	0	0	1	4	263
Pascagoula, MS	3,566	68	6	5	2	6	40	2,788
Pensacola, FL	351	5	0	0	0	0	3	225
Tampa, FL	10,941	329	29	16	12	28	159	13,321
Everglades, FL	38,304	71	7	7	3	7	52	3,225
New Orleans, LA	27,575	2,670	224	208	98	227	1,678	103,988
Baton Rouge, LA	4,627	1,091	87	80	36	85	648	40,082
South Louisiana, LA	18,366	2,897	229	212	95	225	1,712	105,846
Plaquemines, LA	4,230	244	19	18	8	19	144	8,910
Albany, NY	396	48	4	4	2	5	30	1,845
New York/New Jersey	86,980	881	83	76	54	105	547	34,706
Portland, ME	3,968	48	4	4	2	4	30	1,839
Georgetown, SC	609	16	1	1	1	1	105	615
Hopewell, VA	185	22	2	2	1	2	196	781

Table 3-18 Reduced Speed Zone Emissions by Deep Sea Port in 2002(continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	245	20	18	9	20	1,996	9,058
Morehead City, NC	967	2	0	0	0	0	16	75
Paulsboro, NJ	3,272	254	21	19	9	21	1,841	9,527
Chester, PA	1,467	86	7	7	3	8	343	3,292
Fall River, MA	290	5	0	0	0	0	29	231
New Castle, DE	765	45	4	3	1	4	295	1,671
Penn Manor, PA	721	82	7	6	3	7	598	3,045
Providence, RI	1,097	26	2	2	1	2	225	971
Brunswick, GA	5,184	215	17	16	7	17	1,015	7,867
Canaveral, FL	17,801	73	7	7	2	6	94	3,316
Charleston, SC	46,233	539	44	41	22	50	2,504	20,265
New Haven, CT	1,801	4	0	0	0	0	27	146
Palm Beach, FL	2,277	5	0	0	0	0	14	235
Bridgeport, CT	1,452	2	0	0	0	0	6	98
Camden, NJ	4,209	346	29	27	14	32	1,208	13,693
Philadelphia, PA	7,644	505	43	40	19	48	2,603	19,709
Wilmington, DE	4,444	206	17	16	10	20	747	7,996
Wilmington, NC	4,888	110	9	9	5	10	620	4,169
Richmond, VA	596	44	4	3	2	4	180	1,688
Jacksonville, FL	13,908	206	17	16	8	19	820	8,030
Miami, FL	57,415	182	17	16	6	15	331	8,194
Searsport, ME	543	11	1	1	0	1	59	442
Boston, MA	13,290	135	13	12	6	13	514	6,009
New Bedford/Fairhaven, MA	181	4	0	0	0	0	10	158
Baltimore, MD	25,197	4,325	347	321	142	336	2,596	159,626
Newport News, VA	5,529	131	11	10	5	11	86	4,998
Savannah, GA	37,523	1,333	107	99	46	110	802	49,492
Catalina, CA	928	11	1	1	0	1	8	523
Carquinez, CA	3,442	183	14	13	6	14	100	6,591
El Segundo, CA	1,685	58	5	4	2	5	32	2,093
Eureka, CA	409	4	0	0	0	0	2	165
Hueneme, CA	3,334	8	1	1	0	256	5	251
Long Beach, CA	56,935	748	62	58	30	69	436	29,056
Los Angeles, CA	50,489	755	63	58	30	69	440	29,305
Oakland, CA	48,762	524	43	40	23	53	272	18,380
Redwood City, CA	456	25	2	2	1	2	14	905
Richmond, CA	3,956	123	10	9	4	10	67	4,427
Sacramento, CA	455	58	5	4	2	4	32	2,088
San Diego, CA	8,255	98	9	8	3	8	63	4,198
San Francisco, CA	6,260	101	8	8	3	8	61	4,015
Stockton, CA	1,210	156	12	11	5	12	85	5,586
Total RSZ Emissions	863,191	34,427	2,887	2,657	1,280	3,804	35,148	1,318,897
Total RSZ Emissions (short tons)		***37,949***	***3,182***	***2,929***	***1,410***	***4,193***	***38,744***	***1,453,835***

Table 3-19 Maneuvering Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	50	5	3	3	5	23	1,610
Barbers Point, HI	472	25	2	2	1	2	12	806
Everett, WA	186	9	1	1	1	1	4	301
Grays Harbor, WA	360	12	1	1	1	1	6	412
Honolulu, HI	8,037	360	36	28	19	32	194	13,248
Kalama, WA	1,190	63	6	4	4	6	31	2,122
Longview, WA	1,619	72	7	5	4	7	35	2,411
Olympia, WA	97	3	0	0	0	0	2	109
Port Angeles, WA	556	19	2	1	1	2	10	666
Portland, OR	11,198	501	49	37	33	50	232	16,173
Seattle, WA	26,292	980	100	76	70	98	445	30,829
Tacoma, WA	19,130	810	81	62	57	82	368	25,644
Vancouver, WA	1,946	75	7	5	4	8	37	2,538
Valdez, AK	6,676	55	8	6	3	5	46	3,156
Other Puget Sound	5,678	252	29	22	13	25	163	11,182
Anchorage, AK	537	1	0	0	0	0	1	54
Coos Bay, OR	399	1	0	0	0	0	0	26
Hilo, HI	4,514	12	1	1	1	1	8	557
Kahului, HI	2,323	6	1	1	0	1	4	283
Nawiliwili, HI	591	1	0	0	0	0	1	73
Nikishka, AK	1,110	2	0	0	0	0	1	90
Beaumont, TX	12,699	49	14	12	2	4	95	1,909
Freeport, TX	7,411	23	7	6	1	2	45	898
Galveston, TX	6,572	40	12	5	1	3	38	1,676
Houston, TX	47,147	169	47	31	6	13	255	6,754
Port Arthur, TX	3,531	17	5	3	1	1	25	683
Texas City, TX	7,382	28	8	7	1	2	59	1,063
Corpus Christi, TX	11,452	112	11	10	8	14	68	4,385
Lake Charles, LA	6,382	54	6	5	4	6	38	2,414
Mobile, AL	8,200	70	7	6	5	8	44	2,835
Brownsville, TX	1,213	8	1	1	1	1	7	323
Gulfport, MS	3,556	27	3	2	2	3	20	1,025
Manatee, FL	2,903	33	3	3	2	4	25	1,301
Matagorda Ship	2,504	16	2	1	1	2	13	609
Panama City, FL	662	4	0	0	0	0	3	144
Pascagoula, MS	3,566	20	2	2	1	2	18	829
Pensacola, FL	351	2	0	0	0	0	2	68
Tampa, FL	10,941	66	7	6	4	8	95	2,637
Everglades, FL	38,304	233	24	23	12	23	163	10,273
New Orleans, LA	27,575	192	19	17	13	22	118	7,540
Baton Rouge, LA	4,627	35	3	3	2	4	21	1,371
South Louisiana, LA	18,366	143	14	12	10	18	87	5,606
Plaquemines, LA	4,230	33	3	3	2	4	20	1,297
Albany, NY	396	3	0	0	0	0	2	120
New York/New Jersey	86,980	455	46	42	36	54	265	17,069
Portland, ME	3,968	37	4	3	2	4	23	1,472
Georgetown, SC	609	3	0	0	0	0	2	126
Hopewell, VA	185	1	0	0	0	0	1	39

Table 3-19 Maneuvering Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	22	2	2	2	3	14	874
Morehead City, NC	967	5	0	0	0	1	3	204
Paulsboro, NJ	3,272	24	2	2	2	3	15	953
Chester, PA	1,467	5	1	1	0	1	3	204
Fall River, MA	290	1	0	0	0	0	1	60
New Castle, DE	765	5	0	0	0	1	3	196
Penn Manor, PA	721	4	0	0	0	0	2	159
Providence, RI	1,097	7	1	1	0	1	4	269
Brunswick, GA	5,184	25	2	2	2	3	15	974
Canaveral, FL	17,801	70	7	6	3	6	50	3,118
Charleston, SC	46,233	199	20	19	17	24	112	7,263
New Haven, CT	1,801	11	1	1	1	1	7	435
Palm Beach, FL	2,277	9	1	1	1	1	6	388
Bridgeport, CT	1,452	10	1	1	1	1	6	419
Camden, NJ	4,209	27	3	2	2	3	17	1,090
Philadelphia, PA	7,644	46	4	4	3	6	28	1,790
Wilmington, DE	4,444	22	2	2	2	3	13	861
Wilmington, NC	4,888	24	2	2	2	3	14	922
Richmond, VA	596	2	0	0	0	0	1	79
Jacksonville, FL	13,908	66	6	6	5	8	40	2,587
Miami, FL	57,415	241	25	23	14	24	164	10,379
Searsport, ME	543	4	0	0	0	0	2	147
Boston, MA	13,290	65	7	6	4	7	44	2,812
New Bedford/Fairhaven, MA	181	1	0	0	0	0	1	52
Baltimore, MD	25,197	130	13	12	10	15	76	4,931
Newport News, VA	5,529	25	3	2	2	3	14	929
Savannah, GA	37,523	164	17	15	14	20	91	5,936
Catalina, CA	928	10	1	1	0	1	6	455
Carquinez, CA	3,442	23	1	1	1	1	11	740
El Segundo, CA	1,685	9	1	1	0	1	4	287
Eureka, CA	409	4	0	0	0	0	2	133
Hueneme, CA	3,334	9	0	0	0	1	4	294
Long Beach, CA	56,935	272	15	13	6	15	120	8,669
Los Angeles, CA	50,489	242	13	12	5	13	106	7,687
Oakland, CA	48,762	241	10	9	5	11	89	6,472
Redwood City, CA	456	3	0	0	0	0	1	83
Richmond, CA	3,956	26	2	1	1	2	12	838
Sacramento, CA	455	3	0	0	0	0	1	84
San Diego, CA	8,255	80	6	6	2	6	46	3,409
San Francisco, CA	6,260	54	4	4	1	4	29	2,105
Stockton, CA	1,210	7	0	0	0	0	3	220
Total Maneuver Emissions	863,191	7,383	758	625	440	724	4,356	266,262
Total Maneuver Emissions (short tons)		***8,138***	***835***	***689***	***485***	***799***	***4,802***	***293,504***

Table 3-20 Hotelling Emissions by Deep Sea Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	545	113	9	8	3	9	71	5,207
Barbers Point, HI	472	66	5	5	2	5	42	3,064
Everett, WA	186	14	1	1	0	1	9	653
Grays Harbor, WA	360	20	2	1	1	2	12	918
Honolulu, HI	8,037	533	45	41	15	40	352	24,445
Kalama, WA	1,190	123	9	9	3	9	77	5,684
Longview, WA	1,619	126	10	9	3	10	79	5,842
Olympia, WA	97	5	0	0	0	0	3	245
Port Angeles, WA	556	29	2	2	1	2	18	1,319
Portland, OR	11,198	413	31	29	11	31	259	19,057
Seattle, WA	26,292	625	49	45	17	47	399	28,774
Tacoma, WA	19,130	624	47	43	17	47	391	28,829
Vancouver, WA	1,946	108	8	7	3	8	67	4,972
Valdez, AK	6,676	210	16	15	6	16	132	9,685
Other Puget Sound	5,678	699	53	48	19	53	438	32,299
Anchorage, AK	537	76	6	5	2	6	47	3,527
Coos Bay, OR	399	20	1	1	1	1	12	903
Hilo, HI	4,514	784	60	54	22	60	491	36,194
Kahului, HI	2,323	396	30	27	11	30	248	18,273
Nawiliwili, HI	591	103	8	7	3	8	65	4,780
Nikishka, AK	1,110	119	9	8	3	9	75	5,505
Beaumont, TX	12,699	622	114	105	22	46	919	28,707
Freeport, TX	7,411	301	55	51	11	22	445	13,884
Galveston, TX	6,572	590	73	67	21	36	587	27,267
Houston, TX	47,147	1,621	269	246	57	115	2,162	74,850
Port Arthur, TX	3,531	138	23	21	5	10	184	6,379
Texas City, TX	7,382	376	73	67	13	28	585	17,352
Corpus Christi, TX	11,452	643	53	49	18	49	430	29,720
Lake Charles, LA	6,382	355	29	27	10	27	237	16,379
Mobile, AL	8,200	321	27	24	9	24	214	14,822
Brownsville, TX	1,213	74	6	6	2	6	49	3,402
Gulfport, MS	3,556	382	31	29	10	29	272	17,521
Manatee, FL	2,903	425	35	32	12	32	307	19,428
Matagorda Ship	2,504	175	15	13	5	13	117	8,080
Panama City, FL	662	25	2	2	1	2	16	1,141
Pascagoula, MS	3,566	248	21	19	7	19	168	11,451
Pensacola, FL	351	17	1	1	0	1	12	797
Tampa, FL	10,941	573	49	45	16	43	392	26,370
Everglades, FL	38,304	2,634	240	222	73	200	1,870	121,678
New Orleans, LA	27,575	2,492	211	194	69	189	1,688	115,102
Baton Rouge, LA	4,627	621	51	47	17	47	414	28,676
South Louisiana, LA	18,366	2,427	201	185	67	185	1,620	112,104
Plaquemines, LA	4,230	547	45	42	15	42	365	25,286
Albany, NY	396	32	3	2	1	2	21	1,467
New York/New Jersey	86,980	2,762	234	215	76	210	1,867	127,364
Portland, ME	3,968	442	37	34	12	34	296	20,394
Georgetown, SC	609	38	3	3	1	3	26	1,773
Hopewell, VA	185	13	1	1	0	1	9	589

Table 3-20 Hotelling Emissions by Deep Sea Port in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Marcus Hook, PA	2,754	555	46	42	15	42	371	25,657
Morehead City, NC	967	70	6	5	2	5	47	3,230
Paulsboro, NJ	3,272	223	19	17	6	17	150	10,309
Chester, PA	1,467	41	3	3	1	3	27	1,891
Fall River, MA	290	15	2	2	1	2	13	918
New Castle, DE	765	108	9	8	3	8	72	4,975
Penn Manor, PA	721	50	4	4	1	4	34	2,323
Providence, RI	1,097	108	9	8	3	8	72	4,975
Brunswick, GA	5,184	208	17	16	6	16	139	9,616
Canaveral, FL	17,801	2,252	213	198	62	169	1,634	102,912
Charleston, SC	46,233	1,368	114	105	38	104	917	63,159
New Haven, CT	1,801	179	15	14	5	14	120	8,276
Palm Beach, FL	2,277	122	10	9	3	9	82	5,623
Bridgeport, CT	1,452	175	15	13	5	13	117	8,102
Camden, NJ	4,209	430	36	33	12	33	287	19,882
Philadelphia, PA	7,644	807	67	61	22	61	539	37,262
Wilmington, DE	4,444	220	18	17	6	17	147	10,180
Wilmington, NC	4,888	294	24	22	8	22	196	13,576
Richmond, VA	596	15	1	1	0	1	10	675
Jacksonville, FL	13,908	665	55	51	18	51	444	30,702
Miami, FL	57,415	4,665	434	402	128	351	3,348	213,476
Searsport, ME	543	68	6	5	2	5	46	3,163
Boston, MA	13,290	982	85	78	27	74	673	45,202
New Bedford/Fairhaven, MA	181	25	2	2	1	2	17	1,160
Baltimore, MD	25,197	944	79	73	26	72	646	43,593
Newport News, VA	5,529	136	11	10	4	10	91	6,274
Savannah, GA	37,523	698	55	50	19	53	466	32,248
Catalina, CA	928	21	2	2	1	2	13	961
Carquinez, CA	3,442	159	10	9	4	13	107	7,178
El Segundo, CA	1,685	37	2	2	1	3	25	1,646
Eureka, CA	409	55	4	3	2	4	36	2,489
Hueneme, CA	3,334	164	11	10	5	13	107	7,413
Long Beach, CA	56,935	2,189	144	130	60	172	1,420	99,027
Los Angeles, CA	50,489	1,941	127	116	53	152	1,259	87,816
Oakland, CA	48,762	581	37	34	16	46	376	26,285
Redwood City, CA	456	55	4	3	2	4	36	2,479
Richmond, CA	3,956	137	9	8	4	11	92	6,160
Sacramento, CA	455	54	3	3	1	4	35	2,424
San Diego, CA	8,255	326	23	21	9	25	209	14,758
San Francisco, CA	6,260	257	18	16	7	20	167	11,604
Stockton, CA	1,210	107	7	6	3	8	70	4,808
Total Hotel Emissions	863,191	45,603	4,060	3,726	1,287	3,456	33,218	2,096,566
Total Hotel Emissions (short tons)		***50,268***	***4,475***	***4,107***	***1,419***	***3,809***	***36,617***	***2,311,068***

Table 3-21 Auto Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	539	59	5	5	3	5	35	2,397
Port Angeles, WA	6	1	0	0	0	0	1	47
Portland, OR	2,331	416	38	33	21	42	246	16,911
Seattle, WA	9	3	0	0	0	0	2	109
Tacoma, WA	2,123	733	61	55	27	59	414	27,690
Vancouver, WA	278	48	4	4	2	5	28	1,946
Beaumont, TX	31	4	1	1	0	0	4	195
Galveston, TX	560	59	6	5	2	4	43	2,372
Houston, TX	1,141	122	12	11	4	8	92	5,019
Mobile, AL	692	72	6	6	2	16	47	2,993
Manatee, FL	4	0	0	0	0	0	0	14
Matagorda Ship	16	1	0	0	0	0	1	48
Pensacola, FL	169	13	1	1	0	1	8	520
Tampa, FL	284	24	2	2	1	2	15	994
Everglades, FL	136	22	2	2	1	2	14	938
New Orleans, LA	225	50	4	4	2	4	32	2,089
South Louisiana, LA	16	3	0	0	0	0	2	129
New York/New Jersey	4,588	361	30	28	15	32	218	13,923
Morehead City, NC	35	3	0	0	0	0	2	102
Chester, PA	9	2	0	0	0	0	4	65
Brunswick, GA	3,350	368	30	28	12	29	499	14,351
Canaveral, FL	53	4	0	0	0	0	3	153
Charleston, SC	1,922	182	15	14	6	14	169	7,234
Bridgeport, CT	40	3	0	0	0	0	2	133
Camden, NJ	0	0	0	0	0	0	0	0
Philadelphia, PA	111	16	1	1	1	1	27	604
Wilmington, DE	1,012	126	10	10	5	11	180	5,014
Jacksonville, FL	4,420	389	32	29	14	32	362	15,430
Miami, FL	131	10	1	1	0	1	7	395
Boston, MA	744	62	5	5	2	5	54	2,495
Baltimore, MD	5,458	1,290	103	95	43	101	768	48,152
Newport News, VA	270	27	2	2	1	2	20	1,127
Savannah, GA	644	76	6	6	3	6	46	2,898
Carquinez, CA	682	84	6	6	3	6	49	3,246
Hueneme, CA	2,036	125	9	8	4	157	71	4,650
Long Beach, CA	1,068	96	7	6	3	7	55	3,681
Los Angeles, CA	947	87	6	6	3	7	50	3,339
Oakland, CA	10	1	0	0	0	0	1	42
Richmond, CA	468	51	4	3	2	4	30	1,986
San Diego, CA	1,374	131	9	9	4	10	77	5,123
San Francisco, CA	20	2	0	0	0	0	1	81
Total Auto Carrier	37,954	5,125	421	384	185	577	3,676	198,637
Total Auto Carrier (short tons)		***5,649***	***464***	***424***	***204***	***636***	***4,052***	***218,960***

Table 3-22 Barge Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Mobile, AL	2	0	0	0	0	0	0	17
New Orleans, LA	472	87	8	7	3	8	57	3,738
Morehead City, NC	73	6	1	1	0	0	5	330
Charleston, SC	420	55	4	4	2	4	78	2,279
Total Barge Carrier	967	148	13	12	5	12	141	6,364
Total Barge Carrier (short tons)		***163***	***14***	***13***	***6***	***14***	***156***	***7,015***

Table 3-23 Bulk Carrier Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	67	28	2	2	1	2	15	1,033
Barbers Point, HI	82	14	1	1	1	1	9	599
Everett, WA	71	33	3	2	1	3	18	1,206
Grays Harbor, WA	140	24	2	2	1	2	14	974
Honolulu, HI	158	29	2	2	1	2	17	1,188
Kalama, WA	1,007	233	19	17	8	20	136	9,408
Longview, WA	1,142	265	22	19	10	22	154	10,659
Olympia, WA	73	45	4	3	2	4	24	1,628
Port Angeles, WA	72	22	2	2	1	2	12	848
Portland, OR	2,351	633	51	46	23	53	364	25,061
Seattle, WA	523	244	19	18	8	19	135	9,103
Tacoma, WA	872	445	35	32	15	35	247	16,617
Vancouver, WA	1,003	256	21	19	9	22	147	10,127
Valdez, AK	7	1	0	0	0	0	1	59
Anchorage, AK	52	22	2	2	1	2	12	763
Coos Bay, OR	87	10	1	1	0	1	6	389
Hilo, HI	31	3	0	0	0	0	2	125
Kahului, HI	34	4	0	0	0	0	2	145
Nikishka, AK	246	74	6	5	2	6	41	2,609
Beaumont, TX	1,055	185	19	16	9	18	129	6,998
Freeport, TX	392	35	4	3	1	3	25	1,347
Galveston, TX	1,063	114	11	9	4	8	78	4,285
Houston, TX	5,996	655	66	54	22	48	446	24,640
Port Arthur, TX	890	106	11	9	4	9	74	4,025
Texas City, TX	481	60	6	5	2	4	40	2,221
Corpus Christi, TX	3,359	460	37	34	16	121	278	17,665
Lake Charles, LA	1,116	147	13	12	6	46	91	5,870
Mobile, AL	2,752	401	32	30	14	115	241	15,258
Brownsville, TX	685	106	9	8	3	8	65	4,234
Gulfport, MS	120	21	2	2	1	2	13	834
Manatee, FL	322	60	5	4	2	5	36	2,364
Matagorda Ship	586	118	10	9	4	10	71	4,713
Panama City, FL	79	13	1	1	0	1	8	515
Pascagoula, MS	586	116	9	8	4	9	70	4,586
Pensacola, FL	25	4	0	0	0	0	3	178
Tampa, FL	3,380	604	49	43	20	48	365	23,968
Everglades, FL	626	109	9	8	3	9	70	4,652
New Orleans, LA	8,311	2,511	202	187	79	196	1,550	100,577

Table 3-23 Bulk Carrier Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Baton Rouge, LA	1,668	722	58	53	23	56	439	28,070
South Louisiana, LA	11,606	4,014	323	298	127	313	2,470	159,561
Plaquemines, LA	2,714	665	54	50	21	52	417	27,385
Albany, NY	280	79	6	6	3	7	49	3,152
New York/New Jersey	3,168	482	41	37	16	39	317	20,791
Portland, ME	470	62	5	5	2	5	38	2,458
Georgetown, SC	408	63	5	5	2	5	116	2,606
Hopewell, VA	127	30	2	2	1	2	144	1,167
Marcus Hook, PA	243	54	4	4	2	4	192	2,146
Morehead City, NC	130	17	1	1	1	1	13	692
Paulsboro, NJ	168	38	3	3	1	3	57	1,522
Chester, PA	35	7	1	1	0	1	26	289
Fall River, MA	127	13	2	1	1	1	30	792
New Castle, DE	240	51	4	4	2	4	37	2,080
Penn Manor, PA	659	161	13	12	5	13	637	6,326
Providence, RI	511	78	6	6	3	6	154	3,157
Brunswick, GA	370	75	6	6	2	6	276	2,934
Canaveral, FL	464	59	5	4	2	5	54	2,453
Charleston, SC	1,589	238	19	18	8	19	449	9,729
New Haven, CT	424	55	4	4	2	4	43	2,282
Palm Beach, FL	83	11	1	1	0	1	9	442
Bridgeport, CT	98	13	1	1	0	1	10	547
Camden, NJ	775	176	14	13	6	14	714	6,918
Philadelphia, PA	473	105	8	8	3	8	296	4,161
Wilmington, DE	345	66	5	5	2	5	215	2,611
Wilmington, NC	422	68	5	5	2	5	160	2,718
Richmond, VA	11	3	0	0	0	0	18	117
Jacksonville, FL	1,394	203	17	15	6	16	337	8,436
Miami, FL	122	16	1	1	1	1	17	653
Searsport, ME	37	6	0	0	0	0	9	227
Boston, MA	450	59	5	5	2	5	90	2,652
Baltimore, MD	2,851	1,273	102	95	41	99	773	48,126
Newport News, VA	692	118	10	9	4	9	78	4,815
Savannah, GA	1,474	334	27	25	11	26	205	13,237
Carquinez, CA	717	172	12	11	5	13	103	6,934
Eureka, CA	114	28	2	2	1	2	18	1,201
Long Beach, CA	2,297	468	33	30	14	36	283	19,185
Los Angeles, CA	2,037	423	29	27	13	33	255	17,295
Oakland, CA	280	40	3	3	1	3	23	1,568
Redwood City, CA	437	103	7	7	3	8	61	4,155
Richmond, CA	385	82	6	5	2	6	50	3,371
Sacramento, CA	218	72	5	5	2	6	42	2,842
San Diego, CA	350	64	4	4	2	5	39	2,638
San Francisco, CA	498	101	7	6	3	8	61	4,139
Stockton, CA	638	198	14	13	6	15	116	7,780
Total Bulk Carrier	82,437	19,373	1,570	1,431	633	1,732	14,945	767,825
Total Bulk Carrier (short tons)		***21,355***	***1,731***	***1,577***	***697***	***1,909***	***16,474***	***846,382***

Table 3-24 Container Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Everett, WA	24	6	0	0	0	0	3	210
Honolulu, HI	2,190	308	30	25	15	27	181	12,403
Port Angeles, WA	14	2	0	0	0	0	1	78
Portland, OR	5,227	879	85	74	59	96	486	33,142
Seattle, WA	21,749	5,230	445	396	218	441	2,857	191,094
Tacoma, WA	15,446	3,109	264	236	124	253	1,741	116,552
Vancouver, WA	7	4	0	0	0	0	2	143
Freeport, TX	1,575	74	6	6	2	6	46	2,679
Galveston, TX	427	22	2	2	1	2	14	792
Houston, TX	13,441	698	59	55	23	53	446	25,617
Corpus Christi, TX	24	2	0	0	0	0	1	84
Lake Charles, LA	36	4	0	0	0	1	2	135
Mobile, AL	39	4	0	0	0	1	2	155
Gulfport, MS	1,538	181	15	14	7	15	110	7,411
Everglades, FL	7,732	658	56	52	23	53	426	27,826
New Orleans, LA	5,756	788	65	60	35	76	482	30,940
South Louisiana, LA	36	5	0	0	0	1	3	197
Plaquemines, LA	12	1	0	0	0	0	1	41
New York/New Jersey	56,253	3,246	268	248	130	281	1,934	122,010
Morehead City, NC	24	2	0	0	0	0	1	58
Chester, PA	1,140	139	11	10	5	11	306	5,313
Charleston, SC	37,982	2,691	219	202	97	222	3,001	103,968
New Haven, CT	14	1	0	0	0	0	1	34
Palm Beach, FL	752	44	4	4	2	3	32	1,861
Philadelphia, PA	2,696	306	25	23	13	28	671	11,715
Wilmington, DE	1,999	197	16	15	8	18	379	7,555
Wilmington, NC	1,779	130	11	10	5	12	162	5,115
Richmond, VA	539	74	6	6	3	7	182	2,807
Jacksonville, FL	3,997	279	24	22	11	24	279	11,419
Miami, FL	20,834	1,310	107	99	46	105	961	51,282
Boston, MA	5,016	325	27	25	13	28	305	12,667
Baltimore, MD	9,224	1,411	112	104	49	113	828	51,462
Newport News, VA	3,797	251	20	19	9	20	148	9,311
Savannah, GA	28,209	2,088	168	156	77	173	1,230	76,805
Carquinez, CA	27	3	0	0	0	0	2	105
Eureka, CA	55	6	0	0	0	0	4	245
Hueneme, CA	82	6	0	0	0	6	4	250
Long Beach, CA	42,292	3,434	244	225	109	272	1,986	134,894
Los Angeles, CA	37,505	3,097	221	203	99	247	1,791	121,601
Oakland, CA	47,109	2,833	208	192	94	224	1,532	102,880
Richmond, CA	165	15	1	1	0	1	8	571
San Diego, CA	385	30	2	2	1	2	17	1,168
San Francisco, CA	1,209	102	7	7	3	8	59	4,003
Total Container Ship	378,355	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
Total Container Ship (short tons)		***37,468***	***3,012***	***2,749***	***1,413***	***3,123***	***24,944***	***1,420,434***

Table 3-25 General Cargo Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	23	5	0	0	0	0	3	218
Everett, WA	58	19	2	1	1	1	11	764
Grays Harbor, WA	220	26	2	2	1	2	16	1,093
Honolulu, HI	43	6	1	1	0	1	4	294
Kalama, WA	116	15	1	1	1	1	8	568
Longview, WA	441	61	5	5	2	5	35	2,376
Olympia, WA	24	11	1	1	0	1	6	419
Port Angeles, WA	390	90	7	7	3	7	49	3,291
Portland, OR	771	123	11	9	5	11	71	4,812
Seattle, WA	841	261	21	19	9	21	145	9,653
Tacoma, WA	264	105	9	8	4	8	61	4,096
Vancouver, WA	514	73	6	6	3	7	43	2,924
Valdez, AK	6	1	0	0	0	0	1	39
Anchorage, AK	4	1	0	0	0	0	1	48
Coos Bay, OR	312	36	3	3	1	3	21	1,421
Hilo, HI	5	1	0	0	0	0	0	21
Kahului, HI	7	1	0	0	0	0	0	29
Nikishka, AK	24	7	1	0	0	1	4	247
Beaumont, TX	744	113	12	12	5	11	89	4,691
Freeport, TX	238	22	2	2	1	2	16	845
Galveston, TX	111	12	1	1	0	1	9	486
Houston, TX	5,806	560	59	52	19	42	439	23,458
Port Arthur, TX	890	100	11	9	4	9	77	4,085
Texas City, TX	46	6	1	1	0	0	4	232
Corpus Christi, TX	188	20	2	2	1	5	14	876
Lake Charles, LA	670	71	7	6	3	22	49	3,150
Mobile, AL	2,529	297	25	23	10	85	190	11,928
Brownsville, TX	206	23	2	2	1	2	15	949
Gulfport, MS	496	51	4	4	2	4	32	2,048
Manatee, FL	301	36	3	3	1	3	22	1,430
Matagorda Ship	27	2	0	0	0	0	2	104
Panama City, FL	545	52	4	4	2	4	33	2,070
Pascagoula, MS	466	45	4	4	2	4	30	1,915
Pensacola, FL	71	7	1	1	0	1	5	287
Tampa, FL	986	118	10	9	4	9	75	4,784
Everglades, FL	1,813	197	18	16	6	16	138	9,057
New Orleans, LA	2,925	601	50	46	20	48	384	24,538
Baton Rouge, LA	356	111	10	9	4	9	73	4,624
South Louisiana, LA	810	216	18	16	7	17	134	8,502
Plaquemines, LA	178	29	2	2	1	2	19	1,192
Albany, NY	83	15	1	1	1	1	10	639
New York/New Jersey	1,841	153	13	12	6	13	95	5,957
Georgetown, SC	202	26	2	2	1	2	35	1,062
Hopewell, VA	44	12	1	1	0	1	42	444
Marcus Hook, PA	39	7	1	1	0	1	16	299
Morehead City, NC	387	40	3	3	1	3	30	1,684
Paulsboro, NJ	22	3	0	0	0	0	2	145
Chester, PA	237	40	3	3	1	3	71	1,679

Table 3-25 General Cargo Ship Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Fall River, MA	139	17	2	1	1	1	16	774
Penn Manor, PA	56	12	1	1	0	1	18	500
Providence, RI	32	4	0	0	0	0	7	158
Brunswick, GA	1,066	168	14	12	6	14	475	6,535
Canaveral, FL	549	61	5	5	2	5	52	2,509
Charleston, SC	1,814	223	18	17	7	18	343	9,045
New Haven, CT	382	43	4	3	1	3	30	1,791
Palm Beach, FL	722	76	7	6	2	6	54	3,524
Camden, NJ	974	180	15	14	6	15	349	7,471
Philadelphia, PA	960	164	14	13	6	14	315	6,907
Wilmington, DE	185	28	2	2	1	2	43	1,165
Wilmington, NC	1,178	155	13	12	5	12	237	6,288
Richmond, VA	38	7	1	1	0	1	5	322
Jacksonville, FL	1,419	152	13	12	5	12	160	6,422
Miami, FL	2,941	354	31	29	11	28	272	16,024
Searsport, ME	3	0	0	0	0	0	1	17
Boston, MA	122	14	1	1	0	1	13	606
Baltimore, MD	2,275	673	56	52	22	52	430	26,796
Newport News, VA	568	74	6	6	2	6	47	3,033
Savannah, GA	2,521	415	34	32	14	32	261	16,543
Carquinez, CA	39	8	1	1	0	1	5	331
Eureka, CA	183	42	3	3	1	3	26	1,750
Hueneme, CA	77	7	0	0	0	10	4	262
Long Beach, CA	996	158	11	10	5	12	94	6,364
Los Angeles, CA	883	143	10	9	4	11	85	5,742
Oakland, CA	462	43	3	3	1	3	23	1,579
Redwood City, CA	19	4	0	0	0	0	2	163
Richmond, CA	67	13	1	1	0	1	8	530
Sacramento, CA	202	58	4	4	2	5	34	2,292
San Diego, CA	867	144	10	9	4	11	87	5,901
San Francisco, CA	453	82	6	5	2	6	50	3,375
Stockton, CA	202	55	4	4	2	4	32	2,147
Total General Cargo	49,711	7,402	630	576	251	684	6,208	302,338
Total General Cargo (short tons)		***8,159***	***694***	***635***	***277***	***754***	***6,843***	***333,270***

Table 3-26 Miscellaneous Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	16	4	0	0	0	0	2	149
Portland, OR	21	7	1	0	0	0	4	269
Seattle, WA	9	5	0	0	0	0	3	180
Anchorage, AK	58	22	2	2	1	2	15	992
Kahului, HI	1	0	0	0	0	0	0	11
Houston, TX	13	1	0	0	0	0	1	49
Corpus Christi, TX	119	16	2	1	1	5	12	759
Lake Charles, LA	3	0	0	0	0	0	0	18
Mobile, AL	604	83	8	7	3	24	62	3,903
Pensacola, FL	65	11	1	1	0	1	8	497
New Orleans, LA	12	7	1	1	0	1	4	281
New York/New Jersey	26	7	1	1	0	1	5	325
Baltimore, MD	23	14	1	1	0	1	10	674
Newport News, VA	6	2	0	0	0	0	2	103
Total Miscellaneous	976	179	16	15	6	35	128	8,209
Total Miscellaneous (short tons)		***197***	***18***	***17***	***7***	***39***	***141***	***9,049***

Table 3-27 Passenger Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	4,359	637	58	53	19	48	427	28,546
Portland, OR	60	12	1	1	1	1	8	558
Seattle, WA	3,017	739	72	66	23	54	540	35,669
Valdez, AK	31	2	0	0	0	0	2	110
Anchorage, AK	200	66	5	5	2	5	43	2,495
Hilo, HI	4,467	923	76	70	27	72	622	44,123
Kahului, HI	2,256	466	38	35	14	36	307	21,755
Nawiliwili, HI	583	120	10	9	4	9	82	5,810
Galveston, TX	3,248	644	76	64	23	42	559	28,782
Houston, TX	751	143	19	15	5	9	131	6,539
Corpus Christi, TX	113	21	2	2	1	3	14	954
Mobile, AL	330	80	7	6	2	11	52	3,538
Manatee, FL	634	66	7	5	2	5	52	3,064
Tampa, FL	3,599	352	34	25	12	28	271	16,166
Everglades, FL	22,083	2,447	244	227	73	187	1,897	117,326
New Orleans, LA	5,401	1,133	110	102	37	91	835	51,550
New York/New Jersey	6,841	745	74	68	25	59	551	34,382
Portland, ME	380	31	3	3	1	2	25	1,523
Paulsboro, NJ	126	30	3	3	1	2	23	1,395
Fall River, MA	11	1	0	0	0	0	1	63
Canaveral, FL	15,756	2,758	256	238	80	209	2,044	126,856
Charleston, SC	758	101	9	9	3	8	75	4,652
Palm Beach, FL	146	15	1	1	0	1	11	684
Philadelphia, PA	44	11	1	1	0	1	8	508
Miami, FL	28,808	4,919	463	430	142	373	3,712	230,290
Boston, MA	2,878	431	41	38	13	33	327	20,219
New Bedford/Fairhaven, MA	16	2	0	0	0	0	2	94
Baltimore, MD	1,058	427	42	39	13	33	320	19,829
Savannah, GA	16	5	1	0	0	0	4	243
Catalina, CA	919	78	7	7	2	6	53	3,608
Eureka, CA	57	6	1	1	0	0	4	290
Hueneme, CA	29	2	0	0	0	4	1	100
Long Beach, CA	5,756	567	52	48	17	43	382	26,353
Los Angeles, CA	5,105	516	47	43	16	40	348	23,970
San Diego, CA	5,172	456	42	38	14	35	307	21,178
San Francisco, CA	2,241	214	19	18	7	16	144	9,935
Total Passenger	127,251	19,165	1,819	1,668	578	1,470	14,184	893,157
Total Passenger (short tons)		***21,126***	***2,005***	***1,838***	***638***	***1,620***	***15,635***	***984,538***

Table 3-28 Refrigerated Cargo Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Honolulu, HI	6	3	0	0	0	0	2	113
Port Angeles, WA	3	1	0	0	0	0	1	57
Seattle, WA	55	30	2	2	1	2	17	1,203
Anchorage, AK	140	62	5	4	2	5	36	2,256
Galveston, TX	532	87	9	8	3	6	70	3,724
Houston, TX	78	13	1	1	0	1	11	563
Corpus Christi, TX	97	21	2	2	1	3	13	897
Mobile, AL	22	5	0	0	0	1	3	209
Gulfport, MS	374	56	5	4	2	4	37	2,320
Manatee, FL	1,277	453	37	33	14	36	307	19,845
Pascagoula, MS	232	54	5	4	2	4	38	2,387
Pensacola, FL	2	0	0	0	0	0	0	13
Tampa, FL	245	38	3	3	1	3	25	1,599
Everglades, FL	116	71	6	5	2	5	47	3,223
New Orleans, LA	163	109	9	8	3	9	72	4,907
New York/New Jersey	1,575	195	16	15	7	16	123	8,151
Morehead City, NC	6	1	0	0	0	0	1	56
Paulsboro, NJ	4	1	0	0	0	0	1	53
Brunswick, GA	158	32	3	2	1	2	20	1,373
Canaveral, FL	525	96	8	7	3	7	63	4,212
Charleston, SC	82	16	1	1	0	1	10	684
Bridgeport, CT	1,086	188	15	14	6	15	121	8,196
Camden, NJ	2,088	531	44	41	19	45	341	22,716
Philadelphia, PA	833	206	17	16	7	18	132	8,874
Wilmington, DE	733	171	14	13	6	14	110	7,319
Jacksonville, FL	173	34	3	3	1	3	22	1,483
Miami, FL	742	130	11	10	4	10	84	5,666
Searsport, ME	5	1	0	0	0	0	1	44
New Bedford/Fairhaven, MA	69	15	1	1	0	1	10	682
Baltimore, MD	45	58	5	4	2	4	38	2,641
Hueneme, CA	963	161	11	10	5	81	99	6,839
Long Beach, CA	662	94	6	6	3	7	56	3,884
Los Angeles, CA	587	84	6	5	2	7	51	3,494
San Diego, CA	48	9	1	1	0	1	5	378
Total Reefer	13,724	3,027	247	226	98	313	1,968	130,060
Total Reefer (short tons)		***3,337***	***273***	***249***	***108***	***345***	***2,170***	***143,367***

Table 3-29 Roll-On/Roll-Off Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Barbers Point, HI	4	0	0	0	0	0	0	3
Everett, WA	27	2	0	0	0	0	1	64
Honolulu, HI	39	3	0	0	0	0	2	129
Longview, WA	5	1	0	0	0	0	1	39
Portland, OR	110	8	1	1	0	1	5	325
Seattle, WA	11	4	0	0	0	0	2	150
Tacoma, WA	148	45	4	3	2	4	25	1,654
Vancouver, WA	11	2	0	0	0	0	1	81
Anchorage, AK	5	2	0	0	0	0	1	75
Beaumont, TX	62	13	1	1	1	1	9	521
Galveston, TX	59	7	1	1	0	0	5	290
Houston, TX	810	99	10	9	3	7	75	4,089
Corpus Christi, TX	6	1	0	0	0	0	1	33
Lake Charles, LA	6	1	0	0	0	0	1	33
Mobile, AL	69	11	1	1	0	2	7	454
Gulfport, MS	1,028	299	26	23	9	23	222	13,769
Manatee, FL	3	1	0	0	0	0	1	36
Pensacola, FL	18	5	0	0	0	0	4	231
Tampa, FL	166	48	4	4	1	4	36	2,230
Everglades, FL	3,734	285	27	25	10	23	209	13,387
New Orleans, LA	783	132	11	10	5	12	81	5,237
South Louisiana, LA	4	1	0	0	0	0	1	34
Albany, NY	6	1	0	0	0	0	1	50
New York/New Jersey	3,323	290	24	22	11	25	176	11,292
Portland, ME	305	28	3	2	1	2	20	1,316
Morehead City, NC	27	2	0	0	0	0	2	104
Chester, PA	47	8	1	1	0	1	5	302
Penn Manor, PA	6	1	0	0	0	0	1	53
Brunswick, GA	219	23	2	2	1	2	14	880
Canaveral, FL	75	9	1	1	0	1	6	418
Charleston, SC	455	43	4	3	1	3	28	1,777
New Haven, CT	32	3	0	0	0	0	2	163
Palm Beach, FL	423	49	4	4	2	4	35	2,302
Bridgeport, CT	23	3	0	0	0	0	2	110
Camden, NJ	22	4	0	0	0	0	3	178
Philadelphia, PA	175	31	3	3	1	3	22	1,456
Wilmington, DE	10	1	0	0	0	0	1	48
Wilmington, NC	342	35	3	3	1	3	22	1,390
Richmond, VA	8	2	0	0	0	0	1	87
Jacksonville, FL	855	102	9	8	3	8	71	4,617
Miami, FL	3,646	380	33	30	12	30	258	16,915
Boston, MA	301	37	3	3	1	3	26	1,734
Baltimore, MD	3,284	841	65	60	28	65	495	30,930
Newport News, VA	77	12	1	1	0	1	8	532
Savannah, GA	2,578	281	22	20	9	22	169	10,774
Hueneme, CA	52	5	0	0	0	8	3	173
Long Beach, CA	483	67	5	4	2	5	39	2,617

Table 3-29 Roll-On/Roll-Off Ship Deep Sea Port Emissions in 2002 (Continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Los Angeles, CA	428	61	4	4	2	5	36	2,379
Oakland, CA	901	104	8	7	3	8	59	3,935
Total RoRo	25,210	3,391	281	259	113	278	2,193	139,396
Total RoRo (short tons)		***3,738***	***310***	***286***	***125***	***306***	***2,418***	***153,658***

Table 3-30 Tanker Ship Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Anacortes, WA	455	370	29	26	13	29	207	14,211
Barbers Point, HI	387	108	9	8	4	9	62	4,432
Everett, WA	6	23	2	2	1	2	13	881
Honolulu, HI	687	221	18	16	8	18	130	9,165
Kalama, WA	67	112	9	8	4	9	66	4,579
Longview, WA	30	86	7	6	3	7	49	3,421
Port Angeles, WA	72	34	3	3	1	3	25	1,721
Portland, OR	309	222	19	17	8	18	133	9,246
Seattle, WA	74	152	12	11	5	12	87	5,952
Tacoma, WA	277	1,306	104	94	45	105	723	49,146
Vancouver, WA	133	64	5	5	2	5	37	2,600
Valdez, AK	6,632	338	36	32	11	27	296	20,581
Other Puget Sound	5,678	2,111	219	197	71	169	1,745	118,629
Anchorage, AK	78	45	4	3	2	4	25	1,608
Hilo, HI	11	2	0	0	0	0	1	99
Kahului, HI	9	2	0	0	0	0	1	77
Nawiliwili, HI	8	2	0	0	0	0	1	74
Nikishka, AK	840	189	19	18	6	15	165	10,938
Beaumont, TX	10,807	1,791	228	210	76	159	1,742	71,331
Freeport, TX	5,206	584	80	74	20	45	630	23,551
Galveston, TX	552	68	12	11	2	5	93	2,832
Houston, TX	19,096	2,334	319	294	80	178	2,494	93,908
Port Arthur, TX	1,751	230	31	28	9	19	237	9,232
Texas City, TX	6,856	905	121	111	31	69	942	36,122
Corpus Christi, TX	7,498	1,213	99	91	40	263	752	48,747
Lake Charles, LA	4,544	627	60	55	26	168	450	29,166
Mobile, AL	1,114	187	15	14	6	46	115	7,432
Brownsville, TX	320	45	4	3	1	4	28	1,859
Manatee, FL	355	51	4	4	2	4	32	2,101
Matagorda Ship	1,875	268	22	20	9	22	166	10,961
Panama City, FL	38	5	0	0	0	0	3	204
Pascagoula, MS	2,275	301	26	24	10	25	205	13,293
Tampa, FL	2,282	323	27	24	11	26	202	13,293
Everglades, FL	2,036	495	41	37	15	39	320	21,592
New Orleans, LA	3,506	1,181	96	89	37	92	744	48,739
Baton Rouge, LA	2,603	1,153	93	86	36	90	711	45,874
South Louisiana, LA	5,886	2,187	177	164	68	170	1,365	88,846
Plaquemines, LA	1,322	349	28	26	11	27	221	14,598
Albany, NY	28	8	1	1	0	1	5	326
New York/New Jersey	9,361	1,885	157	144	65	156	1,202	79,931
Portland, ME	2,813	601	49	45	19	47	383	25,538
Hopewell, VA	14	4	0	0	0	0	25	153
Marcus Hook, PA	2,472	904	74	68	28	71	2,255	38,119

Table 3-30 Tanker Ship Deep Sea Port Emissions in 2002 (continued)

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Morehead City, NC	286	51	4	4	2	4	41	2,169
Paulsboro, NJ	2,952	595	48	45	20	48	2,021	23,560
Fall River, MA	13	3	0	0	0	0	5	120
New Castle, DE	524	147	12	11	5	12	357	6,177
Providence, RI	554	116	10	9	4	9	173	4,907
Brunswick, GA	21	5	0	0	0	0	13	200
Canaveral, FL	351	71	6	5	2	6	55	3,032
Charleston, SC	1,213	260	21	20	8	20	366	11,054
New Haven, CT	951	184	15	14	6	14	131	7,846
Palm Beach, FL	124	22	2	2	1	2	19	923
Bridgeport, CT	206	40	3	3	1	3	29	1,705
Camden, NJ	349	103	8	8	3	8	218	4,257
Philadelphia, PA	2,352	845	70	64	24	67	1,891	36,299
Wilmington, DE	159	38	3	3	1	3	83	1,606
Wilmington, NC	1,167	253	21	19	8	20	375	10,753
Jacksonville, FL	1,633	346	28	26	11	27	419	14,554
Miami, FL	161	33	3	3	1	3	26	1,502
Searsport, ME	498	103	9	8	3	8	114	4,482
Boston, MA	3,775	719	64	59	22	56	757	34,227
New Bedford/Fairhaven, MA	96	22	2	2	1	2	22	924
Baltimore, MD	979	424	33	31	14	33	256	15,951
Newport News, VA	118	21	2	1	1	2	13	840
Savannah, GA	2,083	395	31	29	13	31	258	16,547
Catalina, CA	9	1	0	0	0	0	0	31
Carquinez, CA	1,977	270	20	19	9	21	151	9,920
El Segundo, CA	1,685	192	14	13	6	15	108	7,095
Hueneme, CA	95	13	1	1	0	14	8	547
Long Beach, CA	3,380	419	31	28	13	33	245	16,028
Los Angeles, CA	2,998	383	28	26	12	30	223	14,610
Richmond, CA	2,871	323	24	22	10	25	181	11,904
Sacramento, CA	34	8	1	1	0	1	4	282
San Diego, CA	60	6	0	0	0	0	3	224
San Francisco, CA	1,839	184	14	13	6	14	104	6,823
Stockton, CA	370	79	6	6	3	6	44	2,903
Total Tanker	146,245	29,758	2,796	2,562	994.23952	2,695	27,802	1,259,107
Total Tanker (short tons)		***32,802***	***3,082***	***2,824***	***1,096***	***2,971***	***30,646***	***1,387,928***

Table 3-31 Ocean Going Tug Deep Sea Port Emissions in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Portland, OR	18	6	1	0	0	0	3	234
Seattle, WA	4	2	0	0	0	0	1	78
Kahului, HI	16	2	0	0	0	0	1	77
Galveston, TX	19	2	0	0	0	0	1	80
Houston, TX	16	1	0	0	0	0	1	70
Corpus Christi, TX	47	5	0	0	0	1	4	226
Lake Charles, LA	7	1	0	0	0	0	1	37
Mobile, AL	46	6	1	0	0	2	4	269
Brownsville, TX	3	0	0	0	0	0	0	16
Manatee, FL	7	1	0	0	0	0	1	49
Pascagoula, MS	7	1	0	0	0	0	1	42
Everglades, FL	28	3	0	0	0	0	2	126
New Orleans, LA	21	4	0	0	0	0	3	198
South Louisiana, LA	7	2	0	0	0	0	1	77
Plaquemines, LA	4	1	0	0	0	0	1	43
New York/New Jersey	3	0	0	0	0	0	0	18
Canaveral, FL	28	3	0	0	0	0	2	135
Palm Beach, FL	28	3	0	0	0	0	2	133
Jacksonville, FL	17	2	0	0	0	0	2	97
Miami, FL	31	3	0	0	0	0	2	152
Boston, MA	4	1	0	0	0	0	0	24
Total Ocean Going Tug	361	48	5	4	2	6	34	2,182
Total Ocean Going Tug (short tons)		***53***	***5***	***4***	***2***	***6***	***37***	***2,405***

Table 3-32 Total Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.5	0.3	0.2	0.0	0.1	2.5	156
Buffalo, NY	84	2.9	0.3	0.3	0.1	0.2	2.3	150
Burns Waterway, IN	819	45.5	3.9	3.6	1.5	3.7	30.0	1,982
Calcite, MI	126	3.4	0.3	0.3	0.1	0.3	2.5	158
Cleveland, OH	560	32.6	2.8	2.5	1.0	2.6	21.8	1,448
Dolomite, MI	67	1.9	0.2	0.1	0.1	0.2	1.1	73
Erie, PA	55	2.2	0.2	0.2	0.1	0.2	1.7	112
Escanaba, MI	118	3.1	0.3	0.3	0.1	0.3	2.3	146
Fairport, OH	114	3.0	0.3	0.3	0.1	0.3	2.5	156
Gary, IN	84	3.2	0.3	0.3	0.1	0.3	2.2	141
Lorain, OH	64	1.5	0.2	0.2	0.1	0.1	1.3	84
Marblehead, OH	26	0.5	0.1	0.1	0.0	0.0	0.5	34
Milwaukee, WI	495	26.1	2.3	2.1	0.8	2.1	17.8	1,177
Muskegon, MI	37	0.9	0.1	0.1	0.0	0.1	0.7	47
Presque Isle, MI	562	16.2	1.4	1.3	0.7	1.4	10.0	637
St Clair, MI	156	4.2	0.4	0.4	0.2	0.4	3.0	193
Stoneport, MI	22	0.7	0.1	0.1	0.0	0.1	0.4	28
Two Harbors, MN	48	1.2	0.1	0.1	0.0	0.1	0.9	56
Ashtabula, OH	1,179	36.8	3.4	3.1	1.3	3.1	26.4	1,688
Chicago, IL	492	22.1	1.9	1.8	0.7	1.8	15.3	1,003
Conneaut, OH	1,863	52.6	5.0	4.7	1.9	4.4	39.5	2,501
Detroit, MI	1,359	51.4	4.7	4.4	1.7	4.2	37.5	2,432
Duluth-Superior, MN&WI	3,441	131.8	12.0	11.1	4.5	10.7	94.5	6,130
Indiana, IN	140	5.9	0.5	0.5	0.2	0.5	4.1	272
Inland Harbor, MI	56	1.5	0.1	0.1	0.1	0.1	1.1	69
Manistee, MI	164	17.8	1.5	1.4	0.5	1.4	12.2	827
Sandusky, OH	742	21.0	2.0	1.8	0.8	1.8	15.2	962
Toledo, OH	1,517	57.9	5.1	4.7	2.0	4.7	39.3	2,550
Total Emissions	14,476	549	50	46	19	45	389	25,210
Total Emissions (short tons)		***606***	***55***	***50***	***21***	***50***	***429***	***27,790***

Table 3-33 Auxiliary Engine Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	20	1.2	0.1	0.1	0.0	0.1	0.8	57
Buffalo, NY	19	1.5	0.1	0.1	0.0	0.1	1.0	71
Burns Waterway, IN	181	29.6	2.5	2.2	0.8	2.2	19.7	1,366
Calcite, MI	28	1.4	0.1	0.1	0.0	0.1	0.9	63
Cleveland, OH	122	22.5	1.9	1.7	0.6	1.7	15.0	1,039
Dolomite, MI	15	0.6	0.1	0.0	0.0	0.0	0.4	30
Erie, PA	12	1.5	0.1	0.1	0.0	0.1	1.0	68
Escanaba, MI	26	1.2	0.1	0.1	0.0	0.1	0.8	56
Fairport, OH	25	1.3	0.1	0.1	0.0	0.1	0.9	60
Gary, IN	18	1.5	0.1	0.1	0.0	0.1	1.0	70
Lorain, OH	14	0.7	0.1	0.1	0.0	0.1	0.5	32
Marblehead, OH	6	0.3	0.0	0.0	0.0	0.0	0.2	12
Milwaukee, WI	109	17.5	1.4	1.3	0.5	1.3	11.7	806
Muskegon, MI	8	0.4	0.0	0.0	0.0	0.0	0.3	18
Presque Isle, MI	125	5.6	0.5	0.4	0.2	0.4	3.7	257
St Clair, MI	35	1.6	0.1	0.1	0.0	0.1	1.1	76
Stoneport, MI	5	0.2	0.0	0.0	0.0	0.0	0.2	11
Two Harbors, MN	11	0.5	0.0	0.0	0.0	0.0	0.3	21
Ashtabula, OH	262	16.3	1.3	1.2	0.4	1.2	10.9	752
Chicago, IL	108	13.7	1.1	1.0	0.4	1.0	9.1	633
Conneaut, OH	414	20.9	1.7	1.6	0.6	1.6	13.9	964
Detroit, MI	303	29.6	2.5	2.2	0.8	2.2	19.8	1,367
Duluth-Superior, MN&WI	760	74.0	6.1	5.6	2.0	5.6	49.4	3,418
Indiana, IN	31	3.7	0.3	0.3	0.1	0.3	2.5	170
Inland Harbor, MI	12	0.6	0.0	0.0	0.0	0.0	0.4	27
Manistee, MI	35	15.1	1.3	1.2	0.4	1.2	10.1	699
Sandusky, OH	165	8.1	0.7	0.6	0.2	0.6	5.4	376
Toledo, OH	336	30.9	2.6	2.3	0.9	2.3	20.6	1,426
Total Auxiliary Emissions	3,202	302	25	23	8	23	202	13,944
Total Auxiliary Emissions (short tons)		***333***	***28***	***25***	***9***	***25***	***222***	***15,370***

Table 3-34 Cruise Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.3	0.1	0.1	0.0	0.0	1.2	75
Buffalo, NY	84	0.9	0.1	0.1	0.0	0.1	0.9	55
Burns Waterway, IN	819	11.7	1.0	0.9	0.4	0.9	7.5	453
Calcite, MI	126	1.4	0.1	0.1	0.0	0.1	1.1	66
Cleveland, OH	560	7.7	0.7	0.6	0.3	0.6	5.2	314
Dolomite, MI	67	0.8	0.1	0.1	0.0	0.1	0.5	30
Erie, PA	55	0.6	0.1	0.1	0.0	0.0	0.5	33
Escanaba, MI	118	1.5	0.1	0.1	0.1	0.1	1.2	71
Fairport, OH	114	1.2	0.1	0.1	0.0	0.1	1.1	66
Gary, IN	84	1.1	0.1	0.1	0.0	0.1	0.8	48
Lorain, OH	64	0.6	0.1	0.1	0.0	0.0	0.6	37
Marblehead, OH	26	0.1	0.0	0.0	0.0	0.0	0.3	16
Milwaukee, WI	495	6.4	0.6	0.5	0.2	0.5	4.5	275
Muskegon, MI	37	0.4	0.0	0.0	0.0	0.0	0.3	21
Presque Isle, MI	562	7.3	0.6	0.5	0.2	0.6	4.4	265
St Clair, MI	156	1.7	0.2	0.2	0.1	0.1	1.4	82
Stoneport, MI	22	0.3	0.0	0.0	0.0	0.0	0.2	12
Two Harbors, MN	48	0.6	0.1	0.0	0.0	0.0	0.4	26
Ashtabula, OH	1,179	15.1	1.4	1.3	0.5	1.2	11.3	684
Chicago, IL	492	6.4	0.6	0.5	0.2	0.5	4.6	281
Conneaut, OH	1,863	23.1	2.3	2.1	0.8	1.8	18.4	1,113
Detroit, MI	1,359	16.5	1.6	1.5	0.6	1.3	13.1	793
Duluth-Superior, MN&WI	3,441	43.3	4.2	3.9	1.5	3.4	33.3	2,019
Indiana, IN	140	1.7	0.2	0.2	0.1	0.1	1.3	78
Inland Harbor, MI	56	0.7	0.1	0.1	0.0	0.1	0.5	31
Manistee, MI	164	2.0	0.2	0.2	0.1	0.2	1.6	97
Sandusky, OH	742	9.4	0.9	0.8	0.3	0.7	7.1	428
Toledo, OH	1,517	20.2	1.8	1.7	0.7	1.6	14.0	846
Total Cruise Emissions	14,476	183	17	16	6	14	137	8,313
Total Cruise Emissions (short tons)		***202***	***19***	***18***	***7***	***16***	***151***	***9,164***

Table 3-35 Reduced Speed Zone Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.1	0.0	0.0	0.0	0.0	0.3	19
Buffalo, NY	84	0.2	0.0	0.0	0.0	0.0	0.2	14
Burns Waterway, IN	819	2.8	0.2	0.2	0.1	0.2	1.8	112
Calcite, MI	126	0.3	0.0	0.0	0.0	0.0	0.3	16
Cleveland, OH	560	1.9	0.2	0.1	0.1	0.1	1.3	78
Dolomite, MI	67	0.2	0.0	0.0	0.0	0.0	0.1	7
Erie, PA	55	0.1	0.0	0.0	0.0	0.0	0.1	8
Escanaba, MI	118	0.4	0.0	0.0	0.0	0.0	0.3	18
Fairport, OH	114	0.3	0.0	0.0	0.0	0.0	0.3	16
Gary, IN	84	0.3	0.0	0.0	0.0	0.0	0.2	12
Lorain, OH	64	0.1	0.0	0.0	0.0	0.0	0.1	9
Marblehead, OH	26	0.0	0.0	0.0	0.0	0.0	0.1	4
Milwaukee, WI	495	1.6	0.1	0.1	0.1	0.1	1.1	67
Muskegon, MI	37	0.1	0.0	0.0	0.0	0.0	0.1	5
Presque Isle, MI	562	1.7	0.1	0.1	0.1	0.1	1.0	65
St Clair, MI	156	0.4	0.0	0.0	0.0	0.0	0.3	20
Stoneport, MI	22	0.1	0.0	0.0	0.0	0.0	0.0	3
Two Harbors, MN	48	0.1	0.0	0.0	0.0	0.0	0.1	6
Ashtabula, OH	1,179	3.7	0.3	0.3	0.1	0.3	2.8	170
Chicago, IL	492	1.5	0.1	0.1	0.1	0.1	1.1	69
Conneaut, OH	1,863	5.8	0.6	0.5	0.2	0.5	4.5	277
Detroit, MI	1,359	4.1	0.4	0.4	0.1	0.3	3.1	193
Duluth-Superior, MN&WI	3,441	10.8	1.0	0.9	0.4	0.8	8.1	502
Indiana, IN	140	0.4	0.0	0.0	0.0	0.0	0.3	19
Inland Harbor, MI	56	0.2	0.0	0.0	0.0	0.0	0.1	7
Manistee, MI	164	0.5	0.0	0.0	0.0	0.0	0.4	24
Sandusky, OH	742	2.3	0.2	0.2	0.1	0.2	1.7	106
Toledo, OH	1,517	4.9	0.4	0.4	0.2	0.4	3.4	208
Total RSZ Emissions	14,476	45	4	4	2	4	33	2,052
Total RSZ Emissions (short tons)		***50***	***5***	***4***	***2***	***4***	***37***	***2,262***

Table 3-36 Maneuvering Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	0.2	0.0	0.0	0.0	0.0	0.3	17
Buffalo, NY	84	0.6	0.1	0.1	0.0	0.1	0.4	28
Burns Waterway, IN	819	4.4	0.4	0.4	0.3	0.5	3.0	190
Calcite, MI	126	0.9	0.1	0.1	0.1	0.1	0.6	41
Cleveland, OH	560	2.0	0.2	0.2	0.1	0.2	1.4	89
Dolomite, MI	67	0.5	0.0	0.0	0.0	0.1	0.3	19
Erie, PA	55	0.2	0.0	0.0	0.0	0.0	0.2	11
Escanaba, MI	118	0.3	0.0	0.0	0.0	0.0	0.2	15
Fairport, OH	114	0.8	0.1	0.1	0.0	0.1	0.6	38
Gary, IN	84	0.7	0.1	0.1	0.0	0.1	0.5	32
Lorain, OH	64	0.4	0.0	0.0	0.0	0.0	0.3	18
Marblehead, OH	26	0.1	0.0	0.0	0.0	0.0	0.1	6
Milwaukee, WI	495	2.3	0.2	0.2	0.1	0.3	1.6	105
Muskegon, MI	37	0.2	0.0	0.0	0.0	0.0	0.2	11
Presque Isle, MI	562	4.2	0.4	0.4	0.3	0.5	2.6	167
St Clair, MI	156	1.1	0.1	0.1	0.1	0.1	0.7	47
Stoneport, MI	22	0.2	0.0	0.0	0.0	0.0	0.1	7
Two Harbors, MN	48	0.2	0.0	0.0	0.0	0.0	0.2	10
Ashtabula, OH	1,179	6.0	0.6	0.6	0.3	0.7	4.4	277
Chicago, IL	492	2.0	0.2	0.2	0.1	0.2	1.4	87
Conneaut, OH	1,863	9.7	1.0	0.9	0.6	1.1	7.3	466
Detroit, MI	1,359	5.7	0.6	0.6	0.3	0.6	4.5	284
Duluth-Superior, MN&WI	3,441	15.2	1.6	1.5	0.9	1.7	11.3	718
Indiana, IN	140	0.5	0.1	0.0	0.0	0.1	0.4	24
Inland Harbor, MI	56	0.3	0.0	0.0	0.0	0.0	0.2	13
Manistee, MI	164	0.6	0.1	0.1	0.0	0.1	0.4	27
Sandusky, OH	742	3.8	0.4	0.4	0.2	0.4	2.7	174
Toledo, OH	1,517	6.6	0.7	0.6	0.4	0.8	4.6	291
Total Maneuver Emissions	14,476	70	7	7	4	8	50	3,213
Total Maneuver Emissions (short tons)		***77***	***8***	***7***	***5***	***9***	***56***	***3,542***

Table 3-37 Hotelling Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.0	0.1	0.1	0.0	0.1	0.7	46
Buffalo, NY	84	1.2	0.1	0.1	0.0	0.1	0.8	53
Burns Waterway, IN	819	26.6	2.2	2.0	0.7	2.0	17.7	1,227
Calcite, MI	126	0.8	0.1	0.1	0.0	0.1	0.5	36
Cleveland, OH	560	20.9	1.7	1.6	0.6	1.6	14.0	967
Dolomite, MI	67	0.4	0.0	0.0	0.0	0.0	0.2	16
Erie, PA	55	1.3	0.1	0.1	0.0	0.1	0.9	60
Escanaba, MI	118	0.9	0.1	0.1	0.0	0.1	0.6	42
Fairport, OH	114	0.8	0.1	0.1	0.0	0.1	0.5	36
Gary, IN	84	1.1	0.1	0.1	0.0	0.1	0.7	49
Lorain, OH	64	0.4	0.0	0.0	0.0	0.0	0.3	20
Marblehead, OH	26	0.2	0.0	0.0	0.0	0.0	0.1	8
Milwaukee, WI	495	15.8	1.3	1.2	0.4	1.2	10.5	730
Muskegon, MI	37	0.2	0.0	0.0	0.0	0.0	0.2	11
Presque Isle, MI	562	3.0	0.3	0.2	0.1	0.2	2.0	140
St Clair, MI	156	1.0	0.1	0.1	0.0	0.1	0.6	44
Stoneport, MI	22	0.1	0.0	0.0	0.0	0.0	0.1	6
Two Harbors, MN	48	0.3	0.0	0.0	0.0	0.0	0.2	13
Ashtabula, OH	1,179	12.1	1.0	0.9	0.3	0.9	8.0	557
Chicago, IL	492	12.2	1.0	0.9	0.3	0.9	8.2	565
Conneaut, OH	1,863	14.0	1.2	1.1	0.4	1.1	9.3	645
Detroit, MI	1,359	25.1	2.1	1.9	0.7	1.9	16.8	1,162
Duluth-Superior, MN&WI	3,441	62.6	5.2	4.8	1.7	4.8	41.8	2,891
Indiana, IN	140	3.3	0.3	0.2	0.1	0.2	2.2	152
Inland Harbor, MI	56	0.4	0.0	0.0	0.0	0.0	0.3	18
Manistee, MI	164	14.7	1.2	1.1	0.4	1.1	9.8	679
Sandusky, OH	742	5.5	0.5	0.4	0.2	0.4	3.7	254
Toledo, OH	1,517	26.1	2.2	2.0	0.7	2.0	17.4	1,205
Total Hotel Emissions	14,476	252	21	19	7	19	168	11,631
Total Hotel Emissions (short tons)		***278***	***23***	***21***	***8***	***21***	***185***	***12,821***

Table 3-38 Self-Unloading Bulk Carrier Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Alpena, MI	89	1.5	0.3	0.2	0.0	0.1	2.5	156
Buffalo, NY	71	2.0	0.2	0.2	0.1	0.2	1.8	112
Burns Waterway, IN	236	7.6	0.7	0.7	0.3	0.7	5.7	362
Calcite, MI	126	3.4	0.3	0.3	0.1	0.3	2.5	158
Cleveland, OH	75	1.3	0.2	0.2	0.0	0.1	1.7	109
Dolomite, MI	67	1.9	0.2	0.1	0.1	0.2	1.1	73
Erie, PA	27	0.5	0.1	0.1	0.0	0.0	0.6	37
Escanaba, MI	118	3.1	0.3	0.3	0.1	0.3	2.3	146
Fairport, OH	114	3.0	0.3	0.3	0.1	0.3	2.5	156
Gary, IN	71	2.3	0.2	0.2	0.1	0.2	1.6	104
Lorain, OH	64	1.5	0.2	0.2	0.1	0.1	1.3	84
Marblehead, OH	26	0.5	0.1	0.1	0.0	0.0	0.5	34
Milwaukee, WI	169	4.3	0.5	0.4	0.2	0.4	3.8	238
Muskegon, MI	37	0.9	0.1	0.1	0.0	0.1	0.7	47
Presque Isle, MI	562	16.2	1.4	1.3	0.7	1.4	10.0	637
St Clair, MI	156	4.2	0.4	0.4	0.2	0.4	3.0	193
Stoneport, MI	22	0.7	0.1	0.1	0.0	0.1	0.4	28
Two Harbors, MN	48	1.2	0.1	0.1	0.0	0.1	0.9	56
Ashtabula, OH	1,047	29.2	2.8	2.6	1.1	2.5	21.6	1,363
Chicago, IL	208	5.5	0.5	0.5	0.2	0.5	4.4	282
Conneaut, OH	1,843	51.3	4.9	4.6	1.9	4.3	38.7	2,449
Detroit, MI	802	20.3	2.1	2.0	0.7	1.7	17.5	1,106
Duluth-Superior, MN&WI	2,201	61.8	6.0	5.6	2.3	5.2	47.9	3,034
Indiana, IN	52	1.3	0.1	0.1	0.0	0.1	1.1	68
Inland Harbor, MI	56	1.5	0.1	0.1	0.1	0.1	1.1	69
Manistee, MI	9	0.2	0.0	0.0	0.0	0.0	0.2	11
Sandusky, OH	735	20.6	1.9	1.8	0.8	1.7	14.8	935
Toledo, OH	987	28.1	2.5	2.3	1.0	2.4	19.3	1,226
Total SU Bulk Carrier	10,015	276	27	25	10	23	210	13,273
Total SU Bulk Carrier (short tons)		***304***	***29***	***27***	***11***	***26***	***231***	***14,631***

Table 3-39 Bulk Carrier Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Buffalo, NY	13	0.9	0.1	0.1	0.0	0.1	0.6	38
Burns Waterway, IN	562	36.8	3.0	2.8	1.1	2.9	23.5	1,567
Cleveland, OH	427	27.7	2.3	2.1	0.9	2.2	17.7	1,179
Erie, PA	17	1.1	0.1	0.1	0.0	0.1	0.7	46
Gary, IN	7	0.5	0.0	0.0	0.0	0.0	0.3	22
Milwaukee, WI	292	19.9	1.6	1.5	0.6	1.6	12.7	852
Ashtabula, OH	126	7.4	0.6	0.6	0.2	0.6	4.7	313
Chicago, IL	219	12.8	1.1	1.0	0.4	1.0	8.3	550
Conneaut, OH	20	1.2	0.1	0.1	0.0	0.1	0.8	52
Detroit, MI	458	27.2	2.2	2.1	0.9	2.2	17.3	1,149
Duluth-Superior, MN&WI	1,032	61.1	5.2	4.7	1.9	4.8	40.5	2,692
Indiana, IN	88	4.6	0.4	0.4	0.1	0.4	3.1	203
Sandusky, OH	7	0.4	0.0	0.0	0.0	0.0	0.4	27
Toledo, OH	421	25.1	2.1	2.0	0.8	2.0	16.8	1,116
Total Bulk Carrier	3,689	227	19	17	7	18	147	9,807
Total Bulk Carrier (short tons)		***250***	***21***	***19***	***8***	***20***	***162***	***10,811***

Table 3-40 General Cargo Ship Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Burns Waterway, IN	21	1.2	0.1	0.1	0.0	0.1	0.8	53
Cleveland, OH	58	3.5	0.3	0.3	0.1	0.3	2.4	160
Erie, PA	11	0.6	0.1	0.1	0.0	0.0	0.4	29
Milwaukee, WI	34	1.9	0.2	0.2	0.1	0.2	1.3	87
Ashtabula, OH	6	0.2	0.0	0.0	0.0	0.0	0.2	12
Chicago, IL	44	1.9	0.2	0.2	0.1	0.2	1.3	84
Detroit, MI	44	2.0	0.2	0.2	0.1	0.2	1.3	88
Duluth-Superior, MN&WI	167	6.7	0.6	0.5	0.2	0.5	4.7	305
Toledo, OH	77	3.5	0.3	0.3	0.1	0.3	2.3	152
Total General Cargo	462	22	2	2	1	2	15	969
Total General Cargo (short tons)		***24***	***2***	***2***	***1***	***2***	***16***	***1,068***

Table 3-41 Tanker Ship Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Chicago, IL	15	1.8	0.1	0.1	0.1	0.1	1.2	80
Detroit, MI	6	0.7	0.1	0.1	0.0	0.1	0.4	30
Duluth-Superior, MN&WI	12	1.4	0.1	0.1	0.0	0.1	0.9	63
Manistee, MI	155	17.6	1.5	1.4	0.5	1.4	12.1	816
Toledo, OH	5	0.5	0.0	0.0	0.0	0.0	0.3	24
Total Tanker	193	22	2	2	1	2	15	1,012
Total Tanker (short tons)		***24***	***2***	***2***	***1***	***2***	***16***	***1,116***

Table 3-42 Integrated Tug-Barge Emissions by Great Lake Port in 2002

Port Name	Installed Power (MW)	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Gary, IN	6	0.3	0.0	0.0	0.0	0.0	0.2	15
Chicago, IL	6	0.1	0.0	0.0	0.0	0.0	0.1	7
Detroit, MI	49	1.2	0.1	0.1	0.0	0.1	0.9	59
Duluth-Superior, MN&WI	29	0.7	0.1	0.1	0.0	0.1	0.6	35
Toledo, OH	27	0.7	0.1	0.1	0.0	0.1	0.5	32
Total ITB	117	3	0	0	0	0	2	149
Total ITB (short tons)		***3***	***0***	***0***	***0***	***0***	***3***	***164***

For Great Lake ports, auxiliary emissions are responsible for roughly 50% of the NO_X and PM emissions, primarily due to emissions during the hotelling mode. Bulk Carrier ships are responsible for the vast majority of the emissions.

3.3.2.6.3 Summary

This section provides a summary of the total port emissions for 2002. Table 3-43 and Table 3-44 provide a breakout of the total port emissions by auxiliary and propulsion engines, in units of metric tonnes and short tons, respectively. Table 3-45 and Table 3-46 provide the breakout by mode of operation, while Table 3-47 and Table 3-48 provide a summary of port emissions by ship type.

Auxiliary emissions at ports are responsible for 39-48% of the total inventory, depending on the pollutant. Hotelling, cruise, and RSZ modes of operation are all important contributors to emissions. Container and Tanker ships are the largest contributors to port emissions.

Table 3-43 2002 Port Emissions Summary by Engine and Port Type (metric tonnes)

Engine Type	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Propulsion	Deep Sea	64,288	5,478	5,034	2,532	6,329	52,676	2,360,435
	Great Lakes	248	25	23	11	22	187	11,267
	Total	64,536	5,503	5,057	2,543	6,351	52,863	2,371,702
Auxiliary	Deep Sea	57,317	5,052	4,597	1,615	4,306	41,232	2,635,436
	Great Lakes	302	25	23	8	23	202	13,944
	Total	57,619	5,077	4,620	1,624	4,328	41,433	2,649,380
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-44 2002 Port Emissions Summary by Engine and Port Type (short tons)

Engine Type	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Propulsion	Deep Sea	70,866	6,039	5,549	2,792	6,977	58,065	2,601,934
	Great Lakes	273	27	25	12	24	207	12,419
	Total	71,139	6,066	5,575	2,803	7,001	58,272	2,614,353
Auxiliary	Deep Sea	63,181	5,569	5,067	1,781	4,746	45,450	2,905,071
	Great Lakes	333	28	25	9	25	222	15,370
	Total	63,514	5,597	5,092	1,790	4,771	45,672	2,920,442
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

Table 3-45 2002 Port Emissions Summary by Mode and Port Type (metric tonnes)

Mode	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Cruise	Deep Sea	34,193	2,826	2,623	1,141	2,651	21,186	1,314,146
	Great Lakes	183	17	16	6	14	137	8,313
	Total	34,376	2,843	2,639	1,148	2,665	21,323	1,322,459
RSZ	Deep Sea	34,427	2,887	2,657	1,280	3,804	35,148	1,318,897
	Great Lakes	45	4	4	2	4	33	2,052
	Total	34,472	2,891	2,661	1,281	3,808	35,181	1,320,950
Maneuvering	Deep Sea	7,383	758	625	440	724	4,356	266,262
	Great Lakes	70	7	7	4	8	50	3,213
	Total	7,452	765	632	444	732	4,406	269,476
Hotelling	Deep Sea	45,603	4,060	3,726	1,287	3,456	33,218	2,096,566
	Great Lakes	252	21	19	7	19	168	11,631
	Total	45,855	4,081	3,745	1,294	3,475	33,386	2,108,197
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-46 2002 Port Emissions Summary by Mode and Port Type (short tons)

Mode	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Cruise	Deep Sea	37,691	3,115	2,891	1,258	2,922	23,353	1,448,598
	Great Lakes	202	19	18	7	16	151	9,164
	Total	37,893	3,134	2,909	1,265	2,938	23,504	1,457,762
RSZ	Deep Sea	37,949	3,182	2,929	1,410	4,193	38,744	1,453,835
	Great Lakes	50	5	4	2	4	37	2,262
	Total	37,999	3,187	2,934	1,412	4,197	38,781	1,456,098
Maneuvering	Deep Sea	8,138	835	689	485	799	4,802	293,504
	Great Lakes	77	8	7	5	9	56	3,542
	Total	8,215	843	696	490	807	4,857	297,046
Hotelling	Deep Sea	50,268	4,475	4,107	1,419	3,809	36,617	2,311,068
	Great Lakes	278	23	21	8	21	185	12,821
	Total	50,546	4,498	4,128	1,426	3,830	36,802	2,323,889
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

Table 3-47 2002 Port Emissions Summary by Ship Type and Port Type (metric tonnes)

Ship Type	Port Type	Metric Tonnes						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Auto Carrier	Deep Sea	5,125	421	384	185	577	3,676	198,637
	Great Lakes	0	0	0	0	0	0	0
	Total	5,125	421	384	185	577	3,676	198,637
Barge Carrier	Deep Sea	148	13	12	5	12	141	6,364
	Great Lakes	0	0	0	0	0	0	0
	Total	148	13	12	5	12	141	6,364
Self-Unloading Bulk Carrier	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	276	27	25	10	23	210	13,273
	Total	276	27	25	10	23	210	13,273
Other Bulk Carrier	Deep Sea	19,373	1,570	1,431	633	1,732	14,945	767,825
	Great Lakes	227	19	17	7	18	147	9,807
	Total	19,600	1,589	1,448	640	1,750	15,092	777,632
Container	Deep Sea	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
	Great Lakes	0	0	0	0	0	0	0
	Total	33,990	2,733	2,494	1,282	2,833	22,628	1,288,596
General Cargo	Deep Sea	7,402	630	576	251	684	6,208	302,338
	Great Lakes	22	2	2	1	2	15	969
	Total	7,424	631	578	252	686	6,223	303,307
Miscellaneous	Deep Sea	179	16	15	6	35	128	8,209
	Great Lakes	0	0	0	0	0	0	0
	Total	179	16	15	6	35	128	8,209
Passenger	Deep Sea	19,165	1,819	1,668	578	1,470	14,184	893,157
	Great Lakes	0	0	0	0	0	0	0
	Total	19,165	1,819	1,668	578	1,470	14,184	893,157
Refrigerated Cargo	Deep Sea	3,027	247	226	98	313	1,968	130,060
	Great Lakes	0	0	0	0	0	0	0
	Total	3,027	247	226	98	313	1,968	130,060
Roll-On/Roll-Off	Deep Sea	3,391	281	259	113	278	2,193	139,396
	Great Lakes	0	0	0	0	0	0	0
	Total	3,391	281	259	113	278	2,193	139,396
Tanker	Deep Sea	29,758	2,796	2,562	994	2,695	27,802	1,259,107
	Great Lakes	22	2	2	1	2	15	1,012
	Total	29,780	2,798	2,564	995	2,697	27,817	1,260,119
Ocean Going Tug	Deep Sea	48	5	4	2	6	34	2,182
	Great Lakes	0	0	0	0	0	0	0
	Total	48	5	4	2	6	34	2,182
Integrated Tug-Barge	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	3	0	0	0	0	2	149
	Total	3	0	0	0	0	2	149
All	Deep Sea	121,606	10,530	9,631	4,148	10,635	93,908	4,995,871
	Great Lakes	549	50	46	19	45	389	25,210
	Grand Total	122,155	10,580	9,677	4,167	10,680	94,297	5,021,082

Table 3-48 2002 Port Emissions Summary by Ship Type and Port Type (short tons)

Ship Type	Port Type	Short Tons						
		NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Auto Carrier	Deep Sea	5,649	464	424	204	636	4,052	218,960
	Great Lakes	0	0	0	0	0	0	0
	Total	5,649	464	424	204	636	4,052	218,960
Barge Carrier	Deep Sea	163	14	13	6	14	156	7,015
	Great Lakes	0	0	0	0	0	0	0
	Total	163	14	13	6	14	156	7,015
Self-Unloading Bulk Carrier	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	304	29	27	11	26	231	14,631
	Total	304	29	27	11	26	231	14,631
Other Bulk Carrier	Deep Sea	21,355	1,731	1,577	697	1,909	16,474	846,382
	Great Lakes	250	21	19	8	20	162	10,811
	Total	21,605	1,752	1,597	705	1,929	16,636	857,193
Container	Deep Sea	37,468	3,012	2,749	1,413	3,123	24,944	1,420,434
	Great Lakes	0	0	0	0	0	0	0
	Total	37,468	3,012	2,749	1,413	3,123	24,944	1,420,434
General Cargo	Deep Sea	8,159	694	635	277	754	6,843	333,270
	Great Lakes	24	2	2	1	2	16	1,068
	Total	8,183	696	637	278	756	6,860	334,338
Miscellaneous	Deep Sea	197	18	17	7	39	141	9,049
	Great Lakes	0	0	0	0	0	0	0
	Total	197	18	17	7	39	141	9,049
Passenger	Deep Sea	21,126	2,005	1,838	638	1,620	15,635	984,538
	Great Lakes	0	0	0	0	0	0	0
	Total	21,126	2,005	1,838	638	1,620	15,635	984,538
Refrigerated Cargo	Deep Sea	3,337	273	249	108	345	2,170	143,367
	Great Lakes	0	0	0	0	0	0	0
	Total	3,337	273	249	108	345	2,170	143,367
Roll-On/Roll-Off	Deep Sea	3,738	310	286	125	306	2,418	153,658
	Great Lakes	0	0	0	0	0	0	0
	Total	3,738	310	286	125	306	2,418	153,658
Tanker	Deep Sea	32,802	3,082	2,824	1,096	2,971	30,646	1,387,928
	Great Lakes	24	2	2	1	2	16	1,116
	Total	32,826	3,084	2,826	1,097	2,973	30,663	1,389,044
Ocean Going Tug	Deep Sea	53	5	4	2	6	37	2,405
	Great Lakes	0	0	0	0	0	0	0
	Total	53	5	4	2	6	37	2,405
Integrated Tug-Barge	Deep Sea	0	0	0	0	0	0	0
	Great Lakes	3	0	0	0	0	3	164
	Total	3	0	0	0	0	3	164
All	Deep Sea	134,047	11,608	10,616	4,572	11,723	103,515	5,507,005
	Great Lakes	606	55	50	21	50	429	27,790
	Grand Total	134,653	11,662	10,667	4,593	11,772	103,944	5,534,795

3.3.3 Interport Emissions

This section presents our nationwide analysis of the methodology and inputs used to estimate interport emissions from main propulsion and auxiliary engines used by Category 3 ocean-going vessels for the 2002 calendar year. The modeling domain for vessels operating in the ocean extends from the U.S. coastline to a 200 nautical mile boundary. For ships operating in the Great Lakes, it extends out to the international boundary with Canada. The emission results are divided into nine geographic regions of the U.S. (including Alaska and Hawaii), and then totaled to provide a national inventory.

The interport emissions described in this section represent total interport emissions prior to any adjustments made to incorporate near-port inventories. The approach used to replace the near-port portion of the interport emissions is provided in Section 3.3.3.3. The final adjusted interport emissions are provided in Section 3.3.4.

3.3.3.1 Methodology

The interport emissions were estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[3,4] STEEM was developed by the University of Delaware as a comprehensive approach to quantify and geographically represent interport ship traffic, emissions, and energy consumption from large vessels calling on U.S. ports or transiting the U.S. coastline to other destinations, and shipping activity in Canada and Mexico. The model estimates emissions from main propulsion and auxiliary marine engines used on Category 3 vessels that engage in foreign commerce using historical North American shipping activity, ship attributes (i.e., characteristics), and activity-based emission factor information. These inputs are assembled using a geographic information system (GIS) platform that also contains an empirically derived network of shipping lanes. It includes the emissions for all ship operational modes from cruise in unconstrained shipping lanes to maneuvering in a port. The model, however, excludes hotelling operations while the vessel is docked or anchored, and very low speed maneuvering close to a dock. For that reason, STEEM is referred to as an "interport" model, to easily distinguish it from the near ports analysis.

STEEM uses advanced ArcGIS tools and develops emission inventories in the following way.[39] The model begins by building a spatially-defined waterway network based on empirical shipping location information from two global ship reporting databases. The first is the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which contains reports on marine surface and atmospheric conditions from the Voluntary Observing Ships (VOS) fleet. There are approximately 4,000 vessels worldwide in the VOS system. The ICOADS project is sponsored by the National Oceanic and Atmospheric Administration and National Science Foundation's National Center for Atmospheric Research (NCAR). The second database is the Automated Mutual-Assistance Vessel Rescue (AMVER) system. The AMVER data set is based on a ship search and rescue reporting network sponsored by the U.S. Coast Guard. The AMVER system is also voluntary, but is generally limited to ships over 1,000 gross tons on voyages of 24 hours or longer. About 8,600 vessels reported to AMVER in 2004.

The latitude and longitude coordinates for the ship reports in the above databases are used to statistically create and spatially define the direction and width of each shipping lane in the waterway network. Each statistical lane (route and segment) is given a unique identification number for computational purposes. For the current analysis, STEEM used 20 years of ICOADS data (1983-2002) and about one year of AMVER data (part of 2004 and part of 2005) (Figure 3-2).

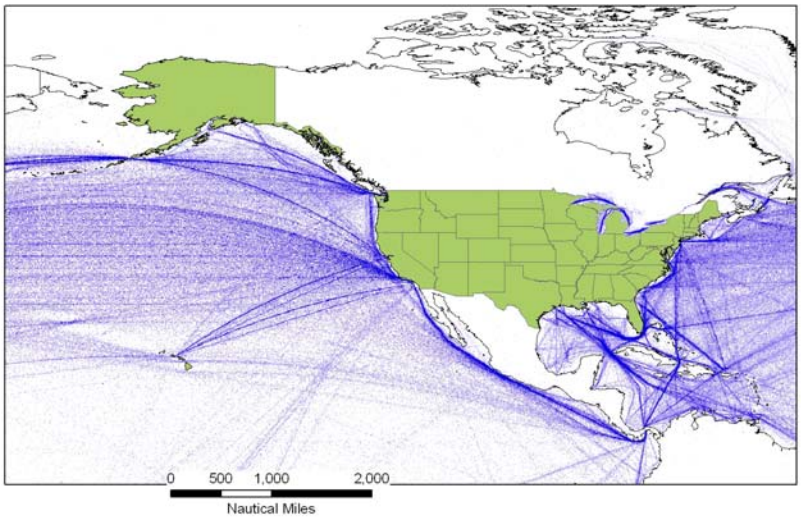


Figure 3-2 AMVER and ICOADS data

Every major ocean and Great Lake port is also spatially located in the waterway network using ArcGIS software. For the U.S., the latitude and longitude for each port is taken from the USACE report on vessel entrances and clearances.[13] There are 251 U.S. ports in the USACE entrances and clearances report. Each port also has a unique identification number for computational purposes.

As illustrated in Figure 3-3, the waterway network represented by STEEM resembles a highway network on land. It is composed of ports, which are origins and destinations of shipping routes: junctions where shipping routes intersect, and segments that are shipping lanes between two connected junctions. Each segment can have only two junctions or ports, and ship traffic flow can enter and leave a segment only through a junction or at a port. The figure represents only a sample of the many routes contained in the model.

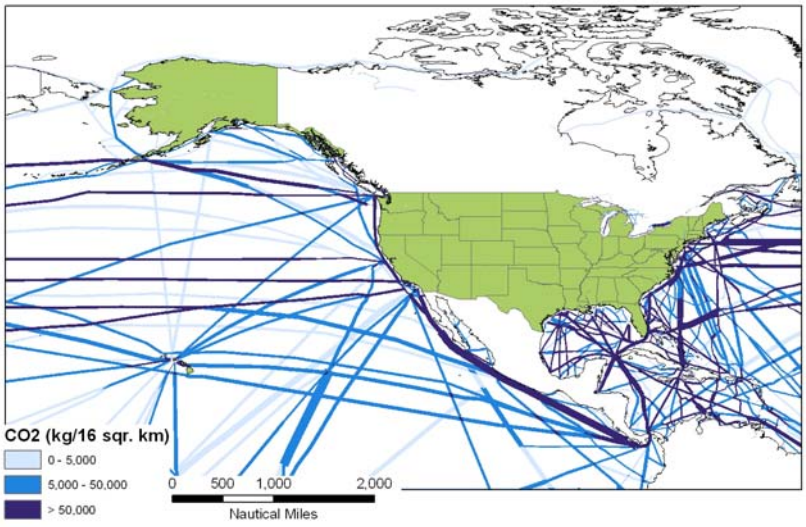


Figure 3-3 Illustration of STEEM Modeling Domain and Spatial Distribution of Shipping Lanes

Every major ocean and Great Lake port is also spatially located in the waterway network using ArcGIS software. For the U.S., the latitude and longitude for each port is taken from the U.S. Army Corps of Engineers report on vessel entrances and clearances (subsequently referred to as USACE).[13] There are 251 U.S. ports in the entrances and clearances report. Each port also has a unique identification number for computational purposes.

The STEEM interport model also employs a number of databases to identify the movements for each vessel (e.g., trips), individual ship attributes (e.g., vessel size and horsepower), and related emission factor information (e.g., emission rates) that are subsequently used in the inventory calculations.

Once the waterway network and various databases are constructed, STEEM uses ArcGIS Network Analyst tools along with specific information on each individual ship movement to solve the most probable path on the network between each pair of ports (i.e., a trip) for a certain ship size. This is assumed to represent the least-energy path, which in most cases is the shortest distance unless prevented by weather or sea conditions, water depth, channel width, navigational regulations, or other constraints that are beyond the model's capability to forecast.

After identifying the shipping route and resulting distance associated with each unique trip, the emissions are simply calculated for each operational mode using the following generalized equation along with information from the ship attributes and emission factor databases:

Emissions per trip = distance (nautical miles) / speed (nautical miles/hour) x horsepower (kW) x fractional load factor x emission factor (g/kW-hour)

In STEEM, emissions are calculated separately for distances representing cruise and maneuvering operational modes. Maneuvering occurs at slower speeds and load factors than during cruise conditions. In STEEM, maneuvering is assumed to occur for the first and last 20 kilometers of each trip when a ship is entering or leaving a port. A ship is assumed to move at maneuvering speed for an entire trip if the distance is less than 20 kilometers.

Finally, the emissions along each shipping route (i.e., segment) for all trips are proportioned among the respective cells that are represented by the gridded modeling domain. For this work, emissions estimates were produced at a cell resolution of 4 kilometers by 4 kilometers, which is appropriate for most atmospheric air quality models. The results for each cell are then summed, as appropriate, to produce emission inventories for the various geographic regions of interest in this analysis.

3.3.3.1.1 Emission Inputs

The STEEM waterway network model relies on a number of inputs to identify the movements for each vessel, individual ship attributes, and related emission factor information. Each of these databases is described separately below.

3.3.3.1.1.1 Shipping Movements

The shipping activity and routes database provides information on vessel movements or trips. It is developed using port entrances and clearances information from the USACE report for the U.S. and the Lloyd's Maritime Intelligence Unit (LMIU) for Canada and Mexico.[40] These sources contain information for each vessel carrying foreign cargo at each major port or waterway that, most importantly for this analysis, includes:

- Vessel name
- Last port of call (entrance record) or next port of call (clearance record)

The database then establishes unique identification numbers for each ship, each port pair, and each resulting trip.

3.3.3.1.1.2 Ship Attributes

The ship attributes data set contains the important characteristics of each ship that are necessary for the STEEM interport model to calculate the emissions associated with each trip. The information in this data set is matched to each previously assigned ship identification number. The following information comes from the USACE entrances and clearances report for each ship identification number:

- Ship type
- Gross registered tonnage (GRT)
- Net registered tonnage (NRT)

The ship attributes data set contains the following information from Lloyd's Register-Fairplay for each ship identification number.[14]

- Main propulsion engine installed power (horsepower)
- Service speed (cruise speed)
- Ship size (length, wide, and draft)

Sometimes data was lacking from the above references for ship speed. In these instances, the missing information was developed for each of nine vessel types and the appropriate value was applied to each individual ship of that type. Specifically, the missing ship speeds for each ship category were obtained from the average speeds used in a Lloyd's Register study of the Baltic Sea and from an Entec UK Limited study for the European Commission.[41,21] The resulting vessel cruise speeds for ships with missing data are shown in Table 3-49.

Table 3-49 Average Vessel Cruise Speed by Ship Type [a]

Ship Type	Average Cruise Speed (knots)
Bulk Carrier	14.1
Container Ship	19.9
General Cargo	12.3
Passenger Ship	22.4
Refrigerated Cargo	16.4
Roll On-Roll Off	16.9
Tanker	13.2
Fishing	11.7
Miscellaneous	12.7

Note:
[a] Used only when ship specific data were missing from the commercial database references.

The average speed during maneuvering is approximately 60 percent of a ship's cruise speed based on using the propeller law described in Section 3.3.2 above and the engine load factor for maneuvering that is presented later in this section.

As with vessel cruise speed, main engine installed power was sometimes lacking in the Lloyd's Register-Fairplay data set. Here again, the missing information was developed for nine different vessel types and the appropriate value was applied to each individual ship of that type when the data were lacking. In this case, the missing main engine horsepower was estimated by regressing the relationships between GRT and NRT, and between installed power and GRT for each category. This operation is performed internally in the model and the result applied to each individual ship, as appropriate.

The ship attributes database also contains information on the installed power of engines used for auxiliary purposes. However, this information is usually lacking in the Lloyds data set, so an alternative technique was employed to estimate the required values. In short, the STEEM model uses a ratio of main engine horsepower to auxiliary engine horsepower that was determined for eight different vessel types using information primarily from ICF International.[42]

(The ICF report attributed these power values to a study for the Port of Los Angeles by Starcrest Consulting.[12]) The auxiliary engine power for each individual vessel of a given ship type is then estimated by multiplying the appropriate main power to auxiliary power ratio and the main engine horsepower rating for that individual ship. The main and auxiliary power values and the resulting auxiliary engine to main engine ratios are shown in Table 3-50.

Table 3-50 Auxiliary Engine Power Ratios

Vessel Type	Average Main Engine Power (kW)	Average Auxiliary Engine Power (kW)	Auxiliary to Main Engine Power Ratio
Bulk Carrier	7,954	1,169	0.147
Container Ship	30,885	5,746	0.186
General Cargo	9,331	1,777	0.190
Passenger Ship	39,563	39,563 [a]	1.000
Refrigerated Cargo	9,567	3,900 [b]	0.136
Roll On-Roll Off	10,696 [c]	2,156 [c]	0.202
Tanker	9,409	1,985	0.211
Miscellaneous	6,252	1,680	0.269

Notes:

[a] The ICF reference reported a value of 11,000 for auxiliary engines used on passenger vessels.[42]

[b] The STEEM used auxiliary engine power as reported in the ARB methodology document.[36]

[c] The STEEM purportedly used values for Roll On-Roll Off main and auxiliary engines that represent a trip weighted average of the Auto Carrier and Cruise Ship power values from the ICF reference.

Finally, the ship attributes database provides information on the load factors for main engines during cruise and maneuvering operation, in addition to load factors for auxiliary marine engines. Main engine load factors for cruise operation were taken from a study of international shipping for all ship types, except passenger vessels.[43] For this analysis, the STEEM model used a propulsion engine load factor for passenger ship engines at cruise speed of 55 percent of the total installed power. This is based on engine manufacturer data contained in two global shipping studies.[43,44] During maneuvering, it was assumed that all main engines, including those for passenger ships, operate at 20 percent of the installed power. This is consistent with a study done by Entec UK for the European Commission.[21] The main engine load factors at cruise speed by ship type are shown in Table 3-51.

Auxiliary engine load factors, except for passenger ships, were obtained from the ICF International study referenced above. These values are also shown in Table 3-51. For cruise mode, neither port nor interport portions of the inventory were adjusted for low load operation, as the low load adjustments are only applied to propulsion engines with load factors below 20%.

Table 3-51 Main and Auxiliary Engine Load Factors at Cruise Speed by Ship Type

Ship Type	Average Main Engine Load Factor (%)	Average Auxiliary Engine Load Factor (%)
Bulk Carrier	75	17
Container Ship	80	13
General Cargo	80	17
Passenger Ship	55	25
Refrigerated Cargo	80	20
Roll On-Roll Off	80	15
Tanker	75	13
Miscellaneous	70	17

3.3.3.1.1.3 Emission Factor Information

The emission factor data set contains emission rates for the various pollutants in terms of grams of pollutant per kilowatt-hour (g/kW-hr). The main engine emission factors are shown in Table 3-52 . The speed specific factors for NO_X, HC, and SO_2 were taken from several recent analyses of ship emissions in the U.S., Canada, and Europe. [21,36,42,43, 45] The PM factor was based on discussions with the California Air Resources Board (ARB) staff. The fuel specific CO emission factor was taken from a report by ENVIRON International.[19] The STEEM study used the composite emission factors shown in the table because the voyage data used in the model do not explicitly identify main engine speed ratings, i.e., slow or medium, or the auxiliary engine fuel type, i.e., marine distillate or residual marine. The composite factor for each pollutant is determined by weighting individual emission factors by vessel engine population data from a 2005 survey of ocean-going vessels that was performed by ARB.[20] Fuel consumption was calculated from CO_2 emissions using the same ratio (1:3.183) as used in the near-port analysis.

Table 3-52 Main Engine Emission Factors by Ship and Fuel Type

Engine Type	Main Engine Emission Factors (g/kW-hr)						
	Fuel Type	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2
Slow Speed	Residual Marine	18.1	1.5	1.4	0.6	1.4	10.5
Medium Speed	Residual Marine	14	1.5	1.4	0.5	1.1	11.5
Composite EF	Residual Marine	17.9	1.5	1.4	0.6	1.4	10.6

Note:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.

The emission factors for auxiliary engines are shown in Table 3-53. The fuel specific main emission factors for NO_X and HC were taken from several recent analyses of ship emissions in the U.S., Canada, and Europe, as referenced above for the main engine load factors. The PM factor for marine distillate was taken from a report by ENVIRON International, which

was also referenced above. The PM factor for residual marine was based on discussions with the California Air Resources Board (ARB) staff. The CO factors are from the Starcrest Consulting study of the Port of Los Angeles.[12] For SO_2, the fuel specific emission factors were obtained from Entec and Corbett and Koehler.[21,43]

The composite emission factors displayed in the table are discussed below.

Table 3-53 Auxiliary Engine Emission Factors by Ship and Fuel Type

Engine Type	Auxiliary Engine Emission Factors (g/kW-hr)						
	Fuel Type	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2
Medium Speed	Marine Distillate	13.9	0.3	0.3	0.4	1.1	4.3
Medium Speed	Residual Marine	14.7	1.5	1.4	0.4	1.1	12.3
Composite EF	Residual Marine	14.5	1.2	1.1	0.4	1.1	**

Note:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] See Table 3-54 for composite SO_2 emission factors by vessel type.

As for main engines, the STEEM study used the composite emission factors for auxiliary engines. For all pollutants other than SO_2, underlying data used in the model do not explicitly identify auxiliary engine voyages by fuel type, i.e., marine distillate or residual marine. Again, the composite factor for those pollutants was determined by weighting individual emission factors by vessel engine population data from a 2005 survey of ocean-going vessels that was performed by ARB.[20]

For SO_2, composite emission factors for auxiliary engines were calculated for each vessel type. These composite factors were determined by taking the fuel specific emission factors from Table 3-53 and weighting them with an estimate of the amount of marine distillate and residual marine that is used by these engines. The relative amount of each fuel type consumed was taken from the 2005 ARB survey. The relative amounts of each fuel type for each vessel type and the resulting SO_2 emission factors are shown in Table 3-54.

Table 3-54 Auxiliary Engine SO_2 Composite Emission Factors by Vessel Type

Vessel Type	Residual Marine (%)	Marine Distillate (%)	Composite Emission Factor (g/kW-hr)
Bulk Carrier	71	29	9.98
Container Ship	71	29	9.98
General Cargo	71	29	9.98
Passenger Ship	92	8	11.66
Refrigerated Cargo	71	29	9.98
Roll On-Roll Off	71	29	9.98
Tanker	71	29	9.98
Miscellaneous	0	100	4.3

3.3.3.1.1.4 EPA Adjustments to STEEM PM and SO_2 Emission Inventories

The interport emission results contained in this study for PM_{10} and SO_2 were taken from the STEEM inventories and then adjusted to reflect EPA's recent review of available engine test data and fuel sulfur levels as described Section 3.3.2.3 for the near port analysis. In the near ports work, a PM emission factor of 1.4 g/kW-hr was used for most main engines, e.g., slow speed diesel and medium speed diesel engines, all of which are assumed to use residual marine. A slightly higher value was used for steam turbine and gas turbine engines, and a slightly lower value was used for most auxiliary engines. However, these engines represent only a small fraction of the total emissions inventory. As shown in Section 3.3.3.1.1.3, the STEEM study used an emission factor of 1.5 g/kW-hr for all main engines and a slightly lower value for auxiliary engines. Here again, the auxiliary engines comprise only a small fraction of the total emissions from these ships. Therefore, for simplicity, EPA adjusted the interport PM inventories by multiplying the STEEM results by the ratio of the two primary emission factors, i.e., 1.4/1.5 or 0.933, to approximate the difference in fuel effects.

The STEEM SO_2 emission inventories were similarly adjusted using SO_2 emission factors from the interport analysis (Section 3.3.3.1.1.3) and the near ports analysis (Section 3.3.2.3). This information is displayed in Table 3-55. The composite values in the table are calculated by mathematically weighting the slow speed and medium speed emission factors from each study by their individual population fraction from the 2005 ARB shipping survey, i.e., 95 percent and 5 percent, respectively.[20] Therefore, the interport SO_2 inventories that appear in this report are the result of multiplying the STEEM inventories by the ratio of the two composite g/kW-hr emission factors shown in table, i.e., 10.33 /10.6 or 0.975.

Table 3-55 SO_2 Emission Factors Used to Adjust STEEM Emission Inventories

Engine Type	Fuel Type	STEEM (g/ kW -hr)	Near Ports (g/ kW -hr)	Composite (g/ kW -hr)
Slow Speed	Residual Marine	10.50	10.29	n/a
Medium Speed	Residual Marine	11.50	11.09	n/a
Composite	Residual Marine	10.6 [a]	10.33 [a]	0.975

Note:
[a] Weighted by ship populations from 2005 ARB survey: 95 percent slow speed and 5 percent medium speed.

3.3.3.2 Interport Domestic Traffic

As previously noted, STEEM includes the emissions associated with ships that are engaged in foreign commerce. As a result, U.S.-flagged vessels carrying domestic cargo (Jones Act ships) are not included. The STEEM interport analysis also roughly estimated the emissions associated with these ships that are engaged solely in domestic commerce.[1,4] Specifically, the interport analysis estimated that the large ocean-going vessels carrying only domestic cargo excluded from STEEM represent approximately 2-3 percent of the total U.S. emissions.

In Section 3.3.2.5, in the estimation of port inventories, the estimate of excluded installed power was roughly 6.5 percent. It is not inconsistent that the STEEM estimate of excluded emissions is lower than the excluded power estimated from calls to U.S. ports, since the STEEM model includes ships that are transiting without stopping at U.S. ports. Since most of the Jones Act ships tend to travel closer along the coast line, most of the Jones Act ship traffic is expected to fall within the proposed ECA. Therefore, the results presented in this chapter are expected to underpredict the benefits of the proposed ECA.

3.3.3.3 Combining the Near Port and Interport Inventories

The national and regional inventories in this study are a combination of the results from the near ports analysis described in Section 3.3.2 and the STEEM interport modeling described in this section. The two inventories are quite different in form. As previously presented in Figure 3-1, the STEEM modeling domain spans the Atlantic and Pacific Oceans in the northern hemisphere. The model characterizes emissions from vessels while traveling between ports. That includes when a vessel is maneuvering a distance of 20 kilometers to enter or exist a port, cruising near a port as it traverses the area, or moving in a shipping lane across the open sea. For the U.S., STEEM includes the emissions associated with 251 ports. The results are spatially reported in a gridded format that is resolved to a cell dimension of 4 kilometers by 4 kilometers.

The near port results, however, are much more geographically limited and are not reported in a gridded format. The analysis includes the emissions associated with ship movements when entering or exiting each of 117 major U.S. ports. For deep sea ports that includes when a vessel is hotelling and maneuvering in the port, operating in the RSZ that varies in length for each port, and cruising 25 nautical miles between the end of the RSZ and an unconstrained shipping lane. For Great Lakes ports that includes hotelling and maneuvering, three nautical miles of RSZ operation, and cruising 7 nautical miles between the end of the RSZ and open water. The results are reported for each port and mode of operation.

To precisely replace only the portion of the STEEM interport inventory that is represented in the near port inventory results, it is necessary to spatially allocate the emissions in a format that is compatible with the STEEM 4 kilometers by 4 kilometers gridded output. Once that has been accomplished, the two inventories can be blended together. Both of these processes are described below. This work was conducted by ENVIRON International as a subcontractor under the EPA contract with ICF.[2]

3.3.3.3.1 Spatial Location of the Near Port Inventories

The hotelling, maneuvering, RSZ, and cruise emissions from the near port inventories were spatially located by their respective latitude and longitude coordinates using ArcGIS software. For this study, shapefiles were created that depicted the emission locations as described above. Additional shapefiles were also obtained to locate other geographic features such as the coastline and rivers of the U.S. These shapefiles and the STEEM output can be layered upon each other, viewed in ArcMap, and analyzed together. The following sections provide a more detailed description of how the shapefiles representing the ports, RSZ lanes, and cruise lanes were developed.

3.3.3.3.1.1 Ports

Each port, and thus the designated location for hotelling and maneuvering emissions, is modeled as a single latitude/longitude coordinate point using the port center as defined by the Army Corp of Engineers in the Principal Ports of the United States dataset.[11] One additional port, "Other Puget Sound," which was specially created in the near ports analysis, was added to the list of ports. Some port locations were inspected by consulting Google Earth satellite images to ensure that the point that defined the port's location was physically reasonable for the purposes of this analysis. This resulted in slightly modifying the locations of five ports: Gray's Harbor, Washington; Freeport and Houston, Texas; Jacksonville, Florida; and Moreshead City, North Carolina. In all five cases the change was very small. The hotelling and maneuvering emissions represented by the latitude/longitude coordinate for each port were subsequently assigned to a single cell in the gridded inventory where that point was located. It should be noted that modeling a port as a point will over specify the location of the emissions associated with that port if it occupies an area greater than one grid cell, or 4 kilometers by 4 kilometers. The coordinates of all of the 117 ports used in this work are shown in the Appendix, Table 3-102.

3.3.3.3.1.2 Reduced Speed Zone Operation

The RSZ routes associated with each of the 117 ports were modeled as lines. Line shapefiles were constructed using the RSZ distance information described in Section 3.3.2 and the Army Corp of Engineers National Waterway Network (NWN) geographic database of navigable waterways in and around the U.S.[16] The coordinates of RSZ endpoints for all of the 117 ports used in this work are shown in the Appendix, Table 3-103.

The RSZ emissions were distributed evenly along the length of the line. The latitude/longitude coordinates for each point along the line were subsequently used to assign the emissions to a grid cell based on the proportion of the line segment that occurred in the respective cell. Figure 3-4 illustrates how the length of the RSZ line can vary in any grid cell.

In several instances the NWN links and STEEM data indicated there were two RSZs. These ports are: Honolulu, Hawaii; Los Angeles, Long Beach and El Segundo, California; Brunswick, Georgia; and Baton Rouge, New Orleans, Port of South Louisiana, and Plaquemines, Louisiana. The lengths of the two lines were similar in every case, so the RSZ emissions from the near ports analysis were divided equally between both branches. Figure 3-5 shows an example of a port with multiple RSZs.

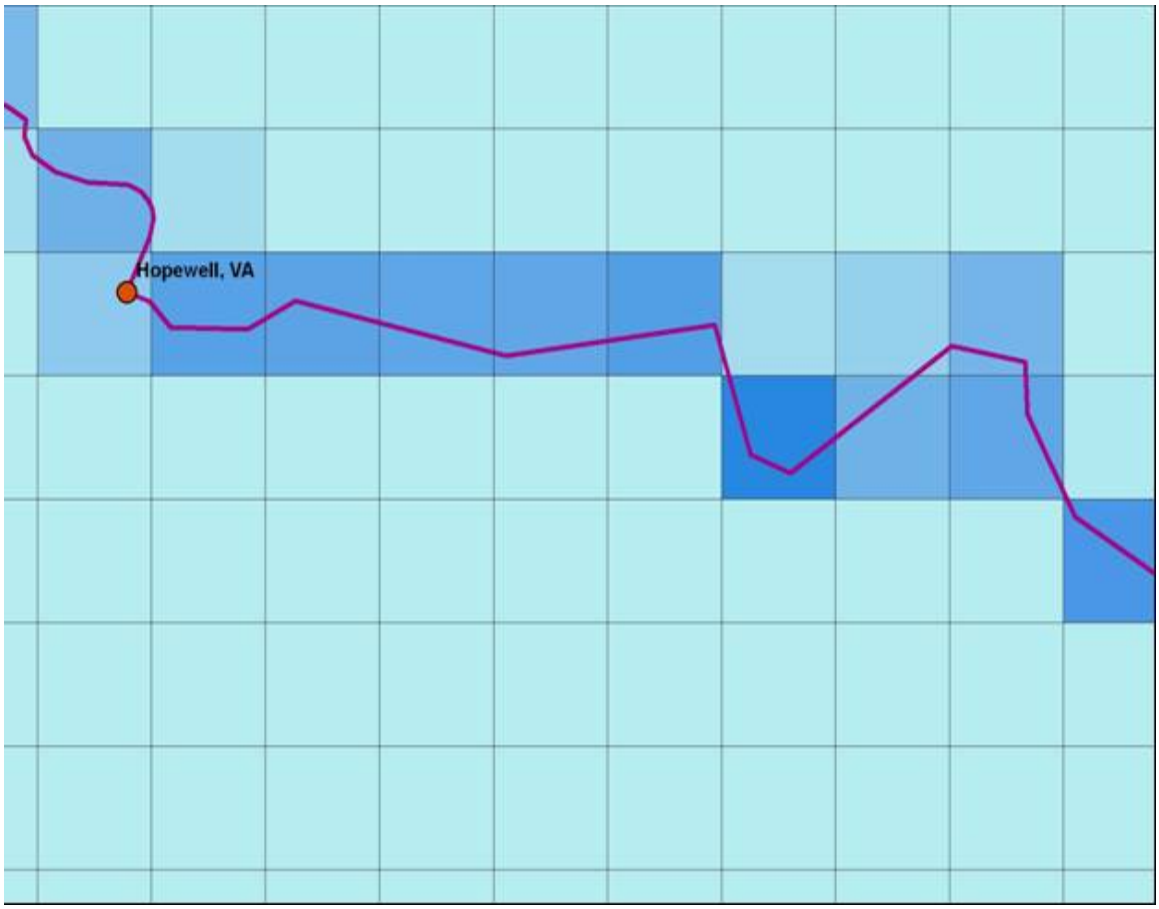


Figure 3-4 Example of Gridded RSZ Lane (Hopewell, Virginia)

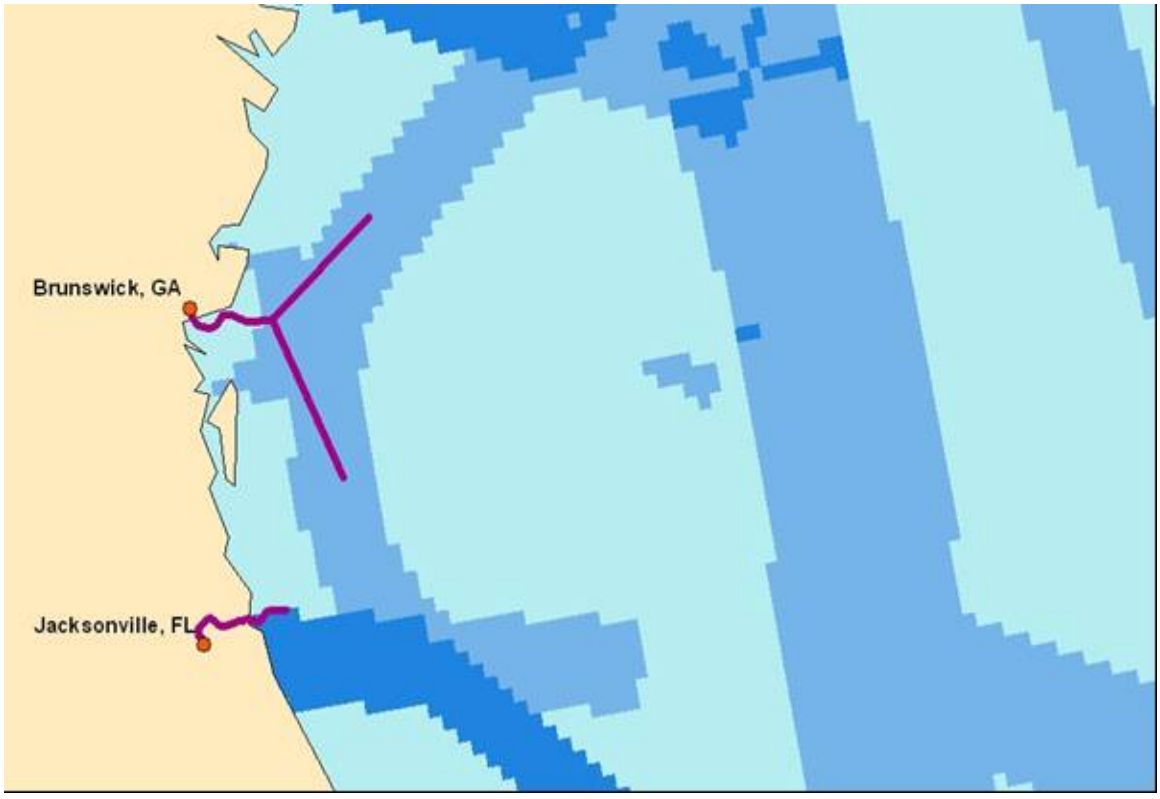


Figure 3-5 Example of Multiple RSZ Lanes (Brunswick, Georgia)

3.3.3.3.1.3 Cruise Operations

The cruise mode links that extend 25 nautical miles for deep sea ports or 7 nautical miles for Great Lake ports from the end of the RSZ end point were also modeled with line shapefiles. These links were spatially described for each port following the direction of the shipping lane evident in the STEEM data. Again, as with RSZ emissions, the latitude/longitude coordinates for each point along the line were subsequently used to assign the emissions to a grid cell based on the proportion of the line segment that occurred in the respective cell.

The STEEM data sometimes indicated there were two or three cruise mode links associated with a port. In these cases, the underlying STEEM ship movement data was evaluated to determine whether any particular route should be assigned larger emissions than the others. That information was judged to be inadequate to justify such differential treatment, so the near port cruise emissions for ports with multiple cruise lanes were assigned equally to each link. Figure 3-6 provides an example of multiple cruise lanes.

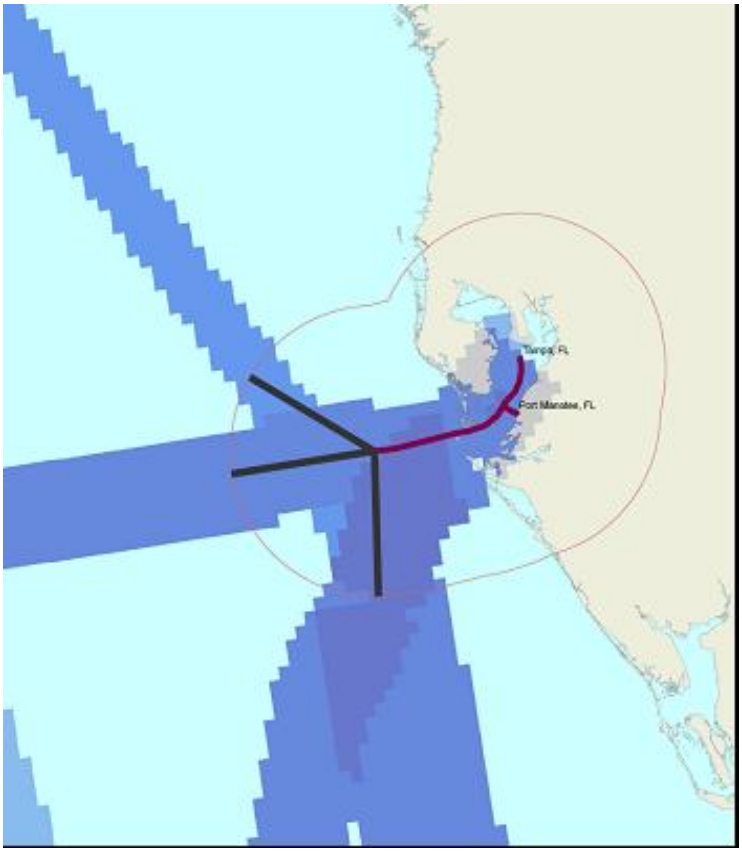


Figure 3-6 Example of Multiple Cruise Lanes (Tampa and Port Manatee, Florida)

3.3.3.3.2 Combining the Near Port and STEEM Emission Inventories

After spatially defining the geographic location of the near port emissions, but before actually inserting them into the gridded STEEM inventory, it was necessary to determine if all of the STEEM emissions within an affected cell should be replaced, or if some of the emissions should be retained. In this latter case, ships would be traversing the area near a port, but not actually entering or exiting the port.

This evaluation was performed for each port by first overlaying the RSZ and cruise shapefiles on the STEEM gridded inventory, and then using ArcGIS tools to create a series of circular buffers with a radius of 25 nautical miles around each of the points that represented an RSZ line. A single elongated buffer was then made from the intersection or outer boundaries of all the individual circular buffers. As illustrated in Figure 3-6, the resulting RSZ buffer encloses the port, RSZ links and cruise mode links. The STEEM emissions underneath the buffer were then evaluated. In cases where the STEEM data showed that ships were routed directly to an isolated port, the STEEM emissions were completely replaced by near port emissions (Figure 3-7). Conversely, when the examination revealed that the underlying STEEM emissions included some ship passages that were simply traversing near the port, the emissions associated with those vessel movements were retained, i.e., not completely replaced with the near port

emission results (Figure 3-8). The methodology for determining the emissions from transient ship operation is described below.

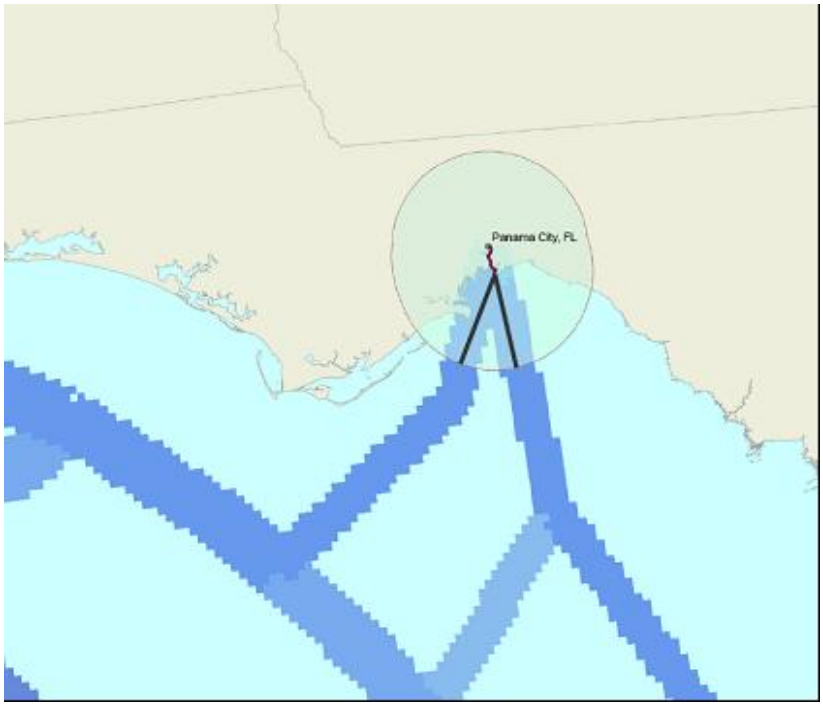


Figure 3-7 Example of Complete Replacement of STEEM Emissions (Panama City, Florida)

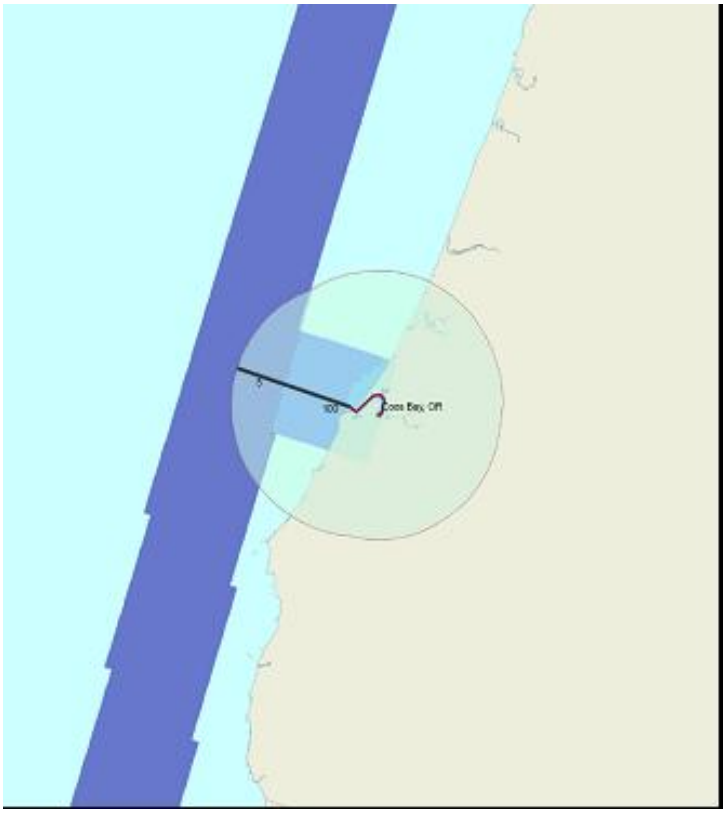


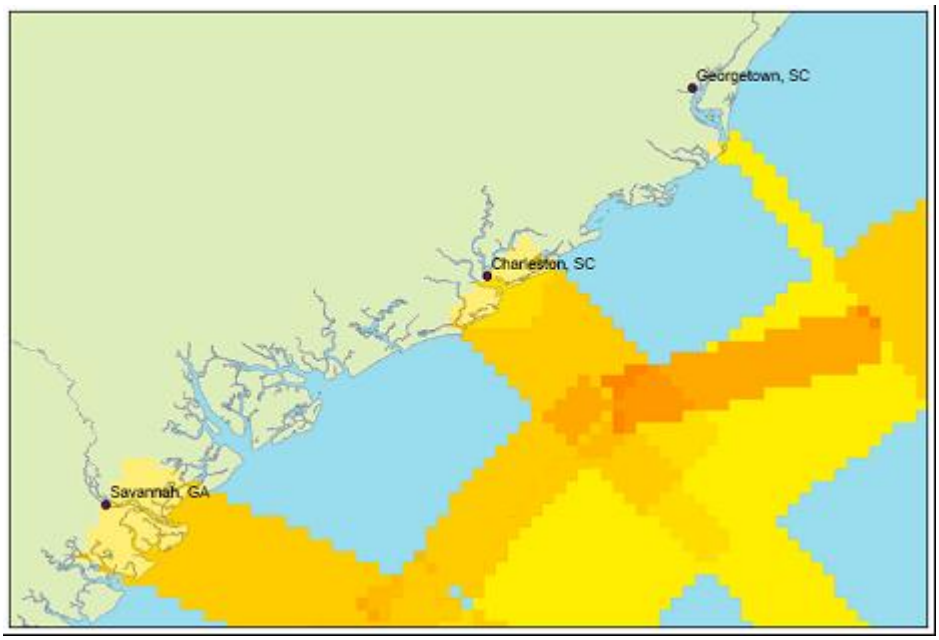
Figure 3-8 Example of Partial Replacement of STEEM Emissions (Coos Bay, Oregon)

The percentage of STEEM emissions that are attributable to a port, and should be replaced, were approximated by dividing the STEEM emissions in the isolated portion of the route that lead only to the port, with the STEEM emissions in the major shipping lane. As an example, the STEEM emissions in the portion of the buffer in Figure 3-8 that only went to the port were approximately 347 kg/cell/year. The emissions within the buffer for just the major shipping lane were 6996 kg/cell/year. Therefore, the emissions in the grid cells that comprised the portion of the buffer overlaying the major shipping lane were reduced by the fraction 347/6996, or 5 percent before the near port emissions were added to the gridded inventory.

The actual merging of the two inventories was performed by creating a number of databases that identified the fraction of the near port inventory for each pollutant species and operating mode that should be added to the grid cells for each port. A similar database was also created that identified how much of the original STEEM emissions should be reduced to account for ship movements associated directly with a port, while preserving those that represented transient vessel traffic. These databases were subsequently used to calculate the new emission results for each affected cell in the original STEEM gridded inventory, resulting in the combined inventory results for this study.

Figure 3-9 provides side-by-side comparisons of the original STEEM emissions inventory and the new merged inventory. The results indicate that the spatial allocation of the near port emissions conducted in this study provides a more precise assessment of vessel travel near a port than the STEEM methodology. As previously described, the near port ship emissions may be over specified, but this approach generally provides a more reasonable placement of emissions near the coastline than the wide shipping lanes in the STEEM model, which in some cases show shipping emissions over land.

Original



New

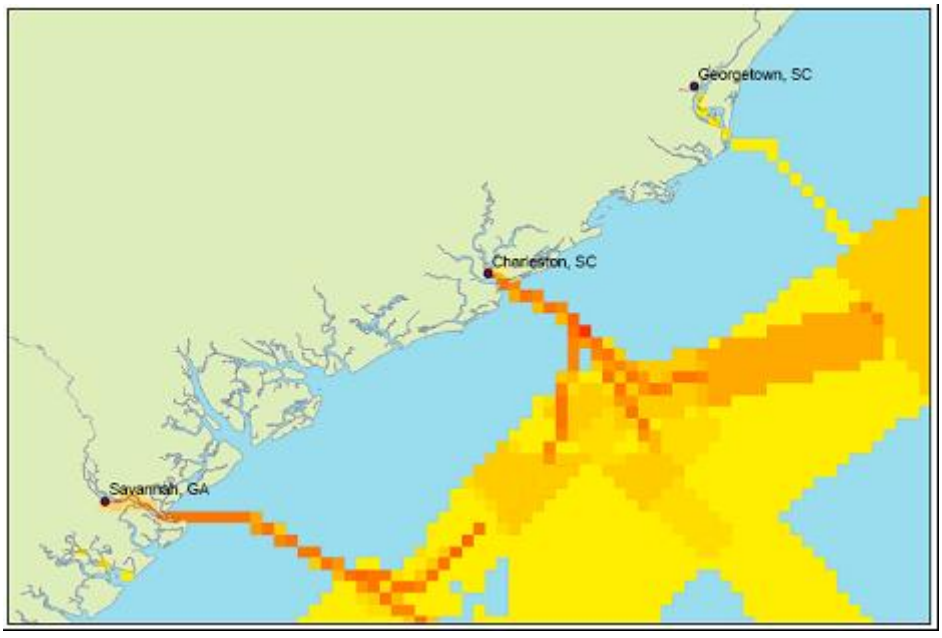


Figure 3-9 Spatial Comparison of the Original STEEM and New Combined Gridded Inventories—Southeast United States

3.3.4 2002 Baseline Emission Inventories

The modeling domain of the new combined emission inventory described above is the same as the original STEEM domain, i.e., the Atlantic and Pacific Oceans, the Gulf of Mexico, the Great Lakes, Alaska and Hawaii. Inventories for the nine geographic regions of the U.S. specified in Section 3.2 were created using ArcGIS software to intersect the regional shapefiles with the 4 kilometers by 4 kilometers gridded domain. Any grid cell split by a regional boundary was considered to be within a region if over 50 percent of its area was within the region. The emissions in each of the cells defined within a region were then summed. The final emission inventories for 2002 are shown in Table 3-56 for each of the nine geographic regions and the nation. The geographic scope of these regions was previously displayed in Figure 3-1. The fuel consumption by fuel type associated with each region is also provided in Table 3-57.

Table 3-56 2002 Regional and National Emissions from Category 3 Vessel Main and Auxiliary Engines

Region	Metric Tonnes						
	NO_X	PM_{10}	$PM_{2.5}$ [a]	HC	CO	SO_2	CO_2
Alaska East (AE)	18,051	1,425	1,311	597	1,410	10,618	657,647
Alaska West (AW)	60,019	4,689	4,313	1,989	4,685	34,786	2,143,720
East Coast (EC)	219,560	17,501	16,101	7,277	17,231	145,024	8,131,553
Gulf Coast (GC)	172,897	14,043	12,920	5,757	14,169	104,852	6,342,139
Hawaii East (HE)	22,600	1,775	1,633	749	1,765	13,182	818,571
Hawaii West (HW)	31,799	2,498	2,297	1,053	2,484	18,546	1,151,725
North Pacific (NP)	26,037	2,154	1,982	938	2,090	15,295	990,342
South Pacific (SP)	104,155	8,094	7,447	3,464	8,437	60,443	3,796,572
Great Lakes (GL)	15,019	1,179	1,085	498	1,174	8,766	541,336
Total Metric Tonnes	670,137	53,358	49,089	22,322	53,445	411,512	24,573,605
Total Short Tons [b]	738,700	58,817	54,112	24,606	58,913	453,614	27,087,763

Notes:
[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-57 2002 Regional and National Fuel Consumption

Region	Metric Tonnes Fuel		
	Distillate	Residual	Total
Alaska East (AE)	1,887	204,725	206,612
Alaska West (AW)	0	673,490	673,490
East Coast (EC)	91,529	2,463,153	2,554,682
Gulf Coast (GC)	63,876	1,928,628	1,992,504
Hawaii East (HE)	4,375	252,794	257,170
Hawaii West (HW)	0	361,836	361,836
North Pacific (NP)	15,905	295,230	311,135
South Pacific (SP)	35,052	1,157,714	1,192,765
Great Lakes (GL)	1,270	168,801	170,071
Total Metric Tonnes	213,894	7,506,371	7,720,265
Total Short Tons [b]	235,778	8,274,358	8,510,136

As previously noted, the inventories in the above table reflect the emissions associated with Category 3 ocean-going vessels that are engaged in foreign commerce. The STEEM interport analysis also roughly estimated the emissions associated with these ships that are engaged solely in domestic commerce.[1,4] These vessels are sometimes referred to as Jones Act ships, as explained in Section 3.3.2.5. Specifically, the interport analysis estimated that the emissions from large ocean-going vessels carrying only domestic cargo represent approximately 2-3 percent of the total values presented in Table 3-56. This is less than the 6.5 percent estimate based on calls to U.S. ports, since the interport traffic includes transiting traffic in U.S. waters.

The relative contributions of the near port and interport emission inventories to the total U.S. emissions are presented in Table 3-58 and Table 3-59. As expected, based on the geographic scope of the two types of inventories, the interport and near port inventories are about 80 percent and 20 percent of the total, respectively. The deep sea ports are about 97 to nearly 100 percent and the Great Lake ports are about 3 to almost zero percent of the total inventories, depending on the port region. This result is also expected given the small number of Great Lake ports and more limited geographic area of the modeling domain.

Table 3-58 2002 Contribution of Near Ports and Interport Emissions to the Total C3 Inventory

Region and Port Type	Metric Tonnes								
	NO_X			PM_{10}			$PM_{2.5}$ [a]		
	Total	% Region	% Type	Total	% Region	% Type	Total	% Region	% Type
Interport	549,852	82.1	100	42,945	80.5	100	39,510	80.5	100
Deep Sea	535,325	--	97.4	41,811	--	97.4	38,465	--	97.4
Great Lakes	14,528	--	2.6	1,135	--	2.6	1,044	--	2.6
Near Port	120,285	17.9	100	10,413	19.5	100	9,580	19.5	100
Deep Sea	119,793	--	99.6	10,368	--	99.6	9,539	--	99.6
Great Lakes	491	--	0.4	44	--	0.4	41	--	0.4
All Regions	670,137	100	--	53,358	100	--	49,089	100	--
Deep Sea	655,118	--	97.8	52,179	--	97.8	48,004	--	97.8
Great Lakes	15,019	--	2.2	1,179	--	2.2	1,085	--	2.2
All Region Short Tons [b]	738,700	--	--	58,817	--	--	54,112	--	--

Notes:

[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.

[b] Converted from metric tonnes using a multiplicative adjustment factor of 1.102 short tons per metric tonne.

Table 3-59 2002 Contribution of Near Ports and Interport Emissions to the Total C3 Inventory (Cont'd)

Region and Port Type	Metric Tonnes								
	HC			CO			SO_2		
	Total	% Region	% Type	Total	% Region	% Type	Total	% Region	% Type
Interport	18,219	81.6	100	42,912	80.3	100	318,450	77.4	*100*
Deep Sea	17,738	--	97.4	41,778	--	97.4	310,030	--	*97.4*
Great Lakes	481	--	2.6	1,134	--	2.6	8,420	--	*2.6*
Near Port	4,103	18.4	100	10,533	19.7	100	93,062	22.6	*100*
Deep Sea	4,086	--	99.6	10,493	--	99.6	92,716	--	*99.6*
Great Lakes	17	--	0.4	40	--	0.4	346	--	*0.4*
All Regions	22,322	100	--	53,445	100	--	411,512	100	--
Deep Sea	21,824	--	97.8	52,271	--	97.8	402,746	--	*97.9*
Great Lakes	498	--	2.2	1,174	--	2.2	8,766	--	*2.1*
All Region Short Tons [a]	24,606	--	--	58,913	--	--	453,614	--	--

Note:
[a] Converted from metric tonnes using a multiplicative adjustment factor of 1.102 short tons per metric tonne.

3.4 Development of 2020 and 2030 Scenarios

3.4.1 Outline of Methodology

The emissions from Category 3 ocean-going vessels (main propulsion and auxiliary engines) are projected to 2020 and 2030 by applying certain adjustment factors to the 2002 emission inventories to account for the change in ship traffic over these time periods, i.e., growth, and the effect of the current controls and the NO_X and fuel controls described in the proposed rule.

The following sections describe the derivation of the growth adjustment factors for each of the modeling regions described in Section 3.2, the emission adjustment factors, and the resulting 2020 and 2030 emission inventories.

The final section describes the baseline and control emission inventories that were developed for calendar years 2020 and 2030. The 2030 inventories were used for air quality modeling, although the 2020 control inventories reported here have been updated relative to those used for the air quality modeling. A comparison of the 2020 control case inventories reported here with those used for the air quality modeling is provided in Section 3.7.

3.4.2 Growth Factors by Geographic Region

This section describes the growth factors that are used to project the emissions to 2020 and 2030 for each of the nine geographic regions evaluated in this analysis. These factors are based on the expected demand for marine bunker fuels that is associated with shipping goods, i.e., commodities, into and out of the U.S. The use of bunker fuel as a surrogate for estimating future emissions is appropriate because the quantity of fuel consumed by C3 engines is highly

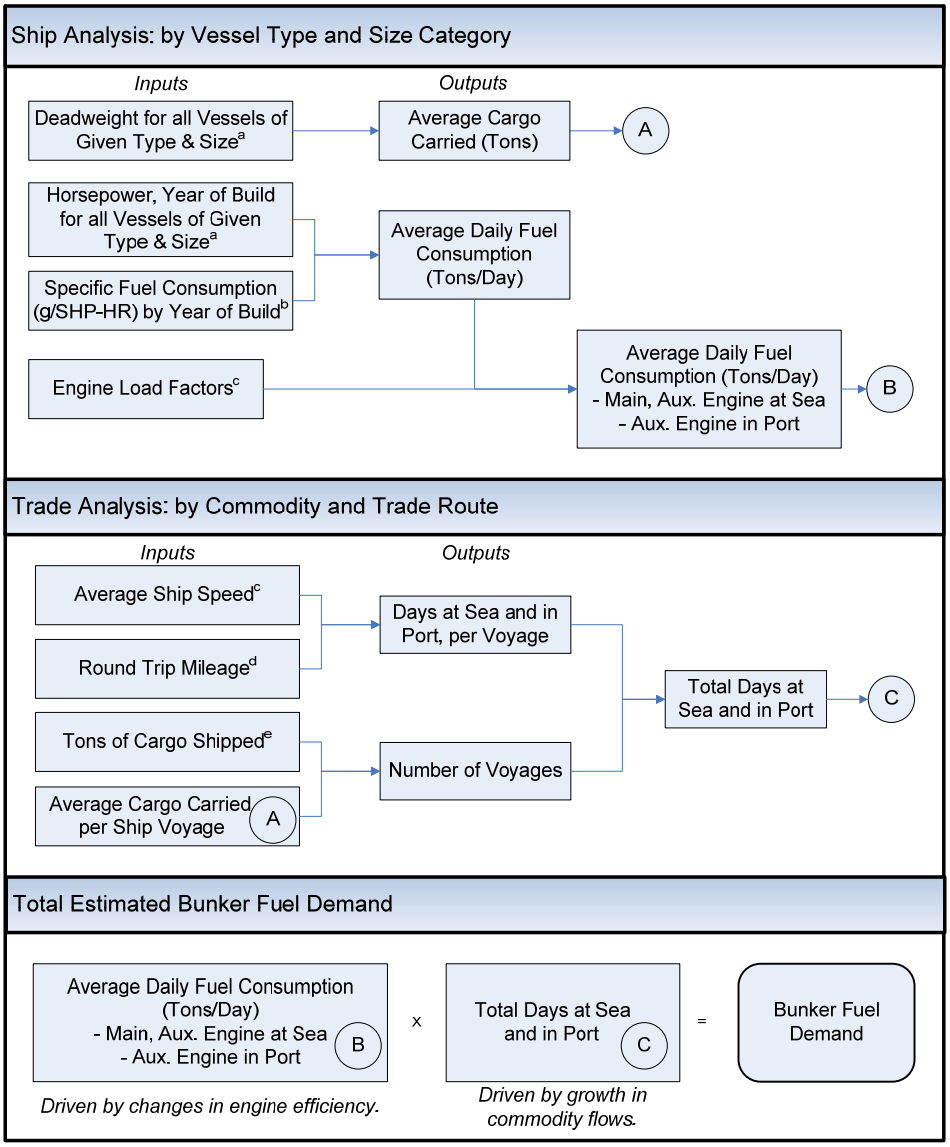
correlated with the amount of combustion products, i.e., pollutants, that are emitted from those vessels. The term bunker fuel in this report also includes marine distillate oil and marine gas oil that are used in some auxiliary power engines.

The remainder of this section first summarizes the development of growth rates by RTI International (RTI) for five geographic regions of the U.S., as performed under contract to EPA (Section 3.4.2.1).[5,6] This is followed by the derivation of the growth factors that are used in this study for the nine geographic regions of interest (Section 3.4.2.9).

3.4.2.1 Summary of Regional Growth Rate Development

RTI developed fuel consumption growth rates for five geographic regions of the U.S. These regions are the East Coast, Gulf Coast, North Pacific, South Pacific, and Great Lakes. The amount of bunker fuel required in any region and year is based on the demand for transporting various types of cargo by Category 3 vessels. This transportation demand is in turn driven by the demand for commodities that are produced in one location and consumed in another, as predicted by an econometric model. The flow of commodities is matched with typical vessels for trade routes (characterized according to cargo capacity, engine horsepower, age, specific fuel consumption, and engine load factors). Typical voyage parameters are then assigned to the trade routes that include average ship speed, round trip mileage, tons of cargo shipped, and days in port. Fuel consumption for each trade route and commodity type thus depends on commodity projections, ship characteristics, and voyage characteristics. Figure 3-10 from RTI illustrates the approach to developing baseline projections of marine fuel consumption.

As a means of comparison, the IMO Secretary General's Informal Cross Government/Industry Scientific Group of Experts presented a growth rate that ranged from 3.3% to 3.7%.[46] RTI's overall U.S. growth rate was projected at 3.4%, which is consistent with that range.



a – Clarksons Ship Register Database
b – Engine Manufacturers' Data, Technical Papers
c – Corbett and Wang (2005) "Emission Inventory Review: SECA Inventory Progress Discussion"
d - Combined trade routes and heavy leg analysis
e – Global Insight Inc. (GII) Trade Flow Projections

Figure 3-10 Illustration of Method for Estimating Bunker Fuel Demand

3.4.2.2 Trade Analysis

The trade flows between geographic regions of the world, as illustrated by the middle portion of Figure 3-10, were defined for the following eight general types of commodities:

- liquid bulk – crude oil
- liquid bulk – refined petroleum products
- liquid bulk – residual petroleum products

- liquid bulk – chemicals (organic and inorganic)
- liquid bulk –gas (including LNG and LPG)
- dry bulk (e.g., grain, coal, steel, ores and scrap)
- general cargo (e.g., lumber/forest products)
- containerized cargo

The analysis specifically evaluated trade flows between 21 regions of the world. Table 3-60 shows the countries associated with each region.

Table 3-60 Aggregate Regions and Associated Countries

Aggregate Regions	Base Countries / Regions
U.S. Atlantic Coast	U.S. Atlantic Coast
U.S. Great Lakes	U.S. Great Lakes
U.S. Gulf Coast	U.S. Gulf Coast
E. Canada[a]	Canada[a]
W. Canada[a]	Canada[a]
U.S. Pacific North	U.S. Pacific North
U.S. Pacific South	U.S. Pacific South
Greater Caribbean	Colombia, Mexico, Venezuela, Caribbean Basin, Central America
South America	Argentina, Brazil, Chile, Peru, Other East Coast of S. America, Other West Coast of S. America
Africa – West	Western Africa
Africa-North/East-Mediterranean	Mediterranean Northern Africa, Egypt, Israel,
Africa-East/South	Kenya, Other Eastern Africa, South Africa, Other Southern Africa
Europe-North	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Norway, Sweden, Switzerland, United Kingdom
Europe-South	Greece, Italy, Portugal, Spain, Turkey, Other Europe
Europe-East	Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic
Caspian Region	Southeast CIS
Russia/FSU	The Baltic States, Russia Federation, Other Western CIS
Middle East Gulf	Jordan, Saudi Arabia, UAE, Other Persian Gulf
Australia/NZ	Australia, New Zealand
Japan	Japan
Pacific-High Growth	Hong Kong S.A.R., Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand
China	China
Rest of Asia	Viet Nam, India, Pakistan, Other Indian Subcontinent

Note:
[a] Canada is treated as a single destination in the GI model. Shares of Canadian imports from and exports to regions of the world in 2004 are used to divide Canada trade into shipments to/from Eastern Canada ports and shipments to/from Western Canada ports.[47]

The overall forecast of demand for shipping services and bunker fuel was determined for each of the areas using information on commodity flows from Global Insight's (GI) World Trade Service. Specifically, GI provided a specialized forecast that reports the flow of each commodity type for the period 1995–2024, based on a proprietary econometric model. The general structure of the GI model for calculating trade flows assumes a country's imports from another country are driven by the importing country's demand forces (given that the exporting country possesses enough supply capacity), and affected by exporting the country's export price and importing country's import cost for the commodity. The model then estimates demand forces, country-specific exporting capacities, export prices, and import costs.

The GI model included detailed annual region-to-region trade flows for eight composite commodities from 1995 to 2024, in addition to the total trade represented by the commodities. Table 3-61 illustrates the projections for 2012 and 2020, along with baseline data for 2005. In 2005, dry bulk accounted for 41 percent of the total trade volume, crude oil accounted for 28 percent, and containers accounted for 12 percent. Dry bulk and crude oil shipments are expected to grow more slowly over the forecast period than container shipments. By 2020, dry bulk represents 39 percent of the total, crude oil is 26 percent, and containers rise to 17 percent.

Table 3-61 Illustration of World Trade Estimates for Composite Commodities, 2005, 2012, and 2020

Commodity Type	Cargo (millions of tons)		
	2005	2012	2020
Dry Bulk	2,473	3,051	3,453
Crude Oil	1,703	2,011	2,243
Container	714	1,048	1,517
Refined Petroleum	416	471	510
General Cargo	281	363	452
Residual Petroleum and Other Liquids	190	213	223
Chemicals	122	175	228
Natural Gas	79	91	105
Total International Cargo Demand	5,979	7,426	8,737

3.4.2.3 Ship Analysis by Vessel Type and Size

Different types of vessels are required to transport the different commodities to the various regions of the world. As shown at the top of Figure 3-10, profiles of these ships were developed to identify the various vessel types and size categories that are assigned to transport commodities of each type along each route. These profiles include attributes such as ship size, engine horsepower, engine load factors, age, and engine fuel efficiency. This information was subsequently used to estimate average daily fuel consumption for each typical ship type and size category.

The eight GI commodity categories were mapped to the type of vessel that would be used to transport that type of cargo using information from Clarksons Shipping Database.[48] These assignments are shown in Table 3-62.

Table 3-62 Assignment of Commodities to Vessel Types

Commodity	Ship Category	Vessel Type
Liquid bulk – crude oil	Crude Oil Tankers	Tanker
Liquid bulk – refined petroleum products	Product Tankers	Product Carrier
Liquid bulk – residual petroleum products	Product Tankers	Product Carrier
Liquid bulk – chemicals (organic and inorganic)	Chemical Tankers	Chemical & Oil Carrier
Liquid bulk – natural gas (including LNG and LPG)	Gas Carriers	LNG Carrier, LPG Carrier, Chemical & LPG Carrier, Ethylene/LPG, Ethylene/LPG/Chemical, LNG/Ethylene/LPG, LNG/Regasification, LPG/Chemical, LPG/Oil, Oil & Liquid Gas Carrier
Dry bulk (e.g. grain, coal, steel, ores and scrap)	Dry Bulk Carriers	Bulk Carrier
General cargo (including neobulk, lumber/forest products)	General Cargo	General Cargo Liner, Reefer, General Cargo Tramp, Reefer Fish Carrier, Ro-Ro, Reefer/Container, Ro-Ro Freight/Passenger, Reefer/Fleet Replen., Ro-Ro/Container, Reefer/General Cargo, Ro-Ro/Lo-Lo, Reefer/Pallets Carrier, Reefer/Pass./Ro-Ro, Reefer/Ro-Ro Cargo
Containerizable cargo	Container Ships	Fully Cellular Container

Each of the vessel types were classified by their cargo carrying capacity or deadweight tons (DWT). The size categories were identified based on both industry definitions and natural size breaks within the data. Table 3-63 summarizes the size categories that were used in the analysis and provides other information on the general attributes of the vessels from Clarksons Shipping Database. The vessel size descriptions are also used to define shipping routes based on physical limitations that are represented by canals or straits through which ships can pass. Very large crude oil tankers are the largest by DWT rating, and the biggest container ships (Suezmax) are also very large.

Table 3-63 Fleet Characteristics

Ship Type	Size by DWT	Minimum Size (DWT)	Maximum Size (DWT)	Number of Ships	Total DWT (millions)	Total Horse Power (millions)
Container	Suezmax	83,000	140,000	101	9.83	8.56
	PostPanamax	56,500	83,000	465	30.96	29.30
	Panamax	42,100	56,500	375	18.04	15.04
	Intermediate	14,000	42,100	1,507	39.80	32.38
	Feeder	0	14,000	1,100	8.84	7.91
General Cargo	All	All		3,214	26.65	27.07
Dry Bulk	Capesize	79,000	0	715	114.22	13.81
	Panamax	54,000	79,000	1,287	90.17	16.71
	Handymax	40,000	54,000	991	46.50	10.69
	Handy	0	40,000	2,155	58.09	19.58
Crude Oil Tanker	VLCC	180,000	0	470	136.75	15.29
	Suezmax	120,000	180,000	268	40.63	5.82
	AFRAmax	75,000	120,000	511	51.83	8.58
	Panamax	43,000	75,000	164	10.32	2.17
	Handymax	27,000	43,000	100	3.45	1.13
	Coastal	0	27,000	377	3.85	1.98
Chemical Tanker	All	All		2,391	38.80	15.54
Petroleum Product Tanker	AFRAmax	68,000	0	226	19.94	3.60
	Panamax	40,000	68,000	352	16.92	4.19
	Handy	27,000	40,000	236	7.90	2.56
	Coastal	0	27,000	349	3.15	1.54
Natural Gas Carrier	VLGC	60,000	0	157	11.57	5.63
	LGC	35,000	60,000	140	6.88	2.55
	Midsize	0	35,000	863	4.79	3.74
Other	All	All		7,675	88.51	53.60
Total	--	--	--	26,189	888.40	308.96

The average fuel consumption for each vessel type and size category was estimated in a multi-step process using individual vessel data on engine characteristics. Clarksons' Shipping Database Register provides each ship's total installed horsepower (HP), type of propulsion (diesel or steam), and year of build. These characteristics are then matched to information on typical specific fuel consumption (SFC), which is expressed in terms of grams of bunker fuel burned per horsepower-hour (g/HP-hr).

The specific SFC values are based on historical data from Wartsila Sulzer, a popular manufacturer of diesel engines for marine vessels. RTI added an additional 10 percent to the reported "test bed" or "catalogue" numbers to account for the guaranteed tolerance level and an in-service SFC differential. Overall, the 10 percent estimate is consistent with other analyses that show some variation between the "test bed" SFC values reported in the manufacturer product catalogues and those observed in actual service. This difference is explained by the fact that old, used engines consume more fuel than brand new engines and in-service fuels may be different than the test bed fuels.[49]

Figure 3-11 shows SFC values that were used in the model regarding the evolution of specific fuel oil consumption rates for diesel engines over time. Engine efficiency in terms of SFC has improved over time, most noticeably in the early 1980s in response to rising fuel prices. However, there is a tradeoff between improving fuel efficiency and reducing emissions. Conversations with engine manufacturers indicate that it is reasonable to assume SFC will remain constant for the projection period of this study, particularly as they focus on meeting NO_X emission standard as required by MARPOL Annex VI, or other potential pollution control requirements.

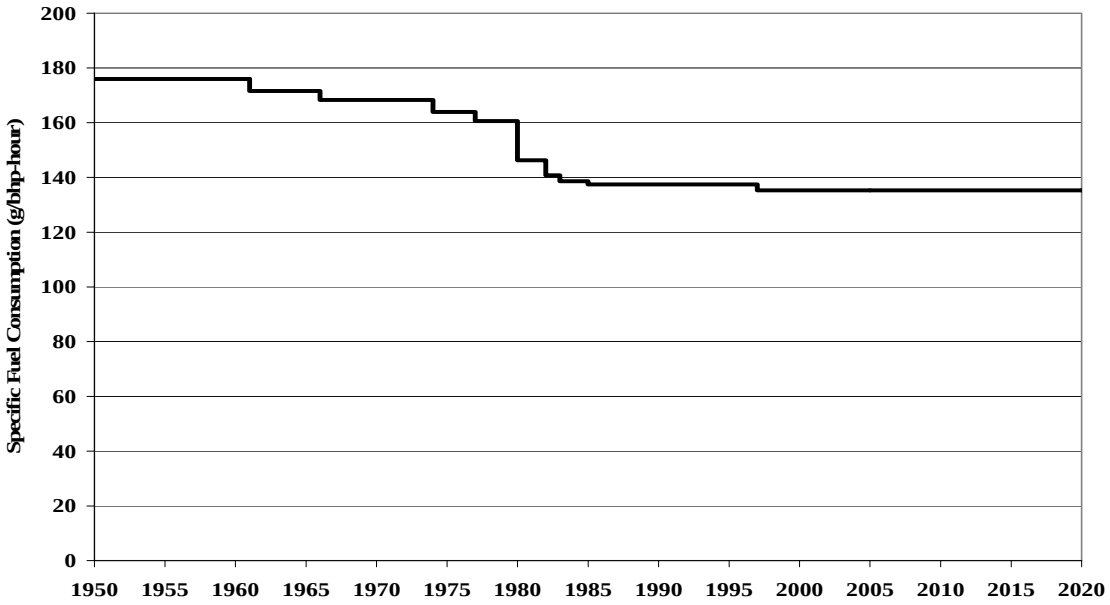


Figure 3-11 Diesel Engine Specific Fuel Consumption

RTI assumed a fixed SFC of 220 g/HP-hr for steam engines operating on bunker fuel.

Using the above information, the average daily fuel consumption (AFC), expressed in metric tons of fuel at full engine load, for each vessel type and size category is found using the following equation:

Equation 3-27

$$\text{Fleet AFC}_{v,s} = \frac{1}{N}\sum\left[SFC_{v,s} \times HP_{v,s} \times 10^{-6} tonnes/g\right]$$

Where:
Fleet AFC = Average daily fuel consumption in metric tonnes at full engine load
v = Vessel type
s = Vessel size category
N = Number of vessels in the fleet
SFC = Specific fuel consumption in grams of bunker fuel burned per horsepower-hour in use(g/HP-hr)
HP = Total installed engine power, in horsepower (HP)
10^6 tonnes/g = Conversion from grams to metric tonnes

As previously noted, AFC values calculated in the above equation are based on total horsepower; therefore, they must be scaled down to reflect typical operation using less than 100 percent of the horsepower rating, i.e., actual engine load. Table 3-64 shows the engine load factors that were used to estimate the typical average daily fuel consumption (tons/day) for the main propulsion engine and the auxiliary engines when operated at sea and in port.[50]

Table 3-64 Main and Auxiliary Engine Load Factors

Vessel Type	Main Engine Load Factor (%)	Auxiliary Engine as Percent of Main Engine	Auxiliary Engine as Percent of Main Engine at Sea
Container Vessels	80	22.0	11.0
General Cargo Carriers	80	19.1	9.5
Dry Bulk Carriers	75	22.2	11.1
Crude Oil Tankers	75	21.1	10.6
Chemical Tankers	75	21.1	10.6
Petroleum Product Tankers	75	21.1	10.6
Natural Gas Carrier	75	21.1	10.6
Other	70	20.0	10.0

The RTI analysis also assumed that the shipping fleet changes over time as older vessels are scrapped and replaced with newer ships. Specifically, vessels over 25 years of age are retired and replaced by new ships of the most up-to-date configuration. This assumption leads to the following change in fleet characteristics over the projection period:

- New ships have engines rated at the current SFC, so even though there are no further improvements in specific fuel consumption, the fuel efficiency of the fleet as a whole will improve over time through retirement and replacement.

- New ships will weigh as much as the average ship built in 2005, so the total cargo capacity of the fleet will increase over time as smaller ships retire and are replaced.

- Container ships will increase in size over time on the trade routes between Asia to either North America or Europe.

3.4.2.4 Trade Analysis by Commodity Type and Trade Route

Determining the total number of days at sea and in port, as shown in the middle portion of Figure 3-10, requires information on the relative amount of each commodity that is carried by the different ship type size categories on each of the trade routes. For example, to serve the large crude oil trade from the Middle East Gulf region to the Gulf Coast of the U.S., 98 percent of the deadweight tonnage is carried on very large oil tankers, while the remaining 2 percent is carried on smaller Suezmax vessels. After the vessel type size distribution was found, voyage parameters were estimated. Specifically, these are days at sea and in port for each voyage (based on ports called, distance between ports, and ship speed**)**, and the number of voyages (based on cargo volume projected by GI and the DTW from Clarksons Shipping Database). The length of each voyage and number of voyages were used to estimate the total number of days at sea and at port, which is a parameter used later to calculate total fuel consumption for each vessel type and size category over each route and for each commodity type. (More information on determining the round trip distance for each voyage that is associated with cargo demand for the U.S. is provided in Section 3.4.2.5.)

The days at sea were calculated by dividing the round trip distance by the average vessel speed:

Equation 3-28

$$\text{Days at Sea Per Voyage}_{v,s,route} = \frac{\text{round trip distance route}}{\text{speed}_{v,s} \times 24\,\text{hrs}}$$

Where:
v = Vessel type
s = Vessel size category
route = Unique trip itinerary
round trip route distance = Trip length in nautical miles
speed = Vessel speed in knots or nautical miles per hour
24 hrs = Number of hours in one day

Table 3-65 presents the speeds by vessel type that were used in the analysis.[50] These values are the same for all size categories, and are assumed to remain constant over the forecast period.

Table 3-65 Vessel Speed by Type

Vessel Type	Speed (knots)
Crude Oil Tankers	13.2
Petroleum Product Tankers	13.2
Chemical Tankers	13.2
Natural Gas Carriers	13.2
Dry Bulk Carriers	14.1
General Cargo Vessels	12.3
Container Vessels	19.9
Other	12.7

The number of voyages along each route for each trade was estimated for each vessel type *v* and size category *s* serving a given route by dividing the tons of cargo moved by the amount of cargo (DTW) per voyage:

Equation 3-29

$$\text{Number of Voyages}_{v,s,trade} = \frac{\text{total metric tonnes of cargo moved}}{\text{fleet average DWT}_{v,s} \times \text{utilization rate}}$$

Where:
v = Vessel type
s = Vessel size category
trade = Commodity type
Fleet average DWT = Median dead weight tonnage carrying capacity in metric tons
Utilization rate = Fraction of total ship DWT capacity used

The cargo per voyage is based on the fleet average ship size from the vessel profile analysis. For most cargo, a utilization rate of 0.9 is assumed to be constant throughout the forecast period. Lowering this factor would increase the estimated number of voyages required to move the forecasted cargo volumes, which would lead to an increase in estimated fuel demand.

In addition to calculating the average days at sea per voyage, the average days in port per voyage was also estimated by assuming that most types of cargo vessels spend four days in port per voyage. RTI notes, however, that this can vary somewhat by commodity and port.

3.4.2.5 Worldwide Estimates of Fuel Demand

This section describes how the information from the vessel and trade analyses were used to calculate the total annual fuel demand associated with international cargo trade. Specifically, for each year *y* of the analysis, the total bunker fuel demand is the sum of the fuel consumed on each route of each trade (commodity). The fuel consumed on each route of each trade is in turn the sum of the fuel consumed for each route and trade for that year by propulsion main engines

and auxiliary engines when operated at sea and in port. These steps are illustrated by the following equations:

Equation 3-30

$$FC_y = \sum_{trade} \sum_{route} FC_{trade,route,year}$$
$$= \sum_{trade} \sum_{route} \left[AFC_{trade,route,y\,at\,sea} \times Days\,at\,Sea_{trade,route,y} + AFC_{trade,route,y\,at\,port} \times Days\,at\,Port_{trade,route,y} \right]$$

Where:
FC = Fuel consumed in metric tonnes
y = calendar year
trade = Commodity type
route = Unique trip itinerary
AFC = Average daily fuel consumption in metric tonnes
yatsea = Calendar year main and auxiliary engines are operated at sea
yatport = Calendar year main and auxiliary engines are operated in port

Equations 3-31

$$AFC_{trade,route,y\,at\,sea} = \sum_{v,s,t,r} (Percent\ of\ trade\ along\ route)_{v,s} \left[Fleet\ AFC_{v,s} \times (MELF + AE\ at\ sea\ LF) \right]$$

$$AFC_{trade,route,y\,at\,port} = \sum_{v,s,t,r} (Percent\ of\ trade\ along\ route)_{v,s} \left[Fleet\ AFC_{v,s} \times AE\ import\ LF \right]$$

$$Days\,at\,Sea_{trade,route,y} = \sum_{v,s,t,r} (Percent\ of\ trade\ along\ route)_{v,s} \left[Days\ at\ sea\ per\ voyage_{v,s} \times Number\ of\ voyages_{v,s} \right]$$

$$Days\,at\,Port_{trade,route,y} = \sum_{v,s,t,r} (Percent\ of\ trade\ along\ route)_{v,s} \left[Days\ at\ port\ per\ voyage \times Number\ of\ voyages \right]$$

Where:
AFC = Average daily fuel consumption in metric tonnes
trade = Commodity type
route = Unique trip itinerary
yatsea = Calendar year main and auxiliary engines are operated at sea
yatport = Calendar year main and auxiliary engines are operated in port
y = calendar year
v = Vessel type
s = Vessel size category
t = Trade
r = Route
Fleet AFC = Average daily fuel consumption in metric tonnes at full engine load
MELF = main engine load factor, unitless
AE at sea LF = auxiliary engine at-sea load factor, unitless
AE in port LF = auxiliary engine in-port load factor, unitless

The inputs for these last four equations are all derived from the vessel analysis in Section 3.4.2.3 and the trade analysis in Section 3.4.2.2.

3.4.2.6 Worldwide Bunker Fuel Consumption

Based on the methodology outlined above, estimates of global fuel consumption over time were computed, and growth rates determined from these projections. Figure 3-12 shows estimated world-wide bunker fuel consumption by vessel type.

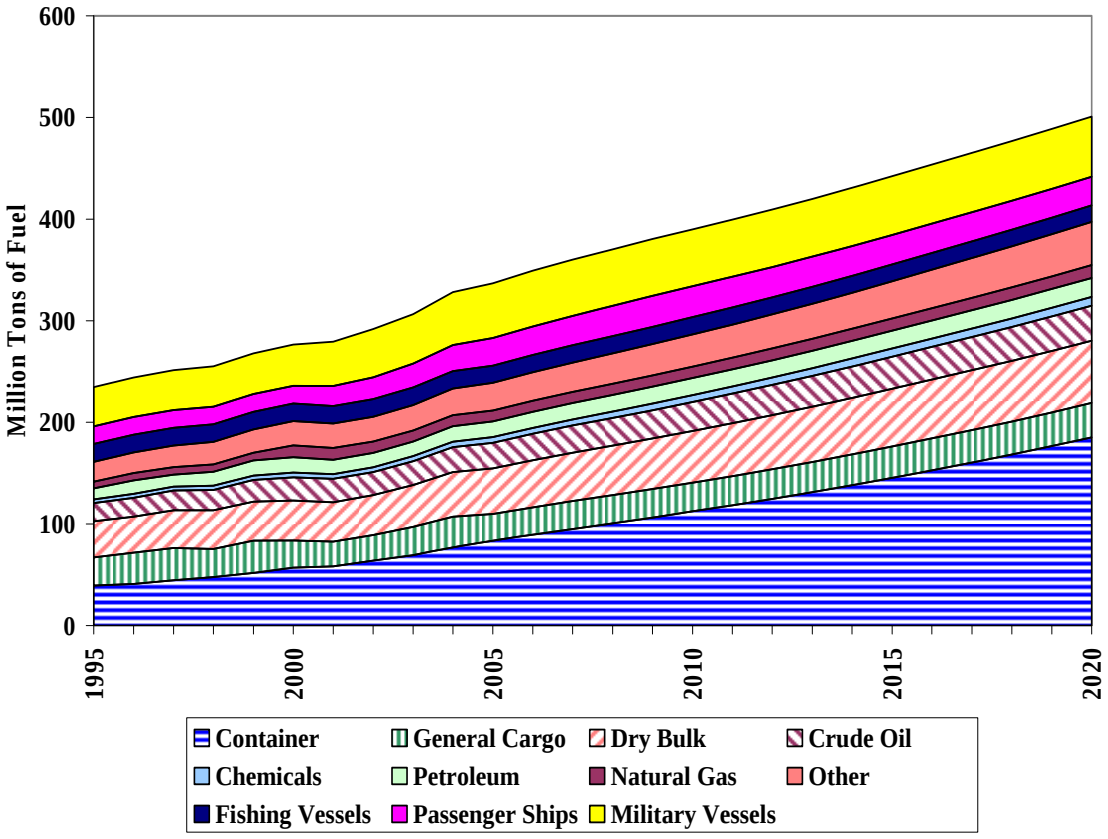


Figure 3-12 Worldwide Bunker Fuel Consumption

Figure 3-13 shows the annual growth rates by vessel-type/cargo that are used in the projections shown in Figure 3-12. Total annual growth is generally between 2.5 percent and 3.5 percent over the time period between 2006 and 2020 and generally declines over time, resulting in an average annual growth of around 2.6 percent.

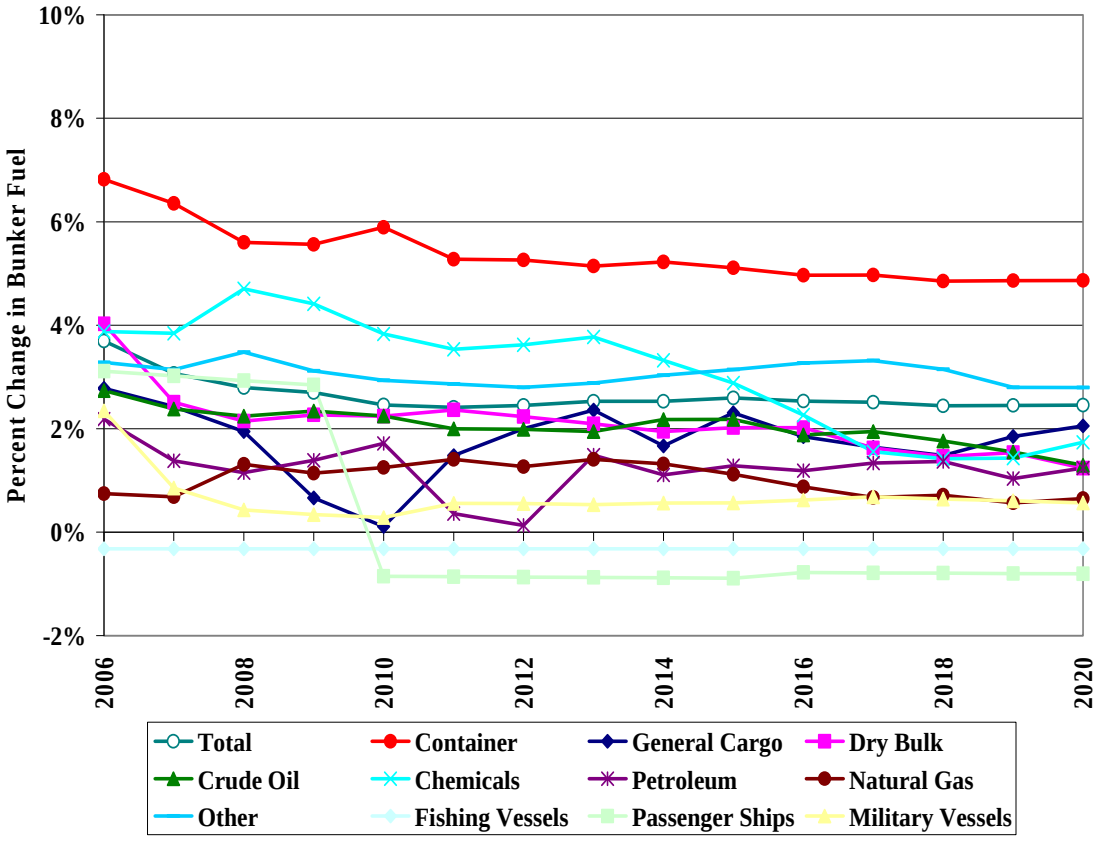


Figure 3-13 Annual Growth Rate in World-Wide Bunker Fuel Use by Commodity Type

3.4.2.7 Fuel Demand Used to Import and Export Cargo for the United States

The methodology described above provides an estimate of fuel consumption for international cargo worldwide. RTI also estimated the subset of fuel demand for cargo imported to and exported from five regions of the U.S. The five regions are:

- North Pacific
- South Pacific
- Gulf
- East Coast
- Great Lakes

For this analysis, the same equations were used, but were limited to routes that carried cargo between specific cities in Asia, Europe and Middle East to the various ports in the specific regions of the U.S.

The trip distances for non-container vessel types were developed from information from Worldscale Association and Maritime Chain.[51] The data from Worldscale is considered to be the

industry standard for measuring port-to-port distances, particularly for tanker traffic. The reported distances account for common routes through channels, canals, or straits. This distance information was supplemented by data from Maritime Chain, a web service that provides port-to-port distances along with some information about which channels, canals, or straits must be passed on the voyage.

Voyage distances for container vessels are based on information from Containerization International Yearbook (CIY) and calculations by RTI. That reference provides voyage information for all major container services. Based on the frequency of the service, number of vessels assigned to that service, and the number of days in operation per year, RTI estimated the average length of voyages for the particular bilateral trade routes in the Global Insights trade forecasts.

The distance information developed above was combined with the vessel speeds previously shown in Table 3-65 to find the length of a voyage in days. Table 3-66 presents the day lengths for non-containerized vessel types and Table 3-67 shows the same information for container vessels.

Table 3-66 Day Length for Voyages for Non-Container Cargo Ship (approximate average)

	Days per Voyage				
Global Insights Trade Regions	US South Pacific	US North Pacific	US East Coast	US Great Lakes	*US Gulf*
Africa East-South	68	75	57	62	*54*
Africa North-Mediterranean	49	56	37	43	*47*
Africa West	56	63	36	46	*43*
Australia-New Zealand	48	47	65	81	*63*
Canada East	37	46	7	18	*19*
Canada West	11	5	40	58	*39*
Caspian Region	95	89	41	46	*48*
China	41	36	73	87	*69*
Europe Eastern	61	68	38	45	*46*
Europe Western-North	53	60	24	32	*34*
Europe Western-South	54	61	30	37	*37*
Greater Caribbean	26	33	16	29	*17*
Japan	35	31	65	81	*62*
Middle East Gulf	77	72	56	65	*83*
Pacific High Growth	52	48	67	76	*88*
Rest of Asia	68	64	66	64	*73*
Russia-FSU	64	71	38	46	*48*
Rest of South America	*51*	*30*	*41*	*46*	*44*

Table 3-67 Day Length for Voyages for Container-Ship Trade Routes

Origin – Destination Regions	*Days per Voyage*
Asia – North America (Pacific)	*37*
Europe – North America (Atlantic)	*37*
Mediterranean – North America	*41*
Australia/New Zealand – North America	*61*
South America – North America	*48*
Africa South – North America (Atlantic)	*54*
Africa West – North America (Atlantic)	*43*
Asia – North America (Atlantic)	*68*
Europe – North America (Pacific)	*64*
Africa South – North America (Pacific)	*68*
Africa West – North America (Pacific)	*38*
Caspian Region – North America (Atlantic)	*42*
Caspian Region – North America (Pacific)	*38*
Middle East/Gulf Region – North America (Atlantic)	*63*
Middle East/Gulf Region – North America (Pacific)	*80*

3.4.2.8 Bunker Fuel Consumption for the United States

Figure 3-14 and Figure 3-15 present the estimates of fuel use for delivering trade goods to and from the U.S. The results in Figure 3-14 show estimated historical bunker fuel use in year 2001 of around 47 million tons (note: while this fuel is used to carry trade goods to and from the U.S., it is not necessarily all purchased in the U.S. and is not all burned in U.S. waters). This amount grows to over 90 million tons by 2020 with the most growth occurring on trade routes from the East Coast and the "South Pacific" region of the West Coast.

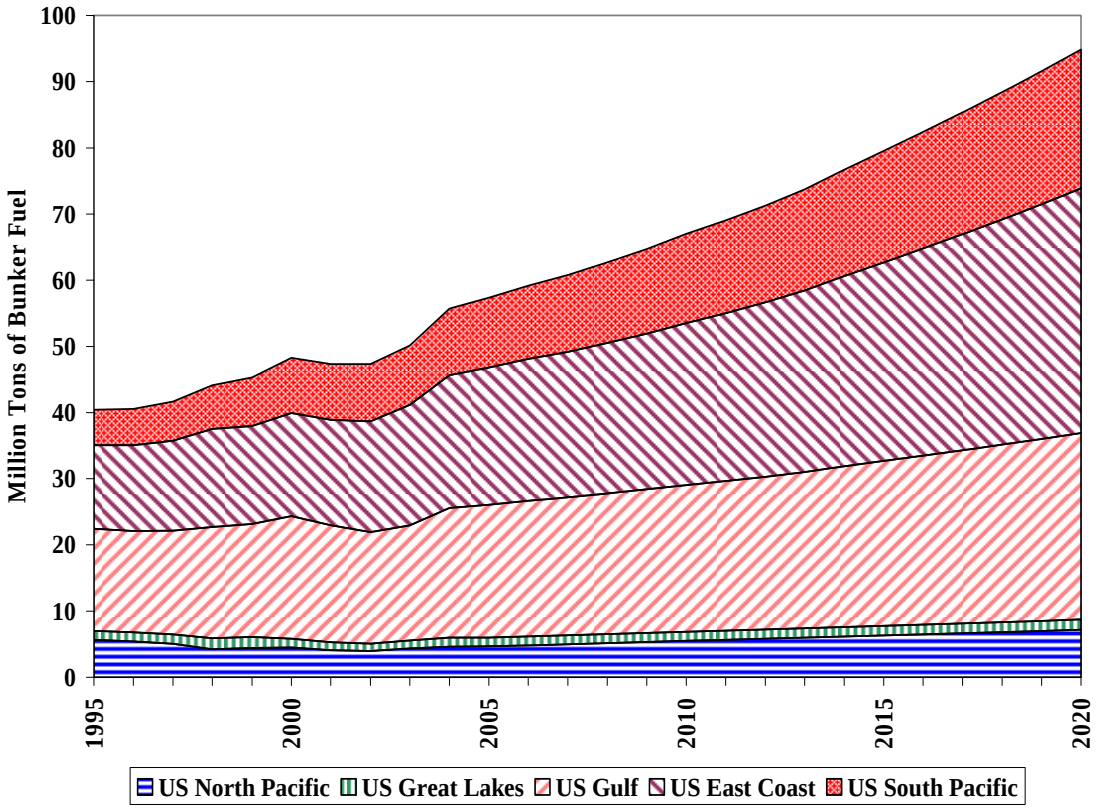


Figure 3-14 Bunker Fuel Used to Import and Export Cargo by Region of the United States

Figure 3-15 shows the estimated annual growth rates for the fuel consumption that are used in the projections shown in Figure 3-14. Overall, the average annual growth rate in marine bunkers associated with future U.S. trade flows is 3.4 percent between 2005 and 2020.

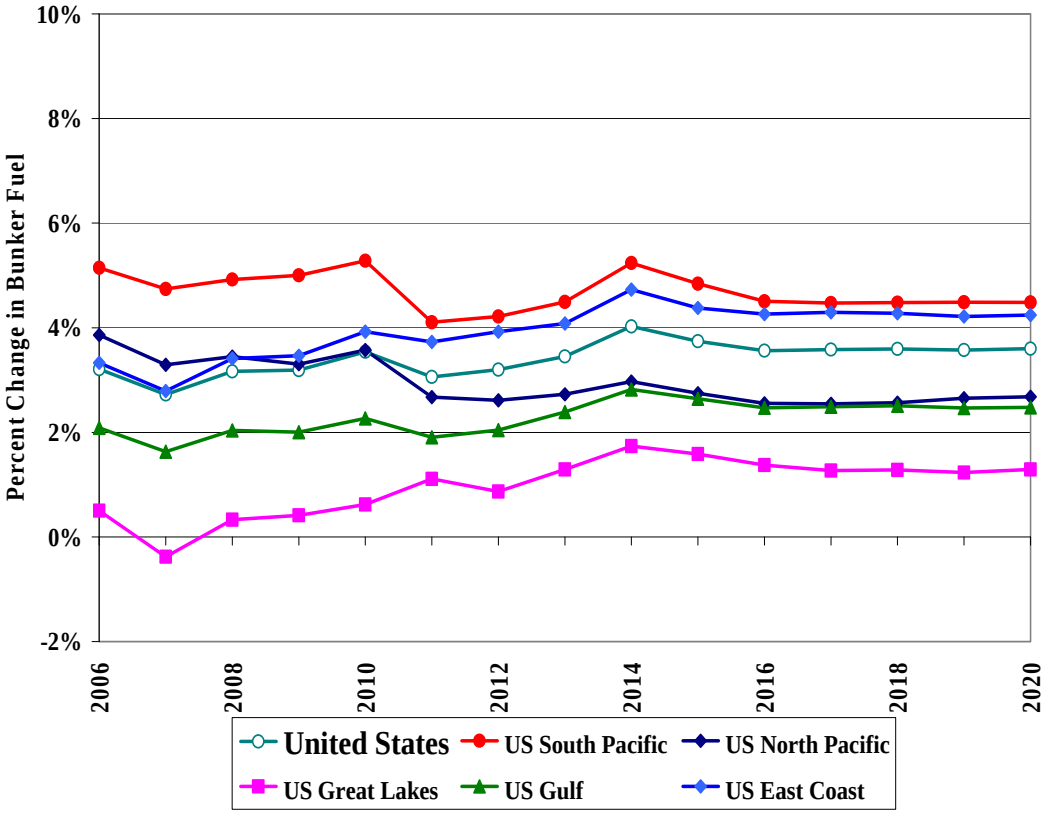


Figure 3-15 Annual Growth Rates for Bunker Fuel Used to Import and Export Cargo by Region of the United States

3.4.2.9 2020 and 2030 Growth Factors for Nine Geographic Regions

The results of the RTI analysis described above are used to develop the growth factors that are necessary to project the 2002 base year emissions inventory to 2020 and 2030. The next two sections describe how the five RTI regions were associated with the nine regions analyzed in this report, and how the specific growth rates for each of the nine regions were developed.

3.4.2.9.1 Mapping the RTI Regional Results to the Nine Region Analysis

As described in Section 3.3.4, the nine geographic regions analyzed in this study were designed to be consistent with the five RTI regional modeling domains. More specifically, four of the nine geographic areas in this study, i.e., Alaska East, Alaska West, Hawaii East, and Hawaii West are actually subsets of two broader regional areas that were analyzed by RTI, i.e., the North Pacific for both Alaska regions and South Pacific for Hawaii. Therefore, the growth rate information from the related larger region was assumed to be representative for that state.

The nine geographic regions represented in the emission inventory study are presented in Figure 3-1. The association of the RTI regions to the emission inventory regions is shown in Table 3-68.

Table 3-68 Association of the RTI Regions to the Nine Emission Inventory Regions

Consumption Region	Corresponding Emission Inventory Region
North Pacific	North Pacific (NP)
North Pacific	Alaska East (AE)
North Pacific	Alaska West (AW)
South Pacific	South Pacific (SP)
South Pacific	Hawaii East (HE)
South Pacific	Hawaii West (HW)
Gulf	Gulf Coast (GC)
East Coast	East Coast (EC)
Great Lakes	Great Lakes (GL)

3.4.2.9.2 Growth Factors for the Emission Inventory Analysis

Emission inventories for 2020 and 2030 are estimated in Section 3.4.5 by multiplying the 2002 baseline inventory for each region by a corresponding growth factor that was developed from the RTI regional results. Specifically, the average annual growth rate from 2002-2020 was calculated for each of the five regions. Each regional growth rate was then compounded over the inventory projection time period for 2020 and 2030, i.e., 18 and 28 years, respectively. The resulting multiplicative growth factors for each emission inventory region and the associated RTI average annual growth rate are presented in Table 3-69 for each projection year.

Table 3-69 Regional Emission Inventory Growth Factors for 2020 and 2030

Emission Inventory Region	2002-2020 Average Annualized Growth Rate (%)	Multiplicative Growth Factor Relative to 2002	
		2020	2030
Alaska East (AE)	3.3	1.79	2.48
Alaska West (AW)	3.3	1.79	2.48
East Coast (EC)	4.5	2.21	3.43
Gulf Coast (GC)	2.9	1.67	2.23
Hawaii East (HE)	5.0	2.41	3.92
Hawaii West (HW)	5.0	2.41	3.92
North Pacific (NP)	3.3	1.79	2.48
South Pacific (SP)	5.0	2.41	3.92
Great Lakes (GL)	1.7	1.35	1.60

3.4.3 Emission Controls in Baseline and Control Scenarios

This section describes the control programs present in the baseline and control scenarios, as well as the resulting emission factors.

The baseline scenario includes the International Marine Organization's (IMO) Tier 1 NO_X standard for marine diesel engines that became effective in 2000. The control scenario applies global controls as well as additional ECA controls within the ECA boundaries

The global NO_X controls include a retrofit program for Tier 0 (pre-control) engines, which was modeled as 11 percent control from Tier 0 for 80 percent of 1990 thru 1999 model year (MY) engines greater than 90 liters per cylinder (L/cyl) starting in 2011. The retrofit program was also modeled with a five year phase-in. The current Tier 1 controls, which also are modeled as achieving an 11 percent reduction from Tier 0, apply to the 2000 thru 2010 MY engines. In 2011 thru 2015, Tier 2 controls are applied. Tier 2 controls are modeled as a 2.5 g/kW-hr reduction from Tier 1. Fuel sulfur content for the global control area is assumed to be controlled to 5,000 ppm. No controls are assumed for HC or CO.

Within the ECA areas, additional Tier 3 NO_X controls are applied for 2016 MY engines and beyond. Tier 3 controls are modeled as achieving an 80 percent reduction from Tier 1 levels. In addition to the NO_X control program, fuel sulfur content is also assumed to be controlled to 1,000 ppm within the ECA in 2020 and 2030. Fuel sulfur content affects SO_2 and PM emissions. Note that gas and steam turbine engines are not subject to any of the NO_X standards; however, these engines are not a large part of the inventory.

Within the control scenario, global controls are applied for the Alaska West and Hawaii West regions. Global controls are also applied beyond 200 nm from shore for the 48 contiguous states, Alaska East, and Hawaii East. The ECA controls are applied within 200 nm from shore for the 48 contiguous states as well as the Alaska East and Hawaii East regions.

3.4.3.1 2020 and 2030 Emission Factors

The baseline scenario described in the previous section includes Tier 1 NO_X control. The control scenario includes additional NO_X controls and fuel sulfur controls, the latter affecting PM and SO_2 emissions. The switch to lower sulfur distillate fuel use is also assumed to lower CO_2 emissions slightly. HC and CO are assumed to remain unchanged.

The NO_X emission factors (EFs) by engine/ship type and tier are provided in Table 3-70. Tier 0 refers to pre-control. There are separate entries for Tier 0/1 base and Tier 0/1 control, since the Tier 0/1 control engines would be using distillate fuel, and there are small NO_X emission reductions assumed when switching from residual to distillate fuel.[21] The NO_X control EFs by tier were derived using the assumptions described in Section 3.4.3.

Table 3-70 Modeled NO_X Emission Factors by Tier

Engine/ Ship Type	NO_X EF (g/kW-hr)						
	Baseline		Control Areas				
	Tier 0	Tier 1	Tier 0	T0 retrofit [a]	Tier 1	Tier 2	Tier 3
Main							
SSD	18.1	16.1	17	15.1	15.1	12.6	3
MSD	14	12.5	13.2	11.7	11.7	9.2	2.3
ST	2.1	n/a	2	n/a	n/a	n/a	n/a
GT	6.1	n/a	5.7	n/a	n/a	n/a	n/a
Aux							
Pass	14.6	13.0	14.6	n/a*	13	10.5	2.6
Other	14.5	12.9	14.5	n/a*	12.9	10.4	2.6

Note:
[a] The retrofit program applies to engines over 90 L/cyl; auxiliary engines are smaller than this cutpoint and would therefore not be subject to the program.

The NO_X EFs by tier were then used with the age distributions in Table 3-71 and Table 3-72 below to generate calendar year NO_X EFs by engine/ship type for the base and control areas included in the scenarios. These calendar year NO_X EFs are provided in Table 3-73. Since the age distributions are different for vessels in the Great Lakes, NO_X EFs were determined separately for the Great Lakes.

Table 3-71 Vessel Age Distribution for Deep Sea Ports by Engine Type

Age Group (years old)	*Propulsion Engine Type*[a] *(Fraction of Total)*				All Auxiliary Engines
	MSD	SSD	GT	ST	
0	0.00570	0.02667	0.00000	0.00447	0.01958
1	0.07693	0.07741	0.07189	0.12194	0.07670
2	0.10202	0.07512	0.14045	0.16464	0.08426
3	0.08456	0.07195	0.05608	0.05321	0.07489
4	0.08590	0.05504	0.67963	0.00000	0.07831
5	0.06427	0.05563	0.04165	0.00000	0.05685
6	0.06024	0.04042	0.00000	0.00000	0.04455
7	0.07867	0.07266	0.00626	0.00000	0.07150
8	0.06730	0.05763	0.00000	0.00000	0.05764
9	0.04181	0.04871	0.00000	0.00000	0.04475
10	0.04106	0.04777	0.00000	0.00000	0.04364
11	0.03100	0.03828	0.00000	0.00000	0.03538
12	0.04527	0.03888	0.00000	0.04873	0.04160
13	0.03583	0.02787	0.00000	0.00000	0.02909
14	0.03519	0.02824	0.00000	0.00000	0.02935
15	0.02921	0.01466	0.00000	0.00000	0.01869
16	0.00089	0.01660	0.00000	0.00000	0.01189
17	0.01326	0.01582	0.00000	0.00000	0.01462
18	0.00847	0.02414	0.00000	0.00000	0.01966
19	0.00805	0.01982	0.00000	0.00000	0.01550
20	0.00566	0.02258	0.00000	0.00000	0.01756
21	0.00495	0.02945	0.00000	0.00000	0.02260
22	0.00503	0.01883	0.00000	0.00875	0.01467
23	0.00676	0.01080	0.00000	0.00883	0.00943
24	0.00539	0.01091	0.00000	0.00883	0.00900
25	0.01175	0.01099	0.00000	0.18029	0.01224
26	0.00803	0.01045	0.00000	0.11065	0.01130
27	0.00522	0.00835	0.00000	0.01395	0.00738
28	0.00294	0.00788	0.00000	0.08657	0.00659
29	0.00285	0.00370	0.00034	0.02907	0.00349
30	0.00254	0.00106	0.00370	0.05126	0.00193
31	0.00084	0.00113	0.00000	0.00605	0.00096
32	0.00023	0.00367	0.00000	0.07105	0.00322
33	0.00117	0.00582	0.00000	0.00000	0.00419
34	0.00132	0.00092	0.00000	0.00000	0.00098
35+	0.01967	0.00013	0.00000	0.03172	0.00598

Note:
[a] MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

Table 3-72 Vessel Age Distribution for Great Lake Ports by Engine Type

Age Group (years old)	Propulsion Engine Type[a] (Fraction of Total)			
	MSD	SSD	ST	All Auxiliary Engines
0	0.01610	0.03913	0.00000	0.02399
1	0.02097	0.03489	0.00000	0.02243
2	0.01370	0.04644	0.00000	0.02544
3	0.02695	0.03040	0.00000	0.02511
4	0.01571	0.04547	0.00000	0.02497
5	0.04584	0.01498	0.00000	0.02442
6	0.01494	0.02180	0.00000	0.01528
7	0.01327	0.01857	0.00000	0.01391
8	0.00099	0.04842	0.00000	0.02107
9	0.00027	0.03376	0.00000	0.01454
10	0.01085	0.01177	0.00000	0.01076
11	0.00553	0.01183	0.00000	0.00782
12	0.00739	0.00546	0.00000	0.00626
13	0.02289	0.02557	0.00000	0.02242
14	0.00000	0.00286	0.00000	0.00121
15	0.00275	0.00510	0.00000	0.00361
16	0.00069	0.00073	0.00000	0.00078
17	0.00000	0.00104	0.00000	0.00041
18	0.00342	0.01967	0.00000	0.01059
19	0.00219	0.01220	0.00000	0.00645
20	0.00867	0.06140	0.00000	0.03034
21	0.00000	0.05638	0.00000	0.02503
22	0.03375	0.02108	0.00000	0.02279
23	0.04270	0.02051	0.00000	0.02606
24	0.08161	0.01010	0.00000	0.03744
25	0.02935	0.05217	0.00000	0.03480
26	0.18511	0.00522	0.00000	0.07701
27	0.01870	0.00389	0.00000	0.01083
28	0.13815	0.01438	0.00000	0.06181
29	0.05487	0.01160	0.00000	0.02697
30	0.00000	0.00114	0.00000	0.00047
31	0.03986	0.00000	0.00000	0.01611
32	0.03654	0.00282	0.00000	0.01631
33	0.03358	0.00000	0.00000	0.01358
34	0.00295	0.00123	0.00000	0.00165
35+	0.06974	0.30796	1.00000	0.31734

Notes:
[a] MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.
[b] Fleet average weighted by installed power (ship port calls x main propulsion engine power).

Table 3-73 Modeled NO_X Emission Factors by Calendar Year and Control Type

Engine/ Ship Type	CY NO_X EF (g/kW-hr)												
	2002	2020 Base		2020 ECA Control		2020 Global Control		2030 Base		2030 ECA Control		2030 Global Control	
		DSP[a]	GL[b]	DSP	GL	DSP	GL	DSP	GL	DSP	GL	DSP	GL
Main													
SSD	18.1	16.36	17.12	10.80	13.07	13.74	14.95	16.13	16.73	5.68	10.44	13.00	14.20
MSD	14	12.58	13.64	7.72	11.79	10.17	12.44	12.50	12.74	3.58	9.95	9.49	11.44
ST	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.1	2.1	2.0	2.0	2.0	2.0
GT	6.1	6.1	n/a[c]	5.7	n/a	5.7	n/a	6.1	n/a	5.7	n/a	5.7	n/a
Aux													
Pass	14.6	13.21	14.13	8.59	11.99	n/a	n/a	13.05	13.61	4.39	10.30	n/a	n/a
Other	14.5	13.06	13.97	8.59	11.99	n/a	n/a	12.90	13.46	4.39	10.30	n/a	n/a

Notes:
[a] DSP = Deep sea ports and areas other than the Great Lakes
[b] GL = Great Lakes
[c] n/a = not applicable. There are no GT engines assumed to be operating in the Great Lakes. Auxiliary engines are assumed to be operating in ports and therefore not subject to global controls.

For PM and SO_2, there are no proposed standards; however, the control of fuel sulfur affects these pollutants. Therefore, the PM and SO_2 EFs are strictly a function of fuel sulfur level. For the baseline portions of the inventory, there are two residual fuel sulfur levels modeled: 25,000 ppm for the West Coast and 27,000 ppm for the rest of the U.S. The baseline distillate fuel sulfur level assumed for all areas is 15,000 ppm. As discussed in Section 3.3.2.3.5, for the baseline, main engines use residual fuel and auxiliary engines use a mix of residual and distillate fuel. For the control areas, there are two levels of distillate fuel sulfur assumed to be used by all engines: 5,000 ppm for the global control areas and 1,000 ppm for the ECA control areas.

Table 3-74 provides the PM_{10} EFs by engine/ship type and fuel sulfur level. For modeling purposes, $PM_{2.5}$ is assumed to be 92 percent of PM_{10}. The PM EFs are adjusted to reflect the appropriate fuel sulfur levels using the equation described in Section 3.3.2.3.6.

Table 3-75 provides the modeled SO_2 EFs. SO_2 emission reductions are directly proportional to reductions in fuel sulfur content.

CO_2 is directly proportional to fuel consumed. Table 3-76 provides the modeled CO_2 and brake specific fuel consumption (BSFC) EFs. Due to the higher energy content of distillate fuel on a mass basis, the switch to distillate fuel for the control areas results in a small reduction to BSFC and, correspondingly, CO_2 emissions.[21]

Table 3-74 Modeled PM_{10} Emission Factors*

Engine/ Ship Type	PM_{10} EF (g/kW-hr)			
	Baseline		Control Areas	
	Other than West Coast 27,000 ppm S	West Coast[a] 25,000 ppm S	ECA 5,000 ppm S	Global Control 1,000 ppm S
Main				
SSD	1.40	1.40	0.31	0.19
MSD	1.40	1.40	0.31	0.19
ST	1.50	1.40	0.35	0.17
GT	1.50	1.40	0.35	0.17
Aux				
Pass	1.40	1.30	0.31	0.19
Other	1.20	1.10	0.31	0.19

Note:
[a] For the base cases, the West Coast fuel is assumed to be used in the following regions: Alaska East (AE), Alaska West (AW), Hawaii East (HE), Hawaii West (HW), North Pacific (NP), and South Pacific (SP).

Table 3-75 Modeled SO_2 Emission Factors*

Engine/ Ship Type	SO_2 EF (g/kW-hr)			
	Baseline		Control Areas	
	Other than West Coast 27,000 ppm S	West Coast[a] 25,000 ppm S	ECA 5,000 ppm S	Global Control 1,000 ppm S
Main				
SSD	10.29	9.53	1.81	0.36
MSD	11.09	10.26	1.96	0.39
ST	16.10	14.91	2.83	0.57
GT	16.10	14.91	2.83	0.57
Aux				
Pass	10.70	9.93	1.96	0.39
Other	9.66	9.07	1.96	0.39

Note:
[a] For the base cases, the West Coast fuel is assumed to be used in the following regions: Alaska East (AE), Alaska West (AW), Hawaii East (HE), Hawaii West (HW), North Pacific (NP), and South Pacific (SP).

Table 3-76 Modeled Fuel Consumption and CO_2 Emission Factors

Engine/ Ship Type	EF (g/kW-hr)			
	Baseline		Control Areas	
	BSFC	CO_2	BSFC	CO_2
Main				
SSD	195	620.62	185	588.86
MSD	210	668.36	200	637.05
ST	305	970.71	290	923.07
GT	305	970.71	290	923.07
Aux				
Pass	210	668.36	200	636.60
Other	210	668.36	200	636.60

3.4.4 Calculation of Near Port and Interport Inventories

Based on the emission factors described in Section 3.4.3.1, appropriate growth factors and emission adjustment factors were applied to the 2002 baseline inventory to obtain the NO_X, PM (PM_{10} and $PM_{2.5}$), SO_2, and CO_2 inventory of each 2020 and 2030 scenario. Adjustment factors are ratios of the 2020 or 2030 calendar year EFs to the 2002 calendar year EFs. Adjustment factors are derived separately by engine type for propulsion and auxiliary engines. The adjustment factors for propulsion engines are applied to the propulsion portion of the port inventory and the interport portion of the inventory. The adjustment factors for auxiliary engines are applied to the auxiliary portion of the port inventory. This section describes the development and application of the adjustment factors to the port and interport inventories, and the methodology for combining the port and interport portions.

3.4.4.1 Port Methodology

3.4.4.1.1 Non-California Ports

For the non-California ports, 2002 emissions for each port are summed by engine/ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The appropriate regional growth factor, as provided in Table 3-69, is then applied, along with EF adjustment factors by engine/ship type. The EF adjustment factors are a ratio of the control EF to the 2002 EF. Table 3-77 thru Table 3-81 provide the EF adjustment factors for each pollutant and control area. The ports will be subject to ECA controls in the control scenarios. These tables are also used as input for the California ports and interport control inventory development, discussed in subsequent sections. Since the control scenario assumes a portion of the inventory is subject to global controls, the adjustment factors for the 2020 and 2030 global controls are also provided. The baseline adjustment factors are also provided.

Table 3-77 NO_X EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	2020 Base		2020 ECA Control		2020 Global Control		2030 Base		2030 ECA Control		2030 Global Control	
	DSP[b]	GL[c]	DSP	GL	DSP	GL	DSP	GL	DSP	GL	DSP	GL
Main												
SSD	0.9037	0.9459	0.5967	0.7219	0.7592	0.8261	0.8913	0.9243	0.3138	0.5771	0.7183	0.7847
MSD	0.8987	0.9744	0.5515	0.8423	0.7265	0.8883	0.8926	0.9101	0.2559	0.7109	0.6776	0.8170
ST	1.0000	1.0000	0.9524	0.9524	0.9524	0.9524	1.0000	1.0000	0.9524	0.9524	0.9524	0.9524
GT	1.0000	n/a	0.9344	n/a	0.9344	n/a	1.0000	n/a	0.9344	n/a	0.9344	n/a
Aux												
Pass	0.9025	0.9657	0.5869	0.8196	n/a	n/a	0.8917	0.9301	0.3003	0.7042	n/a	n/a
Other	0.9025	0.9657	0.5940	0.8295	n/a	n/a	0.8917	0.9301	0.3039	0.7127	n/a	n/a

Notes:
[a] NO_X adjustment factors are a ratio of future base or control EFs to 2002 EFs
[b] DSP = deep sea ports and areas other than the Great Lakes
[c] GL = Great Lakes

Table 3-78 PM_{10} EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.1352	0.1352	0.2183	0.2183
MSD	1.0000	1.0000	0.1328	0.1328	0.2227	0.2227
ST	1.0000	1.0000	0.1108	0.1187	0.2324	0.2490
GT	1.0000	1.0000	0.1108	0.1187	0.2324	0.2490
Aux						
Pass	1.0000	1.0000	0.1328	0.1430	0.2227	0.2398
Other	1.0000	1.0000	0.1550	0.1691	0.2598	0.2834

Notes:
[a] PM_{10} adjustment factors are a ratio of the control EFs to the baseline EFs. PM is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-79 $PM_{2.5}$ EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.1339	0.1339	0.2163	0.2163
MSD	1.0000	1.0000	0.1316	0.1316	0.2207	0.2207
ST	1.0000	1.0000	0.1092	0.1176	0.2291	0.2467
GT	1.0000	1.0000	0.1092	0.1176	0.2291	0.2467
Aux						
Pass	1.0000	1.0000	0.1316	0.1426	0.2207	0.2390
Other	1.0000	1.0000	0.1555	0.1711	0.2608	0.2868

Notes:
[a] $PM_{2.5}$ adjustment factors are a ratio of the control EFs to the baseline EFs. PM is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas. The $PM_{2.5}$ adjustment factors are slightly different from those for PM_{10} due to rounding.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-80 SO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.0351	0.0380	0.1757	0.1898
MSD	1.0000	1.0000	0.0353	0.0381	0.1764	0.1907
ST	1.0000	1.0000	0.0352	0.0380	0.1761	0.1901
GT	1.0000	1.0000	0.0352	0.0380	0.1761	0.1901
Aux						
Pass	1.0000	1.0000	0.0365	0.0394	0.1827	0.1969
Other	1.0000	1.0000	0.0405	0.0431	0.2024	0.2156

Notes:
[a] SO_2 adjustment factors are a ratio of the control EFs to the baseline EFs. SO_2 is not adjusted for the future baselines because fuel sulfur levels are only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

Table 3-81 CO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

Engine/ Ship Type	Base		ECA Control		Global Control	
	Other[b]	WC[c]	Other	WC	Other	WC
Main						
SSD	1.0000	1.0000	0.9488	0.9488	0.9488	0.9488
MSD	1.0000	1.0000	0.9531	0.9531	0.9531	0.9531
ST	1.0000	1.0000	0.9509	0.9509	0.9509	0.9509
GT	1.0000	1.0000	0.9509	0.9509	0.9509	0.9509
Aux						
Pass	1.0000	1.0000	0.9525	0.9593	0.9525	0.9593
Other	1.0000	1.0000	0.9525	0.9683	0.9525	0.9683

Notes:
[a] CO_2 adjustment factors are a ratio of the control EFs to the baseline EFs. CO_2 is not adjusted for the future baselines because fuel consumption (BSFC) is only assumed to change within the ECA and global control areas.
[b] Other = Other than West Coast
[c] WC = Ports/areas within the West Coast. This includes the regions of Alaska, Hawaii, North Pacific, and South Pacific.

3.4.4.1.2 California Ports

For the California ports, 2002 emissions for each port are summed by ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The EF adjustment factors by engine/ship type, provided in the previous section, are consolidated by ship type, using the CARB assumption that engines on all ships except passenger ships are 95 percent slow speed diesel (SSD) engines and 5 percent medium speed diesel engines (MSD) based upon a 2005 ARB survey.[52] All passenger ships were assumed to be medium speed diesel engines with electric drive propulsion (MSD-ED). Steam turbines (ST) and gas-turbines (GT) are not included in the CARB inventory. The EF adjustment factors by ship type are then applied, along with ship-specific growth factors supplied by CARB. The ship-specific growth factors relative to 2002 are provided in Table 3-82 below.

Table 3-82 Growth Factors by Ship Type for California Ports Relative to 2002

Ship Type	Calendar Year		
	2002	2020	2030
Auto	1.0000	1.5010	1.8478
Bulk	1.0000	0.2918	0.1428
Container	1.0000	2.5861	4.2828
General	1.0000	0.7331	0.5985
Passenger	1.0000	7.5764	26.4448
Reefer	1.0000	1.0339	1.0532
RoRo	1.0000	1.5010	1.8478
Tanker	1.0000	2.0979	3.0806

3.4.4.2 Interport Methodology

The interport portion of the inventory is not segregated by engine or ship type. As a result, regional EF adjustment factors were developed based on the assumed mix of main (propulsion) engine types in each region. The mix of main engine types by region was developed using the ship call and power data and is presented in Table 3-83 and Figure 3-16. Main engines are considered a good surrogate for interport emissions, since the majority of emissions while underway are due to the main engines. The EF adjustment factors by main engine type in Section 3.4.4.1.1 were used together with the mix of main engine types by region to develop the EF regional adjustment factors for each control area. The resulting EF regional adjustment factors for each pollutant and control area are provided in Table 3-84 thru Table 3-88 below. These EF regional adjustment factors, together with the regional growth factors in Table 3-69, were applied to calculate the future inventories for each control area.

Table 3-83 Installed Power by Main Engine Type for Deep Sea Ports [a]

Region	2020 Installed Power (%)					2030 Installed Power (%)				
	MSD	SSD	GT	ST	Total	MSD	SSD	GT	ST	Total
Alaska East (AE)	19.1%	18.4%	0.3%	62.2%	0.8%	19.1%	18.4%	0.3%	62.2%	0.6%
Alaska West (AW)	19.1%	18.4%	0.3%	62.2%	0.8%	19.1%	18.4%	0.3%	62.2%	0.6%
East Coast (EC)	25.6%	72.5%	0.9%	1.0%	45.4%	25.6%	72.5%	0.9%	1.0%	42.3%
Gulf Coast (GC)	13.7%	85.5%	0.0%	0.8%	16.8%	13.7%	85.5%	0.0%	0.8%	13.4%
Hawaii East(HE)	66.2%	18.5%	7.4%	8.0%	2.0%	66.2%	18.5%	7.4%	8.0%	2.0%
Hawaii West (HW)	66.2%	18.5%	7.4%	8.0%	2.0%	66.2%	18.5%	7.4%	8.0%	2.0%
North Pacific (NP)	5.1%	83.5%	1.6%	9.7%	5.0%	5.1%	83.5%	1.6%	9.7%	4.1%
South Pacific (SP)	29.2%	70.8%	0.0%	0.0%	30.0%	45.5%	54.5%	0.0%	0.0%	37.6%

Note:
[a] Installed power is main propulsion engine power (kW) multiplied by ship port calls by engine type. MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

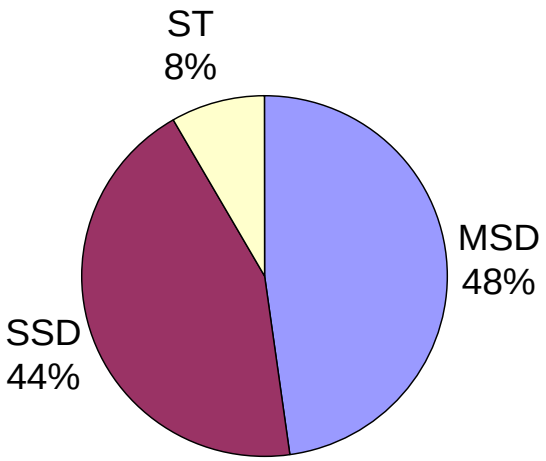


Figure 3-16 Installed Power by Main Engine Type for Great Lake Ports [D]

[D] Installed power is main propulsion engine power (kW) multiplied by ship port calls by engine type. MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

Table 3-84 NO_X EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	0.9629	0.8104	n/a	0.9595	0.7019	n/a
Alaska West (AW)	1.0000	0.9629	n/a	0.8737	0.9595	n/a	0.8568
East Coast (EC)	1.0000	0.9042	0.5917	n/a	0.8937	0.3110	n/a
Gulf Coast (GC)	1.0000	0.9038	0.5935	n/a	0.8924	0.3113	n/a
Hawaii East (HE)	1.0000	0.9152	0.6201	n/a	0.9088	0.3723	n/a
Hawaii West (HW)	1.0000	0.9152	n/a	0.7659	0.9088	n/a	0.7260
North Pacific (NP)	1.0000	0.9143	0.6343	n/a	0.9036	0.3828	n/a
South Pacific (SP)	1.0000	0.9022	0.5837	n/a	0.8919	0.2877	n/a
Great Lakes (GL)	1.0000	0.9641	0.7989	n/a	0.9238	0.6726	n/a
Out of Region[b]	1.0000	0.8942	n/a	0.7557	0.8940	n/a	0.7103

Notes:
[a] NO_X adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-85 PM_{10} EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.1244	n/a	1.0000	0.1244	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.2280	1.0000	n/a	0.2280
East Coast (EC)	1.0000	1.0000	0.1341	n/a	1.0000	0.1341	n/a
Gulf Coast (GC)	1.0000	1.0000	0.1347	n/a	1.0000	0.1347	n/a
Hawaii East (HE)	1.0000	1.0000	0.1311	n/a	1.0000	0.1311	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.2246	1.0000	n/a	0.2246
North Pacific (NP)	1.0000	1.0000	0.1332	n/a	1.0000	0.1332	n/a
South Pacific (SP)	1.0000	1.0000	0.1345	n/a	1.0000	0.1341	n/a
Great Lakes (GL)	1.0000	1.0000	0.1320	n/a	1.0000	0.1320	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.2198	1.0000	n/a	0.2200

Notes:
[a] PM_{10} adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-86 $PM_{2.5}$ EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.1233	n/a	1.0000	0.1233	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.2252	1.0000	n/a	0.2252
East Coast (EC)	1.0000	1.0000	0.1329	n/a	1.0000	0.1329	n/a
Gulf Coast (GC)	1.0000	1.0000	0.1334	n/a	1.0000	0.1334	n/a
Hawaii East (HE)	1.0000	1.0000	0.1299	n/a	1.0000	0.1299	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.2225	1.0000	n/a	0.2225
North Pacific (NP)	1.0000	1.0000	0.1320	n/a	1.0000	0.1320	n/a
South Pacific (SP)	1.0000	1.0000	0.1332	n/a	1.0000	0.1329	n/a
Great Lakes (GL)	1.0000	1.0000	0.1307	n/a	1.0000	0.1307	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.2177	1.0000	n/a	0.2180

Notes:
[a] $PM_{2.5}$ adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-87 SO_2 EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.1814	1.0000	n/a	0.1814
East Coast (EC)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Gulf Coast (GC)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Hawaii East (HE)	1.0000	1.0000	0.0381	n/a	1.0000	0.0381	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.1893	1.0000	n/a	0.1893
North Pacific (NP)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
South Pacific (SP)	1.0000	1.0000	0.0380	n/a	1.0000	0.0380	n/a
Great Lakes (GL)	1.0000	1.0000	0.0352	n/a	1.0000	0.0352	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.1811	1.0000	n/a	0.1821

Notes:
[a] SO_2 adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside the 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

Table 3-88 CO_2 EF Adjustment Factors by Region and Control Type[a]

U.S. Region	2002	2020			2030		
		Base	ECA Control	Global Control	Base	ECA Control	Global Control
Alaska East (AE)	1.0000	1.0000	0.9509	n/a	1.0000	0.9509	n/a
Alaska West (AW)	1.0000	1.0000	n/a	0.9509	1.0000	n/a	0.9509
East Coast (EC)	1.0000	1.0000	0.9499	n/a	1.0000	0.9499	n/a
Gulf Coast (GC)	1.0000	1.0000	0.9494	n/a	1.0000	0.9494	n/a
Hawaii East (HE)	1.0000	1.0000	0.9519	n/a	1.0000	0.9519	n/a
Hawaii West (HW)	1.0000	1.0000	n/a	0.9519	1.0000	n/a	0.9519
North Pacific (NP)	1.0000	1.0000	0.9493	n/a	1.0000	0.9493	n/a
South Pacific (SP)	1.0000	1.0000	0.9501	n/a	1.0000	0.9507	n/a
Great Lakes (GL)	1.0000	1.0000	0.9510	n/a	1.0000	0.9510	n/a
Out of Region[b]	1.0000	1.0000	n/a	0.9499	1.0000	n/a	0.9502

Notes:
[a] CO_2 adjustment factors are a ratio of future base or control EFs to 2002 EFs. These regional adjustment factors are used to adjust the interport portion of the 2002 inventory.
[b] Out of Region refers to areas outside 200nm, but within the air quality modeling domain. The out of region adjustment factors are derived by weighting the regional adjustment factors by the main propulsion power in each region. ECA control is only assumed within 200nm.

3.4.4.3 Estimating and Combining the Near Port and Interport Inventories

To produce future year control scenarios, the interport inventories were scaled by a growth factor to 2020 and 2030, as previously described. An ECA boundary line was drawn so that each point on it was at a 200 nm distance from the nearest point on land. Adjustment factors, as described in Section 3.4.3.1, were then applied to interport emissions within the ECA boundary.

To create control scenarios in the near port inventories, growth and control factors were applied to the 2002 near port inventories (described in Sections 3.4.2 and 3.4.3.1). The near port inventories were then converted into a gridded format (Section 3.3.3.3). Using this grid, STEEM values were removed from near port cells and near port emissions were used as replacement values. In cases where the emissions near ports were only partially attributable to port traffic, the STEEM inventory was reduced rather than removed.

Interport and near port emissions were then aggregated to form regional totals.

3.4.5 2020 and 2030 Baseline Inventories

The resulting 2020 and 2030 estimated emission inventories by region and the nation are shown in Table 3-89 and Table 3-90. These baseline inventories account for growth as well as

implementation of the Tier 1 NO_X standard. Estimated fuel consumption for the baseline inventories by region and fuel type is given in Table 3-91.

Table 3-89 2020 Baseline Emissions Inventory

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	29,242	2,561	2,356	1,073	2,534	19,084	1,182,047
Alaska West (AW)	93,685	8,118	7,469	3,444	8,112	60,227	3,711,596
East Coast (EC)	439,604	39,003	35,882	16,216	38,382	323,038	18,121,202
Gulf Coast (GC)	259,295	23,403	21,531	9,590	23,628	174,751	10,567,512
Hawaii East (HE)	48,026	4,185	3,850	1,765	4,161	31,075	1,930,172
Hawaii West (HW)	67,573	5,888	5,417	2,483	5,855	43,722	2,715,741
North Pacific (NP)	42,644	3,916	3,603	1,706	3,799	27,807	1,800,743
South Pacific (SP)	234,968	20,148	18,536	8,585	20,686	149,751	9,490,502
Great Lakes (GL)	19,842	1,613	1,484	681.914	1,607	11,993	740,624
Total U.S. Metric Tonnes	1,234,879	108,835	100,128	45,544	108,762	841,447	50,260,140
Total U.S. Short Tons[b]	*1,361,221*	*119,970*	*110,372*	*50,204*	*119,890*	*927,537*	*55,402,321*

Notes:
[a] Estimated from PM_{10} using a multiplicative conversion factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-90 2030 Baseline Emissions Inventory

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	42,930	3,544	3,260	1,485	3,505	26,404	1,635,479
Alaska West (AW)	137,951	11,232	10,333	4,765	11,223	83,329	5,135,278
East Coast (EC)	679,271	60,615	55,766	25,207	59,678	502,305	28,163,780
Gulf Coast (GC)	341,903	31,142	28,651	12,761	31,427	232,547	14,062,207
Hawaii East (HE)	78,806	6,818	6,273	2,875	6,780	50,630	3,144,932
Hawaii West (HW)	110,880	9,593	8,825	4,045	9,539	71,237	4,424,900
North Pacific (NP)	58,937	5,433	4,999	2,372	5,278	38,556	2,497,078
South Pacific (SP)	394,335	34,948	32,152	14,635	35,208	259,982	16,470,350
Great Lakes (GL)	22,471	1,910	1,757	807	1,902	14,196	876,636
Total U.S. Metric Tonnes	1,867,484	165,235	152,016	68,951	164,539	1,279,185	76,410,639
Total U.S. Short Tons[b]	*2,058,549*	*182,140*	*167,569*	*76,006*	*181,373*	*1,410,061*	*84,228,311*

Notes:
[a] Estimated from PM_{10} using a multiplicative conversion factor of 0.92.
[b] Converted from metric tonnes using a multiplicative conversion factor of 1.102 short tons per metric tonne.

Table 3-91 Fuel Consumption by Category 3 Vessels in Baseline Scenarios

U.S. Region	Metric Tonnes Fuel					
	2020 Baseline			2030 Baseline		
	Distillate	Residual	Total	Distillate	Residual	Total
Alaska East (AE)	3,386	367,977	371,363	4,685	509,132	513,817
Alaska West (AW)	0	1,166,068	1,166,068	0	1,613,345	1,613,345
East Coast (EC)	202,139	5,490,981	5,693,120	313,916	8,534,271	8,848,187
Gulf Coast (GC)	96,428	3,223,557	3,319,985	128,338	4,289,571	4,417,910
Hawaii East (HE)	10,529	595,871	606,400	17,151	970,889	988,040
Hawaii West (HW)	0	853,202	853,202	0	1,390,166	1,390,166
North Pacific (NP)	28,532	537,206	565,738	39,476	745,028	784,505
South Pacific (SP)	83,576	2,898,045	2,981,622	157,878	5,016,595	5,174,474
Great Lakes (GL)	1,269	231,412	232,681	2,037	273,375	275,412
Total U.S. Metric Tonnes	425,860	15,364,319	15,790,179	663,482	23,342,374	24,005,856
Total U.S. Short Tons	*469,431*	*16,936,262*	*17,405,693*	*731,364*	*25,730,563*	*26,461,926*

3.4.6 2020 and 2030 Control Inventories

For the control scenario, the inventories for each of the nine geographic regions, the U.S. total, and the 48-state total are presented in Table 3-92 and Table 3-93. The regional and total inventories include all emissions within 200nm of shore. For the purposes of this analysis, ECA controls are assumed to apply to all regions, except Alaska West and Hawaii West. For the Alaska West and Hawaii West regions, global controls apply. Estimated fuel consumption for the control inventories by region and fuel type is given in Table 3-94.

Table 3-92 Category 3 Vessel Inventories for 2020 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	25,978	322	296	1,072	2,534	728	1,124,652
Alaska West (AW)	90,787	1,851	1,703	3,444	8,112	10,927	3,529,505
East Coast (EC)	289,671	5,286	4,863	16,231	38,421	11,514	17,233,800
Gulf Coast (GC)	170,861	3,201	2,945	9,581	23,615	6,255	10,034,946
Hawaii East (HE)	32,952	551	507	1,764	4,162	1,187	1,838,832
Hawaii West (HW)	57,406	1,323	1,217	2,483	5,855	8,277	2,585,222
North Pacific (NP)	29,105	539	496	1,709	3,803	1,076	1,715,210
South Pacific (SP)	150,461	2,753	2,533	8,546	20,585	5,786	9,009,986
Great Lakes (GL)	16,420	207	190	676	1,602	420	704,390
Total U.S. Metric Tonnes	863,642	16,032	14,750	45,507	108,688	46,168	47,776,542
Total U.S. Short Tons[b]	*952,002*	*17,673*	*16,259*	*50,163*	*119,808*	*50,892*	*52,664,623*

Note:
[a] This scenario assumes ECA controls apply within 200 nautical miles of all U.S. regions except Alaska West and Hawaii West, with global controls applied in all other areas. Corrected boundaries are used.

Table 3-93 Category 3 Vessel Inventories for 2030 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	30,722	445	410	1,485	3,505	1,008	1,556,045
Alaska West (AW)	123,187	2,677	2,463	4,765	11,223	15,847	4,883,341
East Coast (EC)	235,378	8,221	7,563	25,207	59,678	17,896	26,763,558
Gulf Coast (GC)	118,930	4,261	3,920	12,761	31,426	8,325	13,355,741
Hawaii East (HE)	31,992	899	827	2,875	6,780	1,933	2,995,263
Hawaii West (HW)	88,502	2,175	2,001	4,045	9,539	13,596	4,214,197
North Pacific (NP)	22,758	751	691	2,372	5,278	1,494	2,378,683
South Pacific (SP)	128,302	4,769	4,388	14,635	35,202	10,030	15,713,679
Great Lakes (GL)	16,369	253	233	807	1,902	501	833,733
Total U.S. Metric Tonnes	796,140	24,451	22,495	68,951	164,539	70,630	72,694,239
Total U.S. Short Tons[b]	*877,594*	*26,953*	*24,797*	*76,006*	*181,373*	*77,856*	*80,131,682*

Note:
[a] This scenario assumes ECA controls apply within 200 nautical miles of all U.S. regions, except Alaska West and Hawaii West, with global controls elsewhere. Corrected boundaries are used.

Table 3-94 Fuel Consumption by Category 3 Vessels in Control Scenarios

U.S. Region	Metric Tonnes Fuel					
	2020 Control			2030 Control		
	Distillate	Residual	Total	Distillate	Residual	Total
Alaska East (AE)	353,331	0	353,331	488,861	0	488,861
Alaska West (AW)	1,108,861	0	1,108,861	1,534,194	0	1,534,194
East Coast (EC)	5,414,326	0	5,414,326	8,408,281	0	8,408,281
Gulf Coast (GC)	3,152,669	0	3,152,669	4,195,960	0	4,195,960
Hawaii East (HE)	577,704	0	577,704	941,019	0	941,019
Hawaii West (HW)	812,197	0	812,197	1,323,970	0	1,323,970
North Pacific (NP)	538,866	0	538,866	747,309	0	747,309
South Pacific (SP)	2,830,658	0	2,830,658	4,936,751	0	4,936,751
Great Lakes (GL)	221,297	0	221,297	261,933	0	261,933
Total U.S. Metric Tonnes	15,009,910	0	15,009,910	22,838,278	0	22,838,278
Total U.S. Short Tons	*16,545,593*	*0*	*16,545,593*	*25,174,892*	*0*	*25,174,892*

3.5 Estimated Category 3 Inventory Contribution

This section describes the contribution of Category 3 marine engines to national and selected local emission inventories in 2002, 2020, and 2030. The pollutants analyzed are NO_X, directly emitted $PM_{2.5}$, and SO_2. All weight units in the following tables are short tons.

3.5.1 Baseline Contribution of C3 Vessels to National Level Inventory

Category 3 marine engines contribute to the formation of ground level ozone and concentrations of fine particles in the ambient atmosphere. Based on our current emission inventory analysis, we estimate that these engines contributed nearly 6 percent of mobile source NO_X, over 10 percent of mobile source $PM_{2.5}$, and about 40 percent of mobile source SO_2 in 2002. We estimate that their contribution will increase to about 40 percent of mobile source NO_X, 48 percent of mobile source $PM_{2.5}$, and 95 percent of mobile source SO_2 by 2030 without further controls on these engines. Our current estimates for NO_X, $PM_{2.5}$, and SO_2 inventories are set out in the following tables. Inventory projections for 2020 and 2030 include the effect of existing emission mobile source and stationary source control programs previously adopted by EPA.

Table 3-95 50 State Annual NO_X Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Commercial Marine (C3)	738,700	5.8	3.5	1,361,221	24.4	12.0	2,058,549	39.8	18.8
Locomotive	1,118,786	8.8	5.2	669,405	12.0	5.9	437,245	8.4	4.0
Recreational Marine Diesel	40,437	0.3	0.2	43,579	0.8	0.4	43,665	0.8	0.4
Commercial Marine (C1 & C2)	834,025	6.6	3.9	499,798	8.9	4.4	308,614	6.0	2.8
Land-Based Nonroad Diesel	1,555,812	12.2	7.3	683,481	12.2	6.0	435,774	8.4	4.0
Small Nonroad SI	119,833	0.9	0.6	80,901	1.4	0.7	91,913	1.8	0.8
Recreational Marine SI	49,902	0.4	0.2	87,709	1.6	0.8	73,961	1.4	0.7
SI Recreational Vehicles	10,614	0.1	0.0	30,108	0.5	0.3	34,318	0.7	0.3
Large Nonroad SI (>25hp)	336,292	2.6	1.6	48,270	0.9	0.4	47,766	0.9	0.4
Aircraft	103,591	0.8	0.5	132,278	2.4	1.2	143,986	2.8	1.3
Total Off Highway	4,907,990	38.6	23.0	3,636,750	65.1	32.0	3,675,790	71.0	33.6
Highway Diesel	3,529,046	27.7	16.5	681,142	12.2	6.0	355,817	6.9	3.2
Highway non-diesel	4,293,733	33.7	20.1	1,270,269	22.7	11.2	1,144,199	22.1	10.4
Total Highway	7,822,779	61.4	36.7	1,951,411	34.9	17.2	1,500,016	29.0	13.7
Total Mobile Sources	12,730,769	100.0	59.6	5,588,160	100.0	49.2	5,175,806	100.0	47.3
Stationary Point & Area Sources	8,613,718	-	40.4	5,773,927	-	50.8	5,773,927	-	52.7
Total Man-Made Sources	21,344,488	-	100	11,362,088	-	100	10,949,734	-	100

Table 3-96 50 State Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total
Commercial Marine (C3)	54,112	14.7	1.5	110,372	52.9	3.3	167,569	74.8	4.9
Locomotive	29,660	8.1	0.8	15,145	7.3	0.4	8,584	3.8	0.3
Recreational Marine Diesel	1,096	0.3	0.0	973	0.5	0.0	1,053	0.5	0.0
Commercial Marine (C1 & C2)	28,730	7.8	0.8	15,787	7.6	0.5	10,017	4.5	0.3
Land-Based Nonroad Diesel	159,111	43.3	4.5	46,056	22.1	1.4	17,902	8.0	0.5
Small Nonroad SI	25,700		0.7	31,981		0.9	36,795		1.1
Recreational Marine SI	16,262		0.5	2,845		0.1	1,225		0.0
SI Recreational Vehicles	13,710		0.4	11,901		0.4	10,090		0.3
Large Nonroad SI (>25hp)	1,652		0.0	2,421		0.1	2,844		0.1
Aircraft	17,979		0.5	22,176		0.7	24,058		0.7
Total Off Highway	348,013		9.9	259,656		7.7	280,136		8.2
Highway Diesel	94,982	25.8	2.7	20,145	9.7	0.6	18,802	8.4	0.6
Highway non-diesel	51,694		1.5	45,329		1.3	51,621		1.5
Total Highway	146,676		4.2	65,474		1.9	70,423		2.1
Total Mobile Sources	494,690		14.1	325,131		9.6	350,559		10.3
Stationary Point & Area Sources	3,025,244		85.9	3,047,714		90.4	3,047,714		89.7
Total Man-Made Sources	3,519,933		100	3,372,845		100	3,398,274		100

Table 3-97 50 State Annual SO_2 Baseline Emission Levels for Mobile and Other Source Categories

Category	2002			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Commercial Marine (C3)	453,614	43.2	3.0	927,537	93.3	10.5	1,410,061	94.9	15.1
Locomotive	75,385	7.2	0.5	396	0.0	0.0	464	0.0	0.0
Recreational Marine Diesel	5,145	0.5	0.0	162	0.0	0.0	192	0.0	0.0
Commercial Marine (C1 & C2)	80,353	7.6	0.5	2,961	0.3	0.0	3,002	0.2	0.0
Land-Based Nonroad Diesel	172,304	16.4	1.2	999	0.1	0.0	1,079	0.1	0.0
Small Nonroad SI	6,742	0.6	0.0	8,870	0.9	0.1	10,282	0.7	0.1
Recreational Marine SI	2,755	0.3	0.0	2,995	0.3	0.0	3,184	0.2	0.0
SI Recreational Vehicles	1,530	0.1	0.0	2,862	0.3	0.0	3,019	0.2	0.0
Large Nonroad SI (>25hp)	933	0.1	0.0	905	0.1	0.0	1,020	0.1	0.0
Aircraft	8,701	0.8	0.1	11,171	1.1	0.1	12,197	0.8	0.1
Total Off Highway	807,463	76.9	5.4	958,857	96.5	10.8	1,444,498	97.2	15.4
Highway Diesel	71,147	6.8	0.5	4,218	0.4	0.0	5,478	0.4	0.1
Highway non-diesel	171,866	16.4	1.1	30,922	3.1	0.3	36,011	2.4	0.4
Total Highway	243,013	23.1	1.6	35,140	3.5	0.4	41,489	2.8	0.4
Total Mobile Sources	1,050,475	100.0	7.0	993,998	100.0	11.2	1,485,986	100.0	15.9
Stationary Point & Area Sources	13,897,968	-	93.0	7,864,681	-	88.8	7,864,681	-	84.1
Total Man-Made Sources	14,948,443	-	100	8,858,678	-	100	9,350,667	-	100

3.5.2 Contribution to Mobile Source Inventories for Selected Cities

Commercial marine vessels, powered by Category 3 marine engines, contribute significantly to the emissions inventory for many U.S. ports. This is illustrated in Table 3-98, which presents the mobile source inventory contributions of these vessels for several ports. The ports in this table were selected to present a sampling over a wide geographic area along the U.S. coasts. In 2005, these twenty ports received approximately 60 percent of the vessel calls to the U.S. from ships of 10,000 dead weight tons (DWT) or greater.[53]

Table 3-98 Contribution of Commercial Marine Vessels to Mobile Source Inventories for Selected Ports in 2002[a]

Port Area	% of total NO_X	% of total $PM_{2.5}$	% of total SO_2
Valdez, AK	4	10	43
Seattle, WA	10	20	56
Tacoma, WA	20	38	74
San Francisco, CA	1	1	31
Oakland, CA	8	14	80
LA/Long Beach, CA	5	10	71
Beaumont, TX	6	20	55
Galveston, TX	5	12	47
Houston, TX	3	10	41
New Orleans, LA	14	24	59
South Louisiana, LA	12	24	58
Miami, FL	13	25	66
Port Everglades, FL	9	20	56
Jacksonville, FL	5	11	52
Savannah, GA	24	39	80
Charleston, SC	22	33	87
Wilmington, NC	7	16	73
Baltimore, MD	12	27	69
New York/New Jersey	4	9	39
Boston, MA	4	5	30

Note:
[a] This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Currently, more than 40 major U.S. deep sea ports are located in areas that are designated as being in nonattainment for either or both the 8-hour ozone NAAQS and $PM_{2.5}$ NAAQS. Many ports are located in areas rated as class I federal areas for visibility impairment and regional haze. It should be noted that emissions from ocean-going vessels are not simply a localized problem related only to cities that have commercial ports. Virtually all U.S. coastal areas are affected by emissions from ships that transit between those ports, using shipping lanes that are close to land. Many of these coastal areas also have high population densities. For example, Santa Barbara, which has no commercial port, estimates that engines on ocean-going marine vessels currently contribute about 37 percent of total NO_X in their area.[54] These

emissions are from ships that transit the area, and "are comparable to (even slightly larger than) the amount of NO_X produced onshore by cars and truck." By 2015 these emissions are expected to increase 67 percent, contributing 61 percent of Santa Barbara's total NO_X emissions. This mix of emission sources led Santa Barbara to point out that they will be unable to meet air quality standards for ozone without significant emission reductions from these vessels, even if they completely eliminate all other sources of pollution. Interport emissions from OGV also contribute to other environmental problems, affecting sensitive marine and land ecosystems.

3.6 Projected Emission Reductions

The projected tons reductions for each of the 2020 control cases relative to the 2020 baseline, as well as the tons reductions for the 2030 control case relative to the 2030 baseline, are presented in Table 3-99 thru Table 3-100. Reductions by region, for the total U.S., and for the total 48-states, are provided by pollutant in each table.

Table 3-99 Reductions for 2020 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO_2	CO_2
Alaska East (AE)	3,264	2,239	2,060	0	0	18,356	57,395
Alaska West (AW)	2,897	6,267	5,766	0	0	49,300	182,091
East Coast (EC)	149,933	33,717	31,020	0	0	311,523	887,402
Gulf Coast (GC)	88,434	20,202	18,586	0	0	168,496	532,567
Hawaii East (HE)	15,074	3,634	3,343	0	0	29,888	91,340
Hawaii West (HW)	10,166	4,565	4,200	0	0	35,445	130,519
North Pacific (NP)	13,539	3,377	3,107	0	0	26,731	85,533
South Pacific (SP)	84,507	17,395	16,003	0	0	143,965	480,516
Great Lakes (GL)	3,422	1,406	1,294	0	0	11,574	36,235
Total U.S. Metric Tonnes	371,237	92,803	85,378	0	0	795,279	2,483,598
Total U.S. Short Tons	*409,219*	*102,297*	*94,114*	*0*	*0*	*876,645*	*2,737,698*

Note:
[a] The emission reductions are relative to the 2020 baseline.

Table 3-100 Reductions for 2030 Control Case[a]

U.S. Region	Metric Tonnes per Year						
	NO_X	PM_{10}	$PM_{2.5}$[a]	HC	CO	SO2	CO2
Alaska East (AE)	12,208	3,099	2,851	0	0	25,397	79,434
Alaska West (AW)	14,764	8,555	7,870	0	0	67,482	251,937
East Coast (EC)	443,893	52,394	48,203	0	0	484,409	1,400,222
Gulf Coast (GC)	222,973	26,881	24,731	0	0	224,221	706,466
Hawaii East (HE)	46,814	5,919	5,446	0	0	48,698	149,669
Hawaii West (HW)	22,377	7,417	6,824	0	0	57,641	210,703
North Pacific (NP)	36,179	4,683	4,308	0	0	37,062	118,395
South Pacific (SP)	266,033	30,179	27,764	0	6	249,952	756,671
Great Lakes (GL)	6,102	1,657	1,524	0	0	13,694	42,904
Total U.S. Metric Tonnes	1,071,344	140,783	129,521	0	0	1,208,555	3,716,400
Total U.S. Short Tons	1,180,955	155,187	142,772	0	0	1,332,204	4,096,630

Note:
[a] The emission reductions are relative to the 2030 baseline.

3.7 Inventories Used for Air Quality Modeling

The emission inventories for 2020 presented in this chapter are slightly different from the emissions inventories used in the air quality modeling presented in Chapter 2. Specifically, the 2020 inventories used in the air quality modeling reflect a slightly different boundary for the proposed ECA that was based on a measurement error. Due to the nature of the measurement error, the corrections to the ECA boundaries are not uniform, but are different by coastal area. The measurement error affects only those portions that are farthest from shore. The 2030 inventories are not affected by this error.

A comparison of the air quality and final inventories by region for the 2020 baseline scenario is provided in Table 3-101. Results are provided only for NO_X, $PM_{2.5}$, and SO_2, since the air quality modeling is focused on ozone and $PM_{2.5}$. In addition, Alaska and Hawaii are not included, since the air quality modeling domain does not include these states. As seen in Table 3-101, the changes due to the boundary error are not expected to have a significant impact on the results of our analysis.

Table 3-101 Comparison of Air Quality versus Final Inventories for 2020 Baseline Case

U.S. Region	Metric Tonnes per Year								
	NO_X			$PM_{2.5}$			SO_2		
	AQ	Final	% Diff	AQ	Final	% Diff	AQ	Final	% Diff
East Coast (EC)	439,713	439,604	0%	35,891	35,882	0%	323,108	323,038	0%
Gulf Coast (GC)	261,024	259,295	1%	21,669	21,531	1%	175,862	174,751	1%
North Pacific (NP)	42,291	42,644	-1%	3,575	3,603	-1%	27,580	27,807	-1%
South Pacific (SP)	216,849	234,968	-8%	17,092	18,536	-8%	138,102	149,751	-8%
Great Lakes (GL)	19,842	19,842	0%	1,484	1,484	0%	11,993	11,993	0%
Total 48-State	**979,719**	**996,353**	**-2%**	**79,711**	**81,036**	**-2%**	**676,645**	**687,340**	**-2%**

The 2020 control inventories are also subject to the boundary error. In addition, the 2020 air quality control case does not include global controls for areas that are beyond 200 nm but within the air quality modeling domain. The impact of this latter difference is expected to be minimal.

The modeling for 2030 was based on inventories that reflected an ECA distance closer to shore than what we are proposing. The air quality modeling, and related estimates of benefits, therefore reflect the impacts associated with approximately 80% of the emission reductions achieved by the proposed coordinated strategy. As a result, the 2030 air quality impacts and health benefits presented in Chapters 2 and 6, respectively, should be considered conservative estimates of the improvements in air quality associated with the proposal. For the final RIA, we plan to model the 2030 coordinated strategy to control ship emissions with a 200 nm boundary and global controls beyond.

APPENDIX 3A

Port Coordinates and Reduced Speed Zone Information

Table 3-102 Port Coordinates

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Albany, NY	C0505	-73.7482	42.64271
Alpena, MI	L3617	-83.4223	45.0556
Anacortes, WA	C4730	-122.6	48.49617
Anchorage, AK	C4820	-149.895	61.23778
Ashtabula, OH	L3219	-80.7917	41.91873
Baltimore, MD	C0700	-76.5171	39.20899
Barbers Point, Oahu, HI	C4458	-158.109	21.29723
Baton Rouge, LA	C2252	-91.1993	30.42292
Beaumont, TX	C2395	-94.0881	30.08716
Boston, MA	C0149	-71.0523	42.35094
Bridgeport, CT	C0311	-73.1789	41.172
Brownsville, TX	C2420	-97.3981	25.9522
Brunswick, GA	C0780	-81.4999	31.15856
Buffalo, NY	L3230	-78.8953	42.8783
Burns Waterway Harbor, IN	L3739	-87.1552	41.64325
Calcite, MI	L3620	-83.7756	45.39293
Camden-Gloucester, NJ	C0551	-75.1043	39.94305
Carquinez, CA	CCA01	-122.123	38.03556
Catalina, CA	CCA02	-118.496	33.43943
Charleston, SC	C0773	-79.9216	32.78878
Chester, PA	C0297	-75.3222	39.85423
Chicago, IL	L3749	-87.638	41.88662
Cleveland, OH	L3217	-81.6719	41.47852
Conneaut, OH	L3220	-80.5486	41.96671
Coos Bay, OR	C4660	-124.21	43.36351
Corpus Christi, TX	C2423	-97.3979	27.81277
Detroit, MI	L3321	-83.1096	42.26909
Duluth-Superior, MN and WI	L3924	-92.0964	46.77836
El Segundo, CA	CCA03	-118.425	33.91354
Erie, PA	L3221	-80.0679	42.15154
Escanaba, MI	L3795	-87.025	45.73351
Eureka, CA	CCA04	-124.186	40.79528
Everett, WA	C4725	-122.229	47.98476
Fairport Harbor, OH	L3218	-81.2941	41.76666
Fall River, MA	C0189	-71.1588	41.72166
Freeport, TX	C2408	-95.3304	28.9384
Galveston, TX	C2417	-94.8127	29.31049
Gary, IN	L3736	-87.3251	41.61202
Georgetown, SC	C0772	-79.2896	33.36682
Grays Harbor, WA	C4702	-124.122	46.91167
Gulfport, MS	C2083	-89.0853	30.35216
Hilo, HI	C4400	-155.076	19.72861
Honolulu, HI	C4420	-157.872	21.31111
Hopewell, VA	C0738	-77.2763	37.32231

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Houston, TX	C2012	-95.2677	29.72538
Indiana Harbor, IN	L3738	-87.4455	41.67586
Jacksonville, FL	C2017	-81.6201	30.34804
Kahului, Maui, HI	C4410	-156.473	20.89861
Kalama, WA	C4626	-122.863	46.02048
Lake Charles, LA	C2254	-93.2221	30.22358
Long Beach, CA	C4110	-118.21	33.73957
Longview, WA	C4622	-122.914	46.14222
Lorain, OH	L3216	-82.1951	41.48248
Los Angeles, CA	C4120	-118.241	33.77728
Manistee, MI	L3720	-86.3443	44.25082
Marblehead, OH	L3212	-82.7091	41.52962
Marcus Hook, PA	C5251	-75.4042	39.81544
Matagorda Ship Channel, TX	C2410	-96.5641	28.5954
Miami, FL	C2164	-80.1832	25.78354
Milwaukee, WI	L3756	-87.8997	42.98824
Mobile, AL	C2005	-88.0411	30.72527
Morehead City, NC	C0764	-76.6947	34.71669
Muskegon, MI	L3725	-86.3501	43.19492
Nawiliwili, Kauai, HI	C4430	-159.353	21.96111
New Bedford, MA	C0187	-70.9162	41.63641
New Castle, DE	C0299	-75.5616	39.65668
New Haven, CT	C1507	-72.9047	41.29883
New Orleans, LA	C2251	-90.0853	29.91414
New York, NY and NJ	C0398	-74.0384	40.67395
Newport News, VA	C0736	-76.4582	36.98522
Nikishka, AK	C4831	-151.314	60.74793
Oakland, CA	C4345	-122.308	37.82152
Olympia, WA	C4718	-122.909	47.06827
Other Puget Sound, WA	C4754	-122.72	48.84099
Palm Beach, FL	C2162	-80.0527	26.76904
Panama City, FL	C2016	-84.1993	30.19009
Pascagoula, MS	C2004	-88.5588	30.34802
Paulsboro, NJ	C5252	-75.2266	39.82689
Penn Manor, PA	C0298	-74.7408	40.13598
Pensacola, FL	C2007	-87.2579	30.40785
Philadelphia, PA	C0552	-75.2022	39.91882
Plaquemines, LA, Port of	C2255	-89.6875	29.48
Port Angeles, WA	C4708	-123.453	48.1305
Port Arthur, TX	C2416	-93.9607	29.83142
Port Canaveral, FL	C2160	-80.6082	28.41409
Port Dolomite, MI	L3627	-84.3128	45.99139
Port Everglades, FL	C2163	-80.1178	26.09339
Port Hueneme, CA	C4150	-119.208	34.14824
Port Inland, MI	L3803	-85.8628	45.95508

Port Name	US ACE Code	Port Coordinates	
		Longitude	Latitude
Port Manatee, FL	C2023	-82.5613	27.63376
Portland, ME	C0128	-70.2513	43.64951
Portland, OR	C4644	-122.665	45.47881
Presque Isle, MI	L3845	-87.3852	46.57737
Providence, RI	C0191	-71.3984	41.81178
Redwood City, CA	CCA05	-122.21	37.51306
Richmond, CA	C4350	-122.374	37.92424
Richmond, VA	C0737	-77.4194	37.45701
Sacramento, CA	CCA06	-121.544	38.56167
San Diego, CA	C4100	-117.178	32.70821
San Francisco, CA	C4335	-122.399	37.80667
Sandusky, OH	L3213	-82.7123	41.47022
Savannah, GA	C0776	-81.0954	32.08471
Searsport, ME	C0112	-68.925	44.45285
Seattle, WA	C4722	-122.359	47.58771
South Louisiana, LA, Port of	C2253	-90.6179	30.03345
St. Clair, MI	L3509	-82.4941	42.82663
Stockton, CA	C4270	-121.316	37.9527
Stoneport, MI	L3619	-83.4703	45.28073
Tacoma, WA	C4720	-122.452	47.28966
Tampa, FL	C2021	-82.5224	27.78534
Texas City, TX	C2404	-94.9181	29.36307
Toledo, OH	L3204	-83.5075	41.66294
Two Harbors, MN	L3926	-91.6626	47.00428
Valdez, AK	C4816	-146.346	61.12473
Vancouver, WA	C4636	-122.681	45.62244
Wilmington, DE	C0554	-75.507	39.71589
Wilmington, NC	C0766	-77.954	34.23928

Table 3-103 Port RSZ Information

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s)	
			Longitude	Latitude
Albany, NY	c	142.5	-73.8929	40.47993
Alpena, MI	e	3	-83.2037	44.99298
Anacortes, WA	a	108.3	-124.771	48.49074
Anchorage, AK	14.5	143.6	-152.309	59.5608
Ashtabula, OH	e	3	-80.8097	42.08549
Baltimore, MD	c	157.1	-75.8067	36.8468
Barbers Point, Oahu, HI	10	5.1	-158.132	21.21756
Baton Rouge, LA	10	219.8	-89.4248	28.91161
			-89.137	28.98883
Beaumont, TX	7	53.5	-93.7552	29.55417
Boston, MA	10	14.3	-70.7832	42.37881
Bridgeport, CT	10	2	-73.1863	41.13906
Brownsville, TX	8.8	18.7	-97.0921	26.06129
Brunswick, GA	13	38.8	-80.9345	31.29955
			-81.1357	30.68935
Buffalo, NY	e	3	-79.0996	42.81683
Burns Waterway Harbor, IN	e	3	-87.1032	41.80625
Calcite, MI	e	3	-83.5383	45.39496
Camden-Gloucester, NJ	c	94	-75.0095	38.79004
Carquinez, CA	12	39	-122.632	37.76094
Catalina, CA	12	11.9	-118.465	33.63641
Charleston, SC	12	17.3	-79.6452	32.62557
Chester, PA	c	78.2	-75.0095	38.79004
Chicago, IL	e	3	-87.4141	41.86971
Cleveland, OH	e	3	-81.765	41.63079
Conneaut, OH	e	3	-80.5639	42.13361
Coos Bay, OR	6.5	13	-124.359	43.35977
Corpus Christi, TX	d	30.1	-96.8753	27.74433
Detroit, MI	e	3	-83.1384	42.10308
Duluth-Superior, MN and WI	e	3	-91.8536	46.78916
El Segundo, CA	12	23.3	-118.926	33.91252
			-118.465	33.63641
Erie, PA	e	3	-80.115	42.3151
Escanaba, MI	e	3	-86.9224	45.58297
Eureka, CA	12	9	-124.347	40.75925
Everett, WA	a	123.3	-124.771	48.49074
Fairport Harbor, OH	e	3	-81.3917	41.91401
Fall River, MA	9	22.7	-71.3334	41.41708
Freeport, TX	c	2.6	-95.2949	28.93323
Galveston, TX	c	9.3	-94.6611	29.3247
Gary, IN	e	3	-87.2824	41.77658
Georgetown, SC	12	17.6	-79.0779	33.1924

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s)	
			Longitude	Latitude
Grays Harbor, WA	a	4.9	-124.24	46.89509
Gulfport, MS	10	17.4	-88.9263	30.11401
Hilo, HI	10	7.1	-154.985	19.76978
Honolulu, HI	10	10	-157.956	21.17658
			-157.785	21.23827
Hopewell, VA	10	91.8	-75.8067	36.8468
Houston, TX	c	49.6	-94.6611	29.3247
Indiana Harbor, IN	e	3	-87.4007	41.8401
Jacksonville, FL	10	18.6	-81.3649	30.39769
Kahului, Maui, HI	10	7.5	-156.44	21.01066
Kalama, WA	b	68.2	-124.137	46.22011
Lake Charles, LA	6	38	-93.3389	29.73094
Long Beach, CA	12	18.1	-118.465	33.63641
			-118.13	33.45211
Longview, WA	b	67.3	-124.137	46.22011
Lorain, OH	e	3	-82.2701	41.64023
Los Angeles, CA	12	20.6	-118.465	33.63641
			-118.13	33.45211
Manistee, MI	e	3	-86.3819	44.41573
Marblehead, OH	e	3	-82.7293	41.69638
Marcus Hook, PA	c	94.7	-75.0095	38.79004
Matagorda Ship Channel, TX	7.3	24	-96.2287	28.33472
Miami, FL	12	3.8	-80.1201	25.75787
Milwaukee, WI	e	3	-87.6718	42.97343
Mobile, AL	11	36.1	-88.0644	30.1457
Morehead City, NC	10	2.2	-76.6679	34.68999
Muskegon, MI	e	3	-86.5377	43.29151
Nawiliwili, Kauai, HI	10	7.3	-159.266	21.87705
New Bedford, MA	9	22.4	-71.1013	41.38499
New Castle, DE	c	60.5	-75.0095	38.79004
New Haven, CT	10	2.1	-72.9121	41.26588
New Orleans, LA	10	104.2	-89.4248	28.91161
			-89.137	28.98883
New York, NY and NJ	c	15.7	-73.8929	40.47993
Newport News, VA	14	24.3	-75.8067	36.8468
Nikishka, AK	14.5	90.7	-152.309	59.5608
Oakland, CA	12	18.4	-122.632	37.76094
Olympia, WA	a	185.9	-124.771	48.49074
Other Puget Sound, WA	a	106	-124.771	48.49074
Palm Beach, FL	3	3.1	-79.9973	26.77129
Panama City, FL	10	10	-84.1797	30.0818
Pascagoula, MS	10	17.5	-88.4804	30.09597
Paulsboro, NJ	c	83.5	-75.0095	38.79004
Penn Manor, PA	c	114.5	-75.0095	38.79004
Pensacola, FL	12	12.7	-87.298	30.27777

Port Name	RSZ Speed (knts)	RSZ distance (naut mi)	Final RSZ End Point(s)	
			Longitude	Latitude
Philadelphia, PA	c	88.1	-75.0095	38.79004
Plaquemines, LA, Port of	10	52.4	-89.4248	28.91161
			-89.137	28.98883
Port Angeles, WA	a	65	-124.771	48.49074
Port Arthur, TX	7	21	-93.7552	29.55417
Port Canaveral, FL	10	4.4	-80.5328	28.41439
Port Dolomite, MI	e	3	-84.2445	45.83181
Port Everglades, FL	7.5	2.1	-80.082	26.08627
Port Hueneme, CA	12	2.8	-119.238	34.10859
Port Inland, MI	e	3	-85.6524	45.87553
Port Manatee, FL	9	27.4	-83.0364	27.59078
Portland, ME	10	11.4	-70.1077	43.54224
Portland, OR	b	105.1	-124.137	46.22011
Presque Isle, MI	e	3	-87.082	46.5804
Providence, RI	9	24.9	-71.3334	41.41708
Redwood City, CA	12	36	-122.632	37.76094
Richmond, CA	12	22.6	-122.632	37.76094
Richmond, VA	10	106.4	-75.8067	36.8468
Sacramento, CA	12	90.5	-122.632	37.76094
San Diego, CA	12	11.7	-117.315	32.62184
San Francisco, CA	12	14.4	-122.632	37.76094
Sandusky, OH	e	3	-82.5251	41.56193
Savannah, GA	13	45.5	-78.0498	33.83598
Searsport, ME	9	22.2	-68.7645	44.1179
Seattle, WA	a	133.3	-124.771	48.49074
South Louisiana, LA, Port of	10	142.8	-89.4248	28.91161
			-89.137	28.98883
St. Clair, MI	e	3	-82.5838	42.55923
Stockton, CA	12	86.9	-122.632	37.76094
Stoneport, MI	e	3	-83.2355	45.25919
Tacoma, WA	a	150.5	-124.771	48.49074
Tampa, FL	9	30	-83.0364	27.59078
Texas City, TX	c	15.1	-94.6611	29.3247
Toledo, OH	e	3	-83.3034	41.7323
Two Harbors, MN	e	3	-91.4414	46.93391
Valdez, AK	10	27.2	-146.881	60.86513
Vancouver, WA	b	95.7	-124.137	46.22011
Wilmington, DE	c	65.3	-75.0095	38.79004
Wilmington, NC	10	27.6	-80.325	31.84669

[a] Cruise speed through Strait of Juan de Fuca, then varies by ship type for remaining journey
[b] Inbound on Columbia River at 6.5 knots, outbound at 12 knots
[c] Speed varies by ship type similar to typical like port
[d] Speed varies by ship DWTs
[e] All Great Lake ports have reduced speed zone distances of 3 nautical miles with speeds halfway between service speed and maneuvering speed.

APPENDIX 3B

Inventory Impacts of Alternative Program

The proposed program represents a comprehensive approach to reduce emissions from Category 3 marine diesel engines. As we developed this proposal, we evaluated an alternative, which considers the possibility of pulling ahead the CAA Tier 3 NO_X standard from 2016 to 2014. NO_X emissions were calculated for the year 2023 under three scenarios: Tier 1 only NO_X standards (the base case), the coordinated strategy as proposed in NPRM which includes the 2016 NO_X standards in effect 2016 (the primary case), and NO_X standards for U.S.-vessels only pulled ahead to 2014 (the alternative case). This appendix describes the methodology that was used to estimate the NO_X inventories for the proposed and alternative program scenarios in 2023.

The inventories described in this chapter are for calendar years 2002, 2020, and 2030. To calculate inventories for 2023, a spreadsheet model was developed and used. For both the proposed and alternative scenarios, it was assumed that the proposed ECA controls apply within 200 nautical miles for all 48 contiguous states. The only difference modeled was the different start dates for Tier 3. Note that only emissions from U.S. vessels are impacted by the proposed alternative.

Under the proposed base scenario, 48-state NO_X emissions in 2023 are 10,494,636 short tons. With the coordinated strategy in effect (the primary case), 48-state NO_X emissions in 2023 are 7,515,389 short tons, a 28.4 % reduction from Tier 1 only standards. Under the alternative scenario, 48-state NO_X emissions in 2023 are 7,444,866 short tons, a difference of 0.9 percent from the primary case (Figure 3B-1).

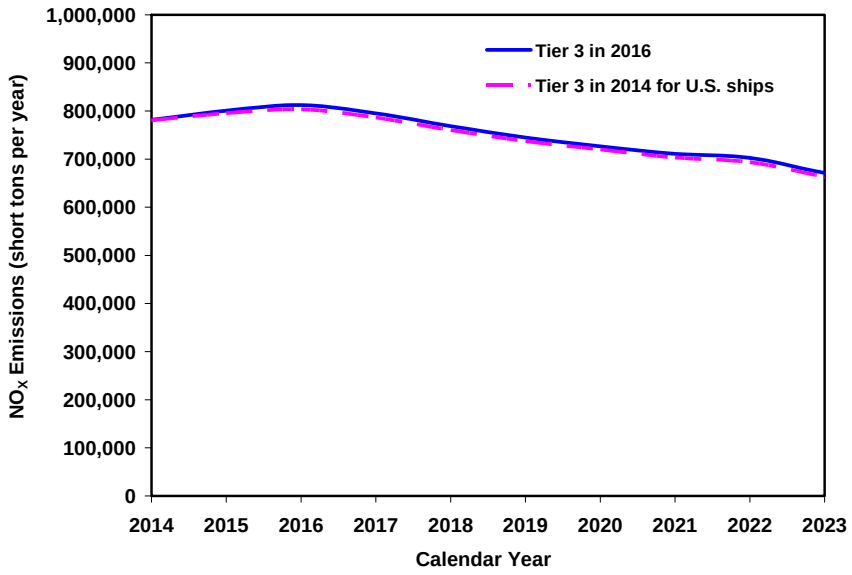


Figure 3B-1 NO_X Emissions with the Primary Case (Tier 3 in 2016) versus the Alternative Case (Tier 3 in 2014 for U.S. vessels only)

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CHAPTER 4: TECHNOLOGICAL FEASIBILITY

CHAPTER 4: Technological Feasibility

In this chapter, we describe in detail the analysis of emission control technologies we used to develop the standards we are proposing. Section 4.1 presents an overview of the proposed standards and the emission control technologies we expect will be used in meeting these standards. Section 4.2 describes the in-cylinder, or engine design-based, emission control technologies that can be used to meet the proposed Tier 2 standards. Section 4.3 describes the exhaust aftertreatment and water-based emission control technologies that can be used to meet the proposed Tier 3 standards. Section 4.4 describes technologies associated with switching to low sulfur distillate fuel or, alternatively, using exhaust gas cleaning devices to remove sulfur from the exhaust. Section 4.5 presents technology that can be used to produce and distribute additional low sulfur distillate fuel. Section 4.6 discusses the potential impact of the proposed standards on safety, noise, and energy.

4.1 Overview of Emissions Standards and Emission Control Technologies

Our current emission standards for Category 3 (C3) marine engines are equivalent to the NO_X limits in Annex VI to the Convention for the Prevention of Pollution from Ships (MARPOL). These standards, referred to as "Tier 1", were adopted by the EPA in 2003 and went into effect in 2004. Globally, these standards went into effect 2003 and became retroactive for vessels built from 2000 to 2002. The Tier 1 standards rely on engine-based technologies to reduce emissions. The International Maritime Organization recently amended Annex VI to include new tiers of NO_X standards for new engines that reflect the use of advanced emission control technologies, including exhaust aftertreatment; these Tier 2 and Tier 3 standards will go into effect in 2011 and 2016, respectively. The Annex VI amendments also include limits on the sulfur content of fuel that will reduce SO_X and PM emissions, and NO_X limits for existing engines that will take effect as soon as certified Approved Methods are available.

To meet the proposed Tier 2 standards (which require approximately 15 to 21% reductions in NO_X relative to Tier 1, depending on rated engine speed), advanced, engine-based improvements will be needed. These engine-based approaches for Tier 2 can include changes and/or advancements to turbocharger, valve timing, compression ratio, combustion chamber, and common-rail fuel injection system designs. The extent to which any or all of these engine-based improvements are used is dependent upon the level of emission reduction needed for a given engine. The fuel injection approaches to reducing engine-out NO_X emissions are described in detail in Section 4.2.

To meet the proposed Tier 3 standards (which require an 80% reduction in NO_X, relative to Tier 1), further engine-based approaches, such as Exhaust Gas Recirculation (EGR), direct water injection, fuel-water emulsification, and intake air humidification are under development. We anticipate that exhaust aftertreatment approaches, such as Selective Catalytic Reduction (SCR), will be used to achieve the necessary NO_X reductions. 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, U.S. and European heavy-duty truck manufacturers are using this technology to meet the more-stringent NO_X limits. In the Category 2 and Category 3 marine sector, at least 300 vessels are currently equipped with SCR systems to

control NO_X emissions. Our analysis , described in detail in Section 4.3, projects that SCR will be a viable technology available to C3 engine manufacturers to meet the Tier 3 NO_X standard we are proposing.

4.2 Emission Control Technologies for Tier 2 Standards

4.2.1 In-Cylinder NO_X Controls

The engine-out, or in-cylinder, NO_X emissions of a diesel engine can be controlled by utilizing engine design and calibration parameters (e.g. fuel delivery and valve timing) to limit the formation of NO_X. The formation rate of NO_X has a strong exponential relationship to combustion temperature; high combustion temperatures result in high NO_X formation rates.[1,2] Any changes to the engine design or combustion process which can lower the peak temperature will reduce NO_X emissions. Most of the engine-out NO_X emission control technologies discussed in the following in this Section reduce NO_X emissions by reducing the level and duration peak combustion temperatures, while balancing the impact on PM emissions, fuel consumption, and torque output.

Control of diesel emissions by modifying the combustion processes is often characterized by trade-offs in NO_X emission control versus other parameters such as PM emissions, and fuel consumption. For example, lower oxygen content (through exhaust gas recirculation, or EGR) lowers NO_X formation but may increase PM formation. Advanced (earlier) injection timing reduces PM emissions but increases NO_X formation, while 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 electronic fuel injection systems and the flexibility these systems provide in terms of injection timing, fuel delivery rate, number of injection events per combustion cycle can improve these tradeoffs, allowing for reduced emissions of both NO_X and PM, while minimizing the impact on fuel efficiency.

Electronic control of injection timing has been used by highway, nonroad, locomotive, and marine diesel engine manufacturers to balance NO_X emissions, PM emissions, fuel efficiency, engine performance and engine durability. While in-line, unit-injector, and common-rail injection systems can all benefit from electronic controls, it is the common-rail system which provides the greatest flexibility of controlling the injection timing, pressure, flow rate, as well as the number of injection events for each combustion cycle. Engine manufactures, such as MAN B&W and Wärtsilä, have already incorporated common rail systems into their Tier 1 engine designs, and we expect that manufacturers will continue to improve these systems to further reduce NO_X emissions while minimizing the effect on PM emissions and fuel consumption.

4.2.1.1 Fuel Injection Pressure and Timing

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.[3,4,5,6] 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.

Injection timing retard typically reduces NO_X while increasing 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. The increases in HC, CO, and PM 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 combustion event to enhance soot oxidation. While injection timing retard can achieve the 20% reduction in NO_X required for Tier 2, and HC, CO, and PM increases can be eliminated, or minimized, through optimization for the injection strategy.

We expect that electronic control of the fuel injection timing and pressure will be used by manufacturers of Tier 2 and Tier 3 engines to reduce engine-out NO_X emissions.

4.2.1.2 Common Rail Fuel Injection Systems

The most recent advances in fuel injection technology for marine use are high-pressure common rail injection systems with the ability to use multiple injections and rate shaping (i.e., adjusting the flow rate of fuel delivered throughout the injection event as a function of crank angle) to control the timing and quantity of fuel delivered to the engine over the course of a single combustion event. Common rail systems can provide both NO_X and PM reductions and are in widespread use in heavy-duty on-highway diesel engines, and are also used in many current nonroad diesel engines. These common rail systems provide precise control of the fuel injection event, allowing it to be broken up into discrete, multiple phases. Injecting a small quantity of fuel early in the compression stroke (or well before the piston reaches top-dead-center) is known as "pilot" injection. The ignition of this smaller quantity of fuel limits the rapid increase in pressure and temperature (and the associated NO_X formation) which is characteristic of premixed diesel combustion. Injecting the remainder of the fuel quantity into the established flame resulting from the pilot injection then allows for a steady burn which limits the combustion temperature, and hence NO_X emissions. Rate shaping of the fuel injection event can be done either mechanically or electronically, and has been shown to reduce NO_X emissions by up to 20 percent diesel engines.[7]

A further splitting of the injection event, using a late cycle, or post-main, injection pulse has been shown to significantly reduce particulate emissions, most notably in cases where retarded injection timing, or a combination of injection timing retard and EGR, is used to control NO_X.[8,9,10,11] With this approach, the typical diffusion-burn combustion event is broken up into two events; a main injection which is terminated, followed by a short dwell period with no injection, and a short, post-main injection event, see Figure 4-1. 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, allowing further combustion of the soot can occur.

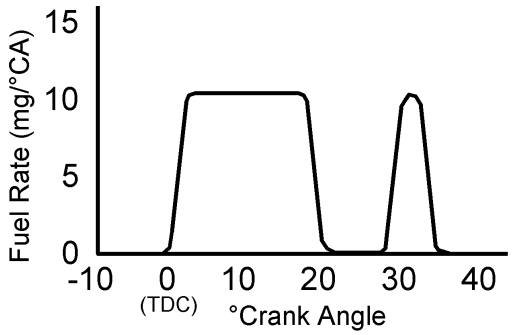


Figure 4-1 An Example of Using Multiple Fuel Injection Events to Induce Late-Combustion Mixing and Increase Soot Oxidation for PM Control (adapted from Pierpont, Montgomery, and Rietz, 1995)

By utilizing a fuel delivery strategy which incorporates retarded injection timing (for reduced NO_X emissions), multiple injections (to reduce the PM which would typically increase with retarded injection timing), and rate shaping (to control the level and duration of peak combustion temperatures), an engine can be operated in a manner which balances NO_X emissions, PM emissions, and fuel consumption under all operating conditions. As in the case of Tier 1 engines, the application of common-rail technology (which allows a broad range of control over the fuel injection and combustion process) can reduce fuel consumption, but the ultimate fuel saving potential is limited by the NO_X standard that the engine must comply with; the lower the NO_X standard, the less potential there is to reduce fuel consumption through control of the fuel injection and combustion parameters.[12] We project that fuel delivery strategies which result in decreases in peak cylinder temperature and pressure to meet the proposed Tier 2 NO_X standard may increase fuel consumption by as much as 2%. However, engine manufacturers may be able to reduce NOx emissions and reduce fuel consumption if the compression ratio is increased while simultaneously reducing the excess air ratio (to maintain an equivalent 'effective' compression ratio).[13] In addition, Miller-cycle supercharging (in which higher intake charge pressures and early closing of the intake valve can result in lower combustion temperatures) can be used to reduce NOx emissions without increasing fuel consumption.[14]

4.3 Emission Control Technologies for Tier 3 Standards

In this section we describe the emission control technologies that we believe will be used to meet the Tier 3 standards. In general, these technologies involve the use of SCR exhaust aftertreatment, water-based approaches (e.g., fuel-water emulsification, intake air humidification, and direct water injection), and EGR to reduce NO_X emissions. These technologies may be used individually, or in combination with other technologies, to achieve the level of NO_X reduction a given manufacturer or engine design requires. SCR is a commonly-used aftertreatment technology for diesel engines that can achieve a 90 to 95% reduction in NO_X emissions in marine applications.[15] Light-duty, heavy-duty (both highway and nonroad), and marine diesel applications have already begun using SCR technology to meet more stringent, aftertreatment-

forcing NO_X standards and water-based technologies have been demonstrated in C3 marine applications. Given the preponderance of studies and data and our analysis summarized in this section, we believe that these technologies are appropriate for C3 marine applications.

4.3.1 Selective Catalytic Reduction

NO_X emissions can be reduced substantially using SCR, a commonly-used technology used to comply with NO_X emissions standards in diesel applications worldwide. 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 gas (greater than 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). The urea dosing strategy and the desired α are dependent on the conditions present in the exhaust; namely gas temperature and the quantity of NO_X present (which can be determined by engine mapping, temperature sensors, and NO_X sensors). However, given the space limitations in packaging exhaust aftertreatment devices mobile and marine 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).

Stationary power plants fueled with coal, diesel, and natural gas have used SCR for three decades as a means of controlling NO_X emissions. European heavy-duty truck manufacturers are using this technology to meet Euro 5 emissions limits and several heavy-duty truck engine manufacturers have indicated that they will use SCR technology to meet stringent U.S. NO_X limits beginning in 2010. Studies have shown that a selective catalytic reduction (SCR) system is capable of providing well in excess of 80% NO_X reduction efficiency in high-power, heavy-duty diesel applications.[16,17,18] SCR has also been demonstrated for use with marine diesel engines. To date, more than 300 SCR systems, developed by Argillon, Wärtsilä, Munters, and other companies, have been installed on marine vessels. Some of which have been in operation for more than 10 years and have accumulated 80,000 hours of operation.[19,20,21,22] These systems are used in a wide range of ship types including ferries, supply ships, RoRos (roll-on roll-off), tankers, container ships, icebreakers, cargo ships, workboats, cruise ships, and foreign navy vessels for both propulsion and auxiliary engines. These SCR units are being used successfully on low- and medium-speed Category 3 propulsion engines and on Category 2 propulsion and auxiliary engines. The fuel used on ships with SCR systems ranges from low sulfur distillate fuel to high sulfur residual fuel. In marine applications, SCR is capable of reducing NO_X emissions more than 90 percent.[23,24,25,26] An example of the performance capability of SCR in a medium-speed diesel marine application is the Staten Island Ferry *Alice Austen*. This demonstration project reports that 90 to 95% NO_X reduction is possible under steady-state conditions where the exhaust gas temperature is above 270 °C.[27]

Marine engine manufacturers report that the minimum exhaust temperature for SCR operation ranges from 250 to 300°C, depending on the catalyst system design and fuel sulfur level.[28,29,30] Below this temperature, the SCR catalyst unit would not be hot enough to efficiently reduce NO_X. An example of the effect of exhaust gas temperature on the NO_X

conversion efficiency of an SCR catalyst is shown in Figure 4-3. If the engine is able to use fuel with very low sulfur levels, a highly reactive oxidation catalyst can be used upstream of the SCR unit to convert NO to NO_2, improving the low temperature efficiency of the SCR. NO_2 reacts in the SCR catalyst at lower temperatures than NO and therefore, use of an oxidation catalyst can lower the exhaust temperature at which an SCR unit is effective. However, as the sulfur concentration in the fuel increases, a less reactive oxidation catalyst must be used to prevent excessive formation of sulfates and poisoning of the oxidation catalyst. When operating on marine distillate fuel with a sulfur level of 1,000 ppm, the minimum exhaust temperature for effective reductions through a current SCR system would be on the order of 270°C. On typical heavy fuel oils, which have sulfur concentrations on the order of 2.5 percent, the exhaust temperature would need to be about 300°C due to high sulfur concentrations. Sea trial test data from a vessel equipped with a 55 MW, low-speed main engine indicates that turbine inlet exhaust gas temperatures, illustrated in Figure 4-2, will be near, or above, the minimum level needed to achieve greater than 80% NO_X reduction for all operating loads of the E3 test cycle (which includes power levels from 25 to 100%).[31]

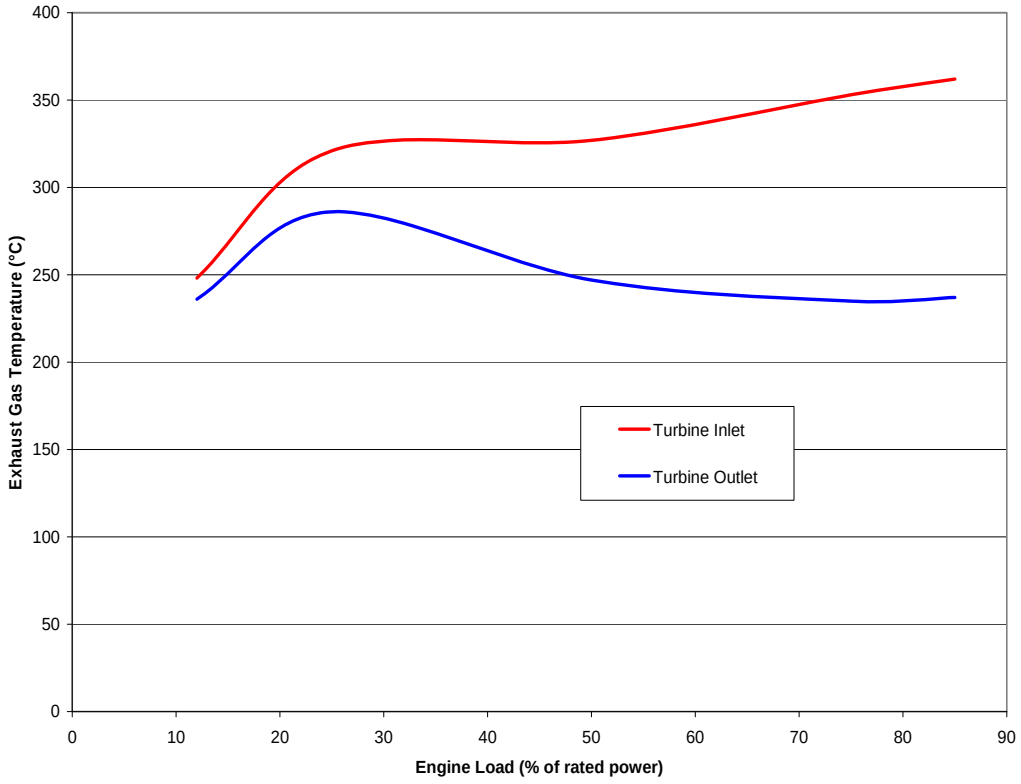


Figure 4-2 Example of Exhaust Gas Temperature as a Function of Engine Load on a 55 MW, 2-stroke, Low-Speed Main Propulsion Engine[31]

As shown in Figure 4-3, the NO_X conversion efficiency of an SCR catalyst can be greater than 90% (for the 'turbine inlet' exhaust gas temperatures observed in the sea trial data shown in Figure 4-2). And even at the relatively cooler turbine temperatures, it is possible to achieve NO_X conversion efficiencies greater than 80%. We believe that modern SCR systems will be able to achieve the NO_X reduction levels sufficient to meet or exceed the proposed Tier 3 standard.

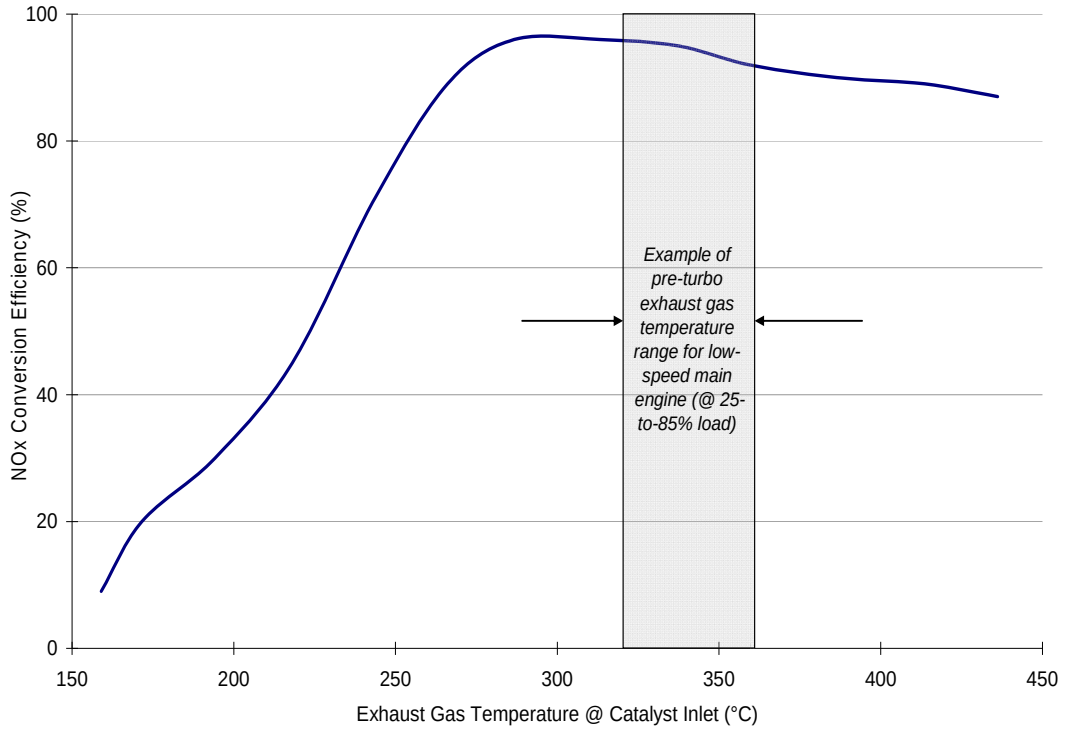


Figure 4-3 SCR NO_X Conversion Efficiency versus Exhaust Temperature Using an Ammonia-to-NO_X Ratio of 1:1[32]

In cases such as low power operation (less than 25% engine load), where exhaust temperatures could fall below the minimum required to ensure proper SCR functioning, we believe there are several approaches to ensure that exhaust temperatures remain high. An example of such approach, proposed by Munters, is to position the SCR system ahead of the turbocharger inlet .[33] On turbocharged engines, the exhaust gas temperature is always higher at the inlet (or before the turbine stage) than at the outlet. When exhaust gasses pass through the turbine stage, heat energy from the exhaust gas is converted into shaft work, where it is then used to compress the intake air. By positioning the SCR before the turbocharger inlet, where exhaust gas temperatures are higher, the engine load range over which the SCR can operate is extended. For example, during sea trials on a 55 MW low-speed main engine, the exhaust gas temperature conditions at the turbine inlet would allow SCR operation at 12% engine load, whereas the turbine outlet temperature conditions would only SCR operation over a narrower much narrower load range (approximately 15 to 50% engine load), unless other measures are taken to increase exhaust heat. Such measures to increase exhaust heat may include reducing the level of charge air cooling or modifying the injection timing. Another approach to increase the exhaust temperature would be to use burner systems during low power operation. The "pre-turbocharger" SCR approach has been used on vessels equipped with slow-speed engines which require NO_X control when operating at low loads near a coastal areas.[34] In one case, SCR was used on a short passenger car ferry which originally had exhaust temperatures below 200°C when the engine was operated at low load.[35] When the SCR unit was installed, controls were placed on the intercooler in the air intake system. By reducing the amount of cooling on the

intake air, the exhaust temperature was increased to be within the operating range of the SCR unit, even during low power operation. On a ship using multiple propulsion engines, one or more engines could be shut down such that the remaining engine (or engines) operating at higher power. Whichever approach is used, we believe that engine manufacturers will be able to design systems which allow the SCR to function at engine loads below 25%, yet still remain below the upper temperature limit (500 °C) of the SCR unit during high-load operation.

The onboard storage of the aqueous urea solution on marine vessels can be accomplished through segmenting of the existing fuel tanks or the 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 sufficient; the amount of solution required is dependent on the expected NH_3-to-NO_X ratio (α) of the engine under the normal operating conditions. At the appropriate intervals, the vessel operator will need to refill the urea tank. The distribution and dispensing of urea is already established for on-road sectors, and is being developed for the nonroad, railroad, and marine sectors as well. We expect that the distribution and dispensing of urea for C3 marine vessels will benefit from any solutions put in place by these other sectors, and should be in place well in advance of the proposed Tier 3 regulations.

SCR- or emissions-grade urea is a widely used industrial chemical around the world. Although an infrastructure for widespread transportation, storage, and dispensing of SCR-grade urea does not currently exist in most shipping ports, we believe that it will develop as-needed, based on market forces. Concerning urea production capacity, the U.S. has more than sufficient capacity to meet the additional needs of the marine sector. Currently, the U.S. consumes 14.7 million tons of ammonia resources per year, and relies on imports for 41 percent of that total (of which, urea is the principal derivative). In 2005, domestic ammonia producers operated their plants at 66 percent of rated capacity, which provides 4.5 million tons of reserve production capacity.[36] Thus we do not project that urea cost, supply, or infrastructure will be an issue in the 2016 timeframe for implementation of the proposed Tier 3 standards.

4.3.2 Water-Based Technologies

In this Section we describe the "water-based" technologies which can be used to reduce NO_X emissions. All of these approaches to reducing engine-out NO_X are based on limiting the formation of NO_X by limiting the peak combustion temperature. It is the heat capacity of water, its ability to absorb combustion energy, which limits the peak combustion temperature, and hence NO_X formation. Whether this water is emulsified with fuel, injected directly into the combustion chamber, or in the form of humidity within the intake air, its purpose is to limit the peak combustion temperature. These water-based approaches to controlling NO_X emissions, when used in combination with the engine design-based approaches, such as fuel injection controls, EGR, and variable valve timing, are also capable of providing significant (up to 60%) NO_X reductions.[13] Whichever approach or combination of approaches is employed by engine manufacturers reduce Tier 2 and Tier 3 NO_X emissions, we believe that these water-based technologies are feasible and can be implemented within the timeframe of this proposed rulemaking.

4.3.2.1 Fuel-Water Emulsions

Fuel-water emulsions for marine engines can be either diesel fuel-water mixtures, with emulsifying and/or stabilizing agents added, or a heavy fuel oil-water mixtures. When a fuel-water mixture is injected into the combustion chamber, vaporization of water within the mixture injection increases fuel dispersion (making the combustion of fuel more efficient) and absorbs combustion heat, which limits the formation of NO_X. For each 0.7 to 1% of water added to the fuel, a 1% reduction in NO_X emissions can be realized.[Error! Bookmark not defined.,37] Engine manufacturers have demonstrated NO_X reductions of up to 50% through the use of fuel-water emulsions alone.[38,39] In many existing engine designs, the limiting factor for fuel-water emulsions is the delivery capacity of the fuel injection system; to maintain the same power level (i.e., keep the quantity of fuel injected constant), the injection system must have enough volume capacity to deliver the quantity of fuel normally injected, plus an additional volume of water emulsified within the fuel. We believe that future injection systems which utilize fuel-water emulsions will be designed to accommodate the amount of water in the fuel necessary to meet the applicable NO_X standard while maintaining engine power at the same level observed when running on 100% fuel.

4.3.2.2 Direct Water Injection

Direct water injection (DWI) technology involves introducing water into the combustion chamber during the combustion process. The injection of water, whether directing into the combustion chamber or into the intake manifold, can be controlled electronically, allowing precise calibration and control of the water-to-fuel ratio. In the case where water is injected directly into the combustion chamber (and separate from the fuel), electronic control also allows precise control over timing and quantity of water injected as well. This approach allows water to be injected at a point in the combustion process where it will provide the optimum NO_X reduction while minimizing the impact on other criteria pollutants (e.g. HC, CO, and PM) and fuel consumption.[40] Engine manufacturers have reported that DWI, when using a water-to-fuel ratio of 40 to 70%, is capable of reducing NO_X emissions by 50 to 60%, without affecting engine power.[26,Error! Bookmark not defined.]

4.3.2.3 Intake Air Humidification

Similar to fuel-water emulsions and direct water injection, increasing the humidity of the intake air on a diesel engine reduces the peak temperature of combustion, and hence, reduces the formation of NO_X. One approach to introducing water into the combustion process is to increase the humidity (water content) of the intake air through evaporation of a water mist, which is injected to the intake air as it exits the compressor stage of the turbocharger. As intake air is compressed by the turbocharger, its temperature increases, and it is this temperature increase which facilitates the evaporation of the injected water mist. To achieve a 50% reduction in NO_X emissions, the quantity of water that must be added to the intake air is roughly twice the quantity of fuel consumed by the engine (or double the amount of water consumed in fuel-water emulsion or DWI approaches for a similar NO_X reduction).[26]

4.3.2.4 Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is a strategy which reduces peak combustion temperature (and hence NO_X formation, similar to water-based approaches) in which a non-combustible gas is added to the combustion process. In this strategy, exhaust gas is typically routed from the exhaust system and mixed with the incoming combustion air. The recycled exhaust gas has lower oxygen content and also absorbs some of the heat energy during combustion, both of which reduce the peak temperatures. MAN B&W has demonstrated that up to 70% NO_X reduction can be achieved when using EGR in combination with intake air humidification.[39] An alternative to routing/mixing exhaust gas with the incoming fresh air charge is use "internal" EGR, where early closing of the exhaust valve is used to trap a portion of the exhaust gas from the previous combustion event within the cylinder.[41]

4.4 Vessel Technologies for Low Sulfur Fuel Standards

The MARPOL Annex VI fuel sulfur limit for ships operating in an ECA is 1.5% today and reduces to 1.0% in March 2010 and further to 0.1% in 2015. We anticipate that the 0.1% fuel sulfur limit, beginning in 2015, will likely result in the use of distillate fuel for operation in ECAs. This would require the vessel to switch from a higher sulfur fuel to 0.1% S fuel before entering the ECA. The practical implications of fuel switching are discussed below. As an alternative operating on low sulfur fuel, an exhaust gas cleaning device may be used to remove sulfur from the exhaust. These devices, which are colloquially known as SO_X scrubbers, are also discussed below.

4.4.1 Fuel Switching on Vessels

4.4.1.1 Impact of fuel switching on emissions

Currently, the majority of ocean-going vessels use residual fuel (also called 'Heavy Fuel Oil (HFO) or 'Intermediate Fuel Oil' (IFO)) in their main propulsion engines, as this fuel is relatively inexpensive and has a good energy density. This fuel is relatively dense ('heavy') and is created as a refining by-product from typical petroleum distillation. Residual fuels typically are composed of heavy, residuum hydrocarbons and can contain various contaminants such as heavy metals, water and sulfur compounds. The current global average sulfur for residual marine fuel is approximately 2.7%.[42] It is these sulfur compounds that cause the SO_X emissions when the fuel is combusted.

Switching from operating marine engines on residual fuel to distillate fuel can reduce exhaust PM emissions, both on a mass basis and on a particle basis. The sulfur in marine fuel is primarily emitted as SO_2; however, a small fraction (about 2 percent) is converted to SO_3. SO_3 almost immediately forms sulfate and is emitted as direct PM by the engine. Consequently, emissions of SO_2 and sulfate PM are very high for engines operating on residual fuel. Switching from high sulfur residual fuel to low sulfur distillate fuel results in large reductions in SO_2 and sulfate PM emissions.

In addition to high sulfur levels, residual fuel contains relatively high concentrations of low volatility, high molecular weight organic compounds and metals. Organic compounds that

contribute to PM can be present either as a nucleation aerosol or as a material adsorbed on the surfaces of agglomerated elemental carbon soot particles and metallic ash particles. The sulfuric acid aerosol in the exhaust provides a nucleus for agglomeration of organic compounds. Operation on higher volatility distillate fuel reduces both nucleation and adsorption of organic compounds into particulate matter. Therefore, in addition to direct sulfate PM reductions, switching from residual fuel to distillate fuel reduces organic PM and metallic ash particles in the exhaust.

The impact of switching from high-sulfur residual fuel to lower sulfur distillate fuel on PM levels has been investigated in a number of test programs.[43,44,45,46,47] On a mass basis, PM from marine engines has been shown to be reduced by 60 to 90 percent when switching from residual to distillate fuel. Figure 4-4 presents the impact of fuel switching on direct PM emissions for testing performed on one slow-speed two-stroke marine engine and four medium-speed four-stroke marine engines.

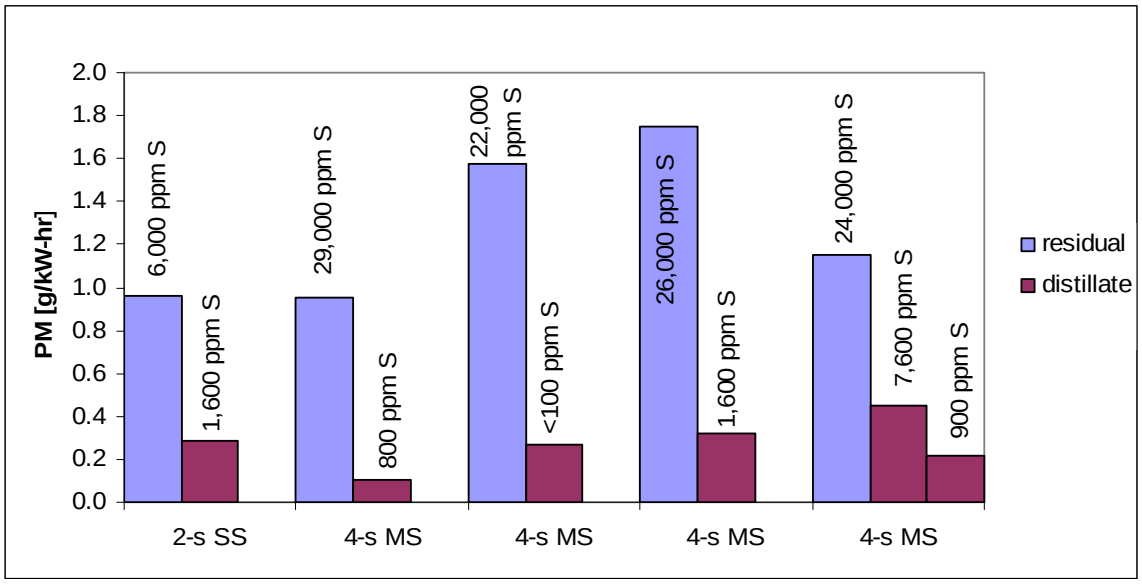


Figure 4-4 Effect of Fuel Switching on PM Emissions from Marine Engines

The PM emissions reductions presented above were primarily due to reductions in direct sulfate PM. However, fuel switching also led to measured reductions in non-sulfate PM for these engines. Specifically, significant reductions were observed in the soluble organic fraction of the PM as well as metallic ash. This is demonstrated in the following charts, excerpted from three of the papers referenced above, which present speciated PM reductions due to fuel switching.

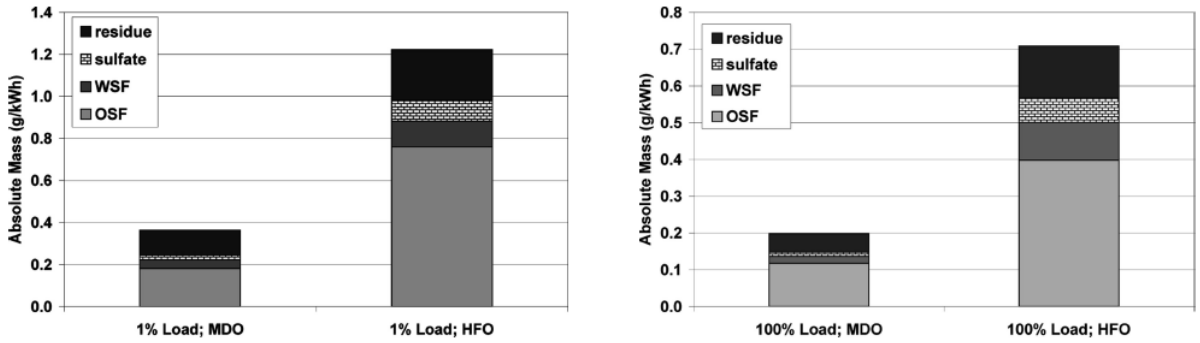
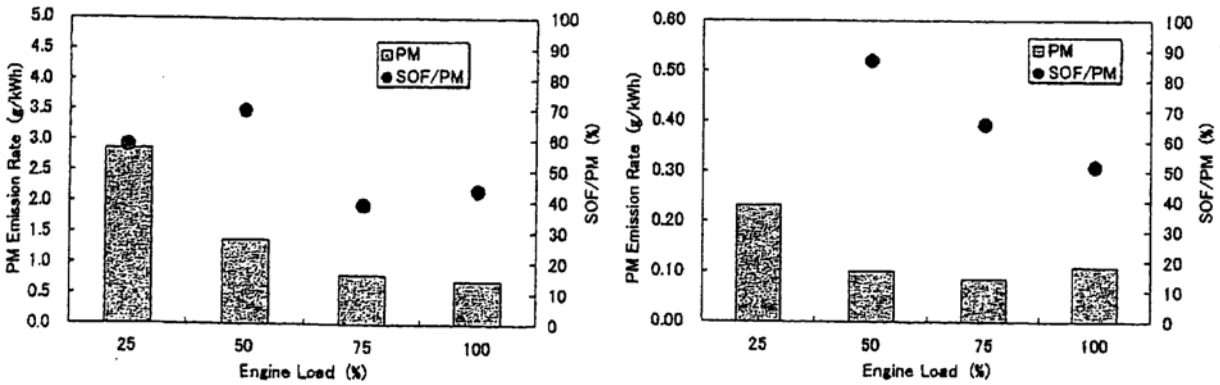


Figure 4-5 Speciated PM from 2-Stroke Slow-Speed Engine (Kasper et al, 2007)



Distillate Fuel Residual Fuel

Figure 4-6 Soluble Organic Fraction of PM from 4-Stroke Medium-Speed Engine (Nakajima et al, 2000)

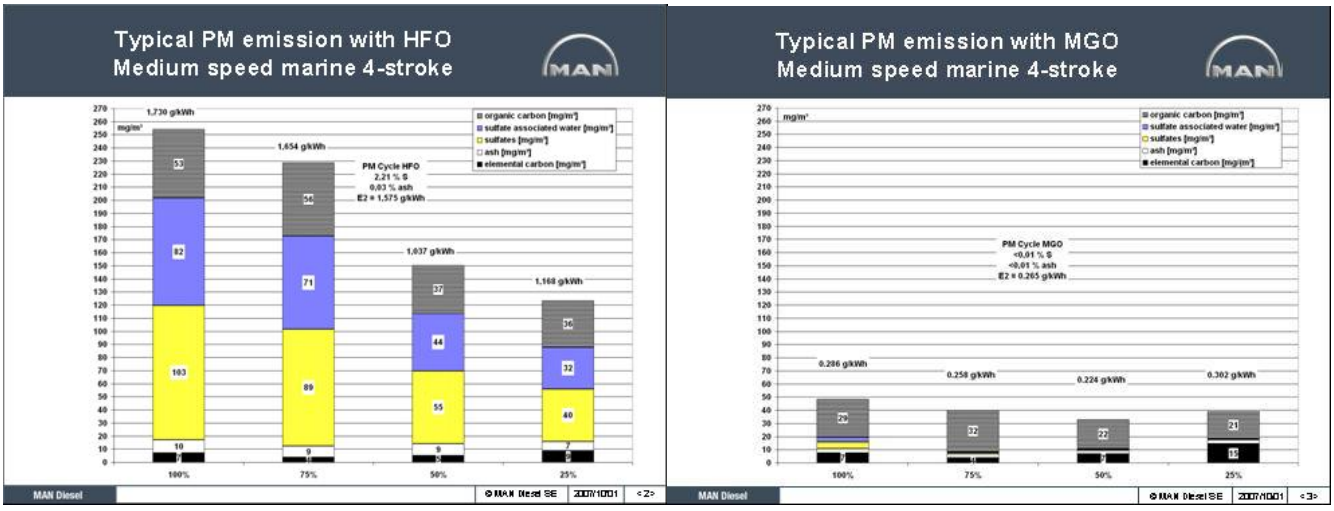


Figure 4-7 Speciated PM from 4-Stroke Medium-Speed Engine (MAN, 2007)

Operating on distillate fuel also reduces the particle count in the exhaust. Lowering the sulfur in the fuel reduces the relative fuel contribution to ultrafine nucleation aerosols by reducing nucleation sites for organic PM. These nucleation particles are the largest contributor to particle number, since the fine particle number count is approximately 1.5 times higher for operation on residual fuel than for operation on distillate fuel. This effect is shown in Figure 4-8.[48,49]

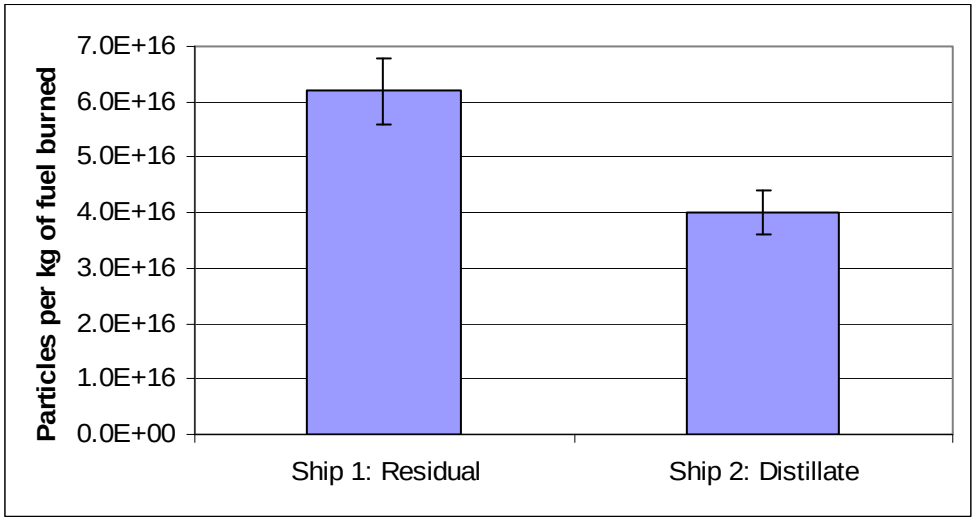


Figure 4-8 Exhaust Particle Concentration for Two Ships

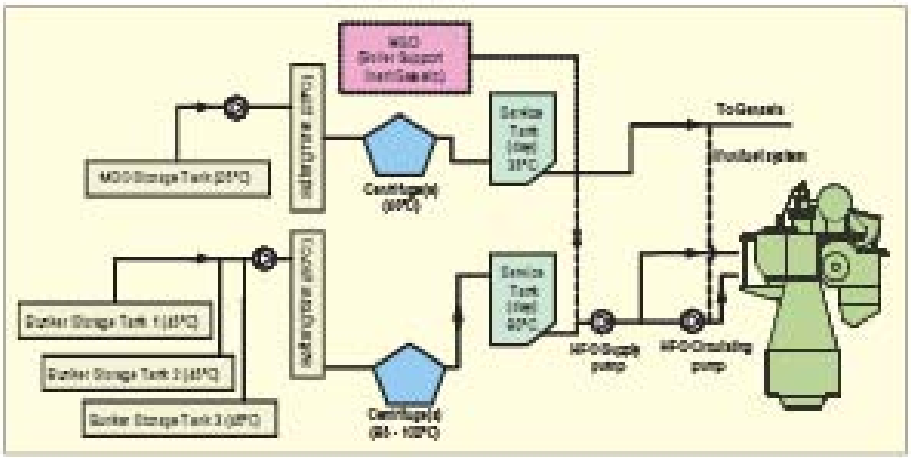
4.4.1.2 Fuel Switching Procedures

Marine distillate fuels are similar in composition and structure to other petroleum based middle distillate fuels such as diesel and No. 2 heating oil, but they have a much lower allowable sulfur content than residual fuels.[50] This lower sulfur content means that by combusting marine distillate fuel in their propulsion engines, vessels operating within the ECA would meet the stricter SO_X requirements. However, sulfur content is not the only difference between the marine residual and distillate fuels; they also have different densities, viscosities, and aromatic contents.

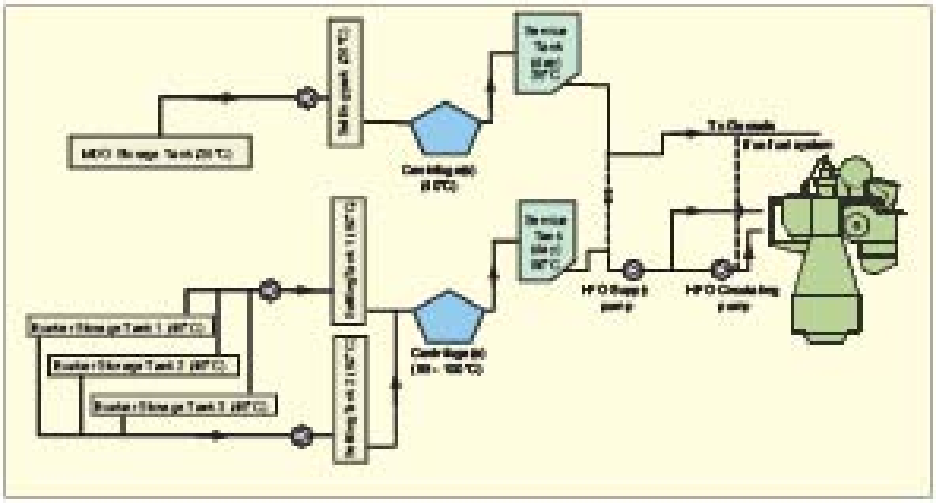
In the majority of vessels today, marine distillate fuel is used for operation during routine maintenance, prior to and immediately after engine shut-down, or in emergencies. Standard procedures today have been established to ensure that this operational fuel switchover is performed safely and efficiently. Mainly, in order for the vessel to completely switch from one type of fuel to another, the fuel pumps and wetted lines will need to be completely purged by the new fuel to ensure that the ship is burning the correct fuel for the area. This purging will vary from ship to ship due to engine capacity, design, operation, and efficiency. Provided the ship has separate service tanks for distillate and residual fuel (most, if not all, vessels do), fuel switching time should be limited only by maximum allowable rate of fuel temperature change,typically not

more than 2°C change per minute. Figure 4-9 presents three common fuel system configurations recommended by a C3 engine manufacturer to facilitate fuel switching.

A.



B.



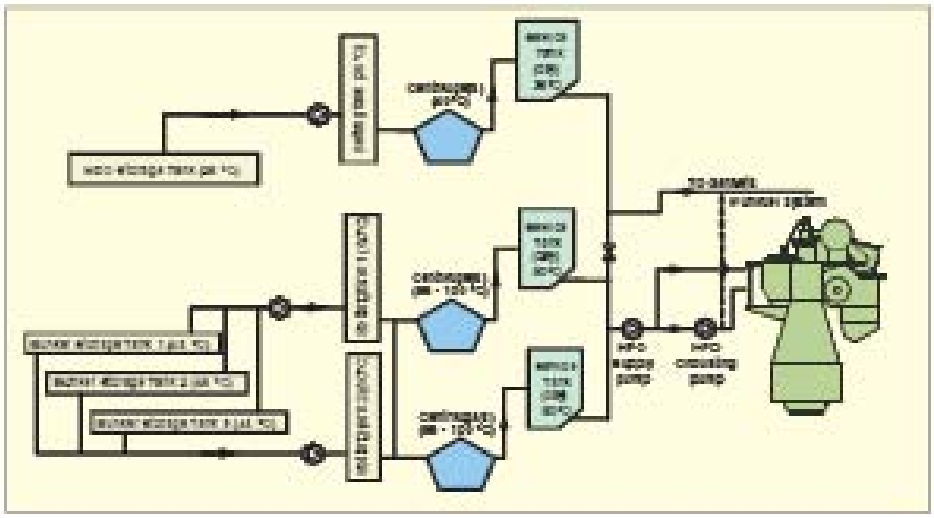
C. 

Figure 4-9 Common C3 Fuel Tank Layouts. A. One MDO and one HFO settling tank, B. One MDO and two HFO settling tanks, C. One MDO settling tank and two sets of HFO settling and service tanks (Courtesy of MAN B&W)

This slow temperature increase will ensure that the fuel's viscosity does not drastically change prior to injection and therefore protects the fuel injection equipment. If the fuel viscosity or temperature is increased too quickly, some of the fuel handling components, such as the fuel valves, pump plungers, or fuel suction valves, could become damaged or 'sticky' and not function correctly. One way to ensure that the fuels are changed out accordingly is to install an automatic system for handling the changeover of different viscosity fuels, as shown in Figure 4-10 from MAN B&W.[34]

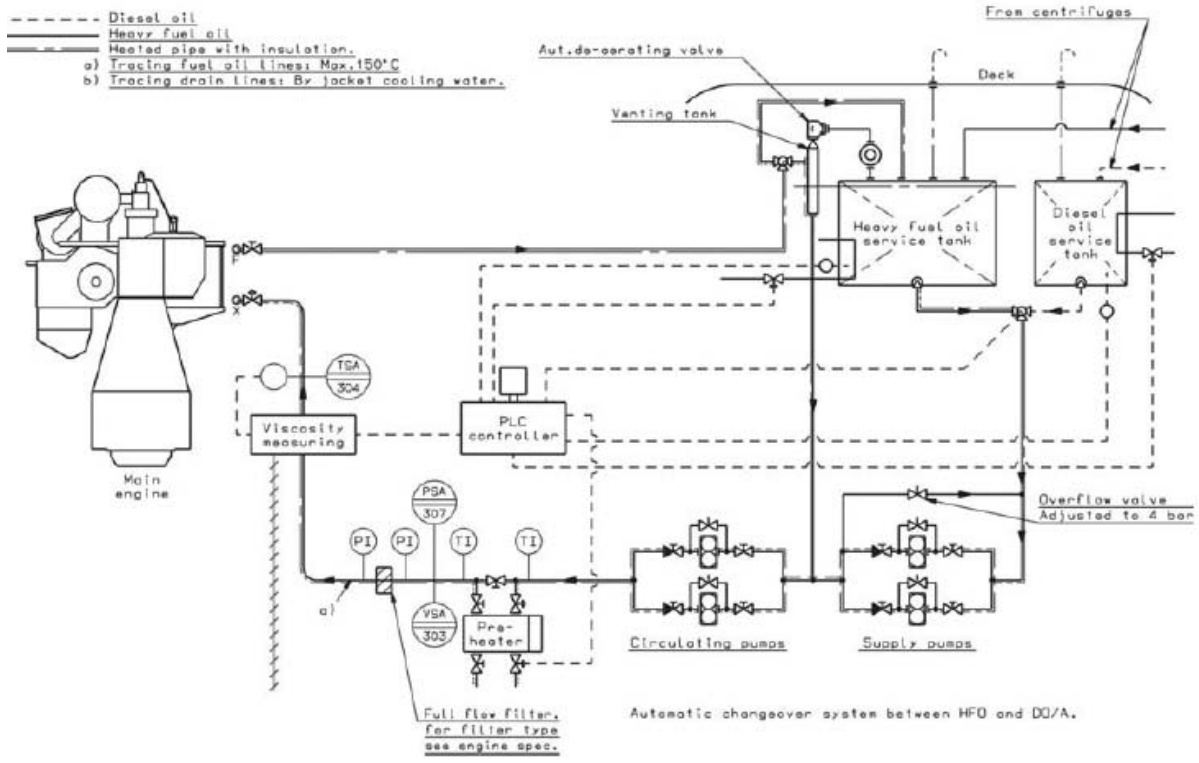


Figure 4-10 Automatic System for Changeover between Fuels of Different Viscosity

The maritime industry has analyzed the differences between the residual and distillate fuel compositions to address any potential issues that could arise from switching operation of a C3 engine from residual fuel to distillate fuel. The results from this research has evolved into routine operational switching procedures that ensure a safe and efficient way for the C3 engines to switch operation between the residual and distillate fuels. A brief summary of the fuel differences, as well as any potential issues and their usual solutions are below.

4.4.1.2.1 Fuel Density

Due to its chemical composition, residual fuel has a slightly higher density than marine distillates. Using a less dense fuel could affect the ballast of a ship at sea and would have to require compensation. Therefore, when beginning to operate on the distillate fuel, the vessel operator would have to pay attention to the vessel's ballast and may have to compensate for any changes that may occur. We anticipate that these procedures would be similar to operating the vessel with partially-full fuel tanks.

Another consideration when switching to a lower density fuel is the change in volumetric energy content. Distillate fuel has a lower energy density content on a per gallon basis when

compared to the residual fuel; however, per ton, distillate fuel's energy density is larger than the residual fuel. This means that when switching from residual fuel to distillate fuel, if the vessel's tanks are volumetrically limited (i.e., the tanks can only hold a set quantity of fuel gallons), the distance a vessel can travel on the distillate fuel may be slightly shorter than the distance the vessel could travel on the residual fuel due to the lower volumetric energy content of distillate fuel, which could require compensation. This distance reduction would be approximately 5% and would only be of concern while the vessel was operating on the distillate fuel (i.e., while in the U.S. ECA) as the majority of the time the vessel will be operating on the residual fuel. However, if the vessel is limited by weight, the higher energy content per ton of fuel would provide an operational advantage.

4.4.1.2.2 Kinematic Viscosity

Residual fuel's kinematic viscosity is much higher than marine distillate fuel's viscosity. Viscosity is the 'thickness' of the fuel. If this parameter is lowered from the typical value used within a pump, some issues could arise. If a distillate fuel with a lower viscosity is used in a system that typically operates on residual fuel, the decrease in viscosity could quickly cause problems with high-pressure fuel injection pumps; whereas older, lower-pressure pumps can develop troubles over a period of time, especially if the pump in question has large clearances and cannot make up the pressure to pump the fuel through with the thinner fuel due to the increased potential for internal leakage of the thinner fuel through the clearances in the pumping elements. Internal leakage is part of the design of a fuel pump and is used in part to lubricate the pumping elements. However, if this leakage rate is too high, the fuel pump could produce less than optimal fuel injection pressures. If the distillate fuel's lower viscosity becomes an issue, it is possible to cool the fuel and increase the viscosity above 2 centistokes, which is how most vessels operate today during routine fuel switchovers as was discussed above. [51,52]

4.4.1.2.3 Flash Point

Flash point is the temperature at which the vapors off the fuel ignite with an outside ignition source. This can be a safety concern if the owner/operator uses an onroad diesel fuel rather than a designated 'marine distillate' fuel for operation because marine fuels have a specified minimum flash point of 60°F to ensure onboard safety, whereas onroad diesel has a minimum specified flash point of 52°F.[53,54] However, since most distillate fuels are created in the same fashion, typical flash points of onroad diesel are above 60°F and would meet the marine fuel specification for this property. If the flash point of the fuel being used on-board the vessel becomes a concern, the operator/bunker supplier would have to ensure that the vessel is obtaining fuel with a minimum flash point of 60°F via the bunker delivery note or through fuel testing.

4.4.1.2.4 Lubricity

Lubricity is the ability of the fuel to lubricate the engine/pump during operation. If the distillate is more 'harsh' (from severely reduced sulfur content or removal of certain chemical structures) than the residual fuel typically used, there can be added friction to the engine/pump which could cause malfunctions and/or failures of equipment. Fuels with higher viscosity and high sulfur content tend to have very good lubricity without the use of specific lubricity

improving additives. Refining processes that lower fuel sulfur levels and their viscosities can also remove some of the naturally-occurring lubricating compounds. Severe hydrotreating of fuel to obtain ultra-low sulfur levels can result in poor fuel lubricity. Therefore, refineries commonly add lubricity improvers to ultra low sulfur diesel. This will most likely become a concern when very low levels of sulfur are present in the fuel and/or the fuel has been hydrotreated to reduce sulfur, e.g., if ultra-low sulfur highway diesel (ULSD) is used in the engine. [55] Several groups have conducted studies on this subject, and for some systems where fuel lubricity has become an issue, lubricity additives can be utilized or the owner/operator can install a lubricating system for the fuel pump.

4.4.1.2.5 Lube Oil

Diesel engines require lubrication in order to operate efficiently, and these lubricating oils need to be compatible with the fuel used in the engine. Lube oil base numbers help to achieve a compatible lubricant between the fuel and the oil. If the lube oil base is too lubricating for the fuel, calcium and other deposits can develop on the surfaces. If the lube base oil is too little of a lubricant for use with the fuel, the fuel's acidity can increase causing additional wear on parts as well as creating problems combusting the fuel. Lube oils are used to neutralize acids formed in combustion, most commonly sulfuric acids created from sulfur in the fuel. The quantity of acid neutralizing additives in lube oil should match the total sulfur content of the fuel. If excessive amounts of these additives are used, they may create deposits on engine components. Marine engine manufacturers have recommended that lube oil only needs to be adjusted if the fuel is switched for more than one week, but the oil feed rate may need to be reduced as well as engine operating power. Additional research has been conducted in this area and several oil companies have been working to create a lubricating oil that would be compatible with several different types of fuel. [56]

4.4.1.2.6 Asphaltenes

Asphaltenes are heavy, non-volatile, aromatic compounds which are contained naturally in some types of crude oil. Asphaltenes may precipitate out of the fuel solution when a fuel rich in carbon disulfide, such as residual fuel, is mixed with a lighter hydrocarbon fuel, such as n-pentane or n-heptane found in some distillate fuels. [57] When these heavy aromatic compounds fall out of the fuel solution, they can clog filters, create deposition along the fuel lines/combustion chamber, seize the fuel injection pump, or cause other system troubles. This risk can be minimized through onboard test kits and by purchasing distillate and residual fuel from the same refiner. However, according to the California Air Resources Board, the formation of asphaltenes is not seen as an issue based on data from previous maritime rules. [58]

As can be seen, if vessel operators choose to operate on marine distillate fuel while in the ECA, some prudence is required. However, as described above, any issues that could arise with switching between residual and distillate fuel are minimal and are relatively easy to address through changes to operating procedures. To conduct a successful switchover between the residual and marine distillate fuels, vessel operators will need to keep the above issues in mind and follow the engine manufacturer's standard fuel switching procedure.

4.4.2 Exhaust Gas Cleaning Systems

Annex VI allows for alternative compliance strategies in including the use of exhaust gas cleaning systems (EGCS). EGCS systems used today for sulfur control are commonly known as SO_X scrubbers.

4.4.2.1 SO_X Scrubber

SO_X scrubbers are capable of removing up to 95 percent of SO_X from ship exhaust using the ability of seawater to absorb SO_X. SO_X scrubbers have been widely used in stationary source applications, where they are a well established SO_X reduction technology. In these applications, lime or caustic soda are typically used to neutralize the sulfuric acid in the washwater. While SO_X scrubbers are not widely used on ocean going vessels, there have been prototype installations to demonstrate their viability in this application such as the Krystallon systems installed on the P&O ferry Pride of Kent and the Holland America Line cruise ship the ms Zaandam.[59, 60] These demonstrations have shown scrubbers can replace and fit into the space occupied by the exhaust silencer units and can work well in marine applications.

There are two main scrubber technologies. The first is an open-loop design which uses seawater as exhaust washwater and discharges the treated washwater back to the sea. Such open loop designs, such as those used on the Pride of Kent and ms Zaandam, discussed above, are also referred to as seawater scrubbers. In a seawater scrubber, the exhaust gases are brought into contact with seawater, either through spraying seawater into the exhaust stream or routing the exhaust gases through a water bath. The SO_2 in the exhaust reacts with oxygen to produce sulfur trioxide which then reacts with water to form sulfuric acid. The sulfuric acid in the water then reacts with carbonate and other salts in the seawater to form sulfates which may be removed from the exhaust. The washwater is then treated to remove solids and raise the pH prior to discharge back to the sea. The solids are collected as sludge and held for proper disposal ashore.

A second type of SO_X scrubber, using a closed loop design, is also feasible for use on marine vessels.[61,62] In a closed loop system, fresh water is used as washwater, and caustic soda is injected into the washwater to neutralize the sulfur in the exhaust. A small portion of the washwater is bled off and treated to remove sludge, which is held and disposed of at port, as with the open loop design. The treated effluent is held onboard or discharged at open sea. Additional fresh water is added to the system as needed. While this design is not completely closed loop, strictly speaking, it can be operated in zero discharge mode for periods of time.

Exhaust gas scrubbers can achieve reductions in particulate matter as well. By removing sulfur from the exhaust, the scrubber removes most of the direct sulfate PM. Sulfates are a large portion of the PM from ships operating on high sulfur fuels. By reducing the SO_X emissions, the scrubber will also control much of the secondary PM formed in the atmosphere from SO_X emissions. However, simply mixing alkaline water in the exhaust does not necessarily remove much of the carbonaceous PM, ash, or metals in the exhaust. While SO_2 associates with the wash water, particles can only be washed out of the exhaust through direct contact with the water. In simple scrubber designs, much of the mass of particles can hide in gas bubbles and escape out the exhaust.

Manufacturers have been improving their scrubber designs to address carbonaceous soot and other fine particles. Finer water sprays, longer mixing times, and turbulent action would be expected to directionally reduce PM emissions through contact impactions. One scrubber design uses an electric charge on the water to attract particles in the exhaust to the water.[63,64] In this design, the exhaust gas is first passed through a preconditioning chamber where a coarse water spray cools the exhaust, removes particles larger than 10 microns and causes very small particles to agglomerate into larger particles. The exhaust gas then moves successively through one or two cloud generation chambers, where highly charged water droplets form a cloud. These droplets serve to attract the particles, and as each water droplet has collected enough tiny particles and thus has its charge neutralized, it coagulates with other droplets and falls to a sump. This liquid is then re-circulated back to the cloud generator and used to form new charged droplets. Finally, the cleaned exhaust passes from the cloud chamber through a mist eliminator to remove excess moisture and out through the exhaust stack. In the dual cloud chamber design, the first chamber contains positively charged water droplets which collect neutral and negatively charged particles. Conversely, the second chamber contains negatively charged water droplets which collect positively charged and remaining neutral particles. Since most particles are neutral, this second chamber would only be utilized in designs requiring very high particle removal efficiency.

In another design, demisters are used that help effectively wash out PM from the exhaust stream.[65] In this design, the exhaust gases are compressed and then expanded in a saturated environment. The expansion process in the supersaturated environment results in condensation and agglomeration of fine particulate, which is then washed from the exhaust stream using a water spray. In either of these PM control system designs, however, the systems would be effective at removing SO_2 from the exhaust even if the additional hardware needed for non-sulfate PM reduction were not used.

Water-soluble components of the exhaust gas such as SO_2, SO_3, and NO_2 form sulfates and nitrates that are dissolved into the discharge water. Scrubber wash water also includes suspended solids, heavy metals, hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). Before the scrubber water is discharged, it may be processed to remove solid particles through several approaches. Heavier particles may be trapped in a settling or sludge tank for disposal. The removal process may include cyclone technology similar to that used to separate water from residual fuel prior to delivery to the engine. However, depending on particle size distribution and particle density, settling tanks and hydrodynamic separation may not effectively remove all suspended solids. Other approaches include filtration and flocculation techniques. Flocculation, which is used in many waste water treatment plants, refers to adding a chemical agent to the water that will cause the fine particles to aggregate so that they may be filtered out. Sludge separated from the scrubber water would be stored on board until it is disposed of at proper facilities.

IMO is developing guidance criteria for the use of exhaust gas cleaning devices, such as SO_X scrubbers, as alternative to operating on low sulfur fuel. This draft guidance, includes monitoring and water discharge practices.[66] The washwater should be continuously monitored for pH, PAH and turbidity. Further, the IMO guidance include specifications for these same items, as well as nitrate content when washwater is discharged in ports, harbors or estuaries.

Finally, the IMO guidance recommends that washwater residue (sludge) be delivered ashore to adequate reception facilities, and not discharged to the sea or burned on board.

Finally, we would not consider an exhaust gas scrubber to be an acceptable control strategy for reducing NO_X emissions. In a typical diesel exhaust gas mixture, NO_X is composed of roughly 5-10% NO_2, with the majority of the remainder in the form of NO. NO_2 is soluble in water, and therefore may be removed by the water in the scrubber. It is possible to treat the exhaust upstream of the scrubber to convert more of the NO_X to NO_2, thereby facilitating the use of a scrubber to remove NO_2. However we are concerned that this would add to nitrogen loading of the water in which the ship is operating. As discussed in Section 2.3.1, nitrogen loading can lead to serious water quality impacts. The issue of NO_X scrubbing is addressed in the draft IMO EGCS guidelines by limiting the amount of NO_X that may be removed by the scrubber.

4.4.2.2 Equivalence to Fuel Switching

MARPOL Annex VI does not present specific exhaust gas limits that are deemed to be equivalent to the primary standard of operating on low sulfur fuel. Prior to the recent amendments to Annex VI, regulation 13 included a limit of 6 g/kW-hr SO_2 as an alternative to the 1.5% sulfur limit for sulfur emission control areas. Under the amended requirements, the specific SO_2 limit was removed and more general language on alternative approaches was included. Specifically, regulation 4 of MARPOL Annex VI now states "The Administration of a Party may allow any fitting, material, appliance or apparatus to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as a alternative to that required by this Annex if such fitting, material, appliance or apparatus or other procedures, alternative fuel oils, or compliance methods are at least as effective in terms of emissions reductions as that required by this Annex, including any of the standards set forth in regulations 13 and 14."

Based on the methodology that was used to determine the SO_2 limit of 6.0 g/kW hr for existing ECAs, the corresponding limit, which is presented in the draft ECGS guidelines, would be 0.4 g/kW-hr SO_2 for a 0.1% fuel S limit. This limit is based on an assumed fuel consumption rate of 200 g/kW-hr and the assumption that all sulfur in the fuel is converted to SO_2 in the exhaust. This calculation is presented in the following equation:

$$SO_2\ [g/kW\text{-}hr] = BSFC \times \text{fuel S} \times \text{conversion} \times MWR_{SO2/S}$$
$$= 200 \times 0.1\% \times 100\% \times 64/32$$
$$= 0.4\ g/kW\text{-}hr, \text{ where:}$$

BSFC = brake specific fuel consumption = 200 g/kW-hr
fuel S = fuel sulfur level (weight percent) = 0.1%
conversion = percentage of sulfur in fuel that is converted to SO_2 = 100%
$MWR_{SO2/S}$ = molecular weight ratio of SO_2 to sulfur = 64/32

The draft EGCS guidelines also use an approach of basing the limit on a ratio of SO_2 to CO_2. This has the advantage of being easier to measure during in-use monitoring. In addition, this ratio holds more constant at lower loads than a brake-specific limit, which would approach infinity as power approaches zero. For the 1.5% fuel sulfur limit, a SO_2 (ppm)/CO_2(%) limit of 65 was developed.[67] As with the equation above, the simplifying assumption is made that all

fuel sulfur is converted to SO_2 and all carbon is converted to CO_2. The equivalent limit for 0.1% fuel sulfur presented in the ECGS guidelines is 4.0 SO_2 (ppm)/CO_2(%).

SO_2/CO_2 [ppm/%] = (fuel S / fuel C) × 10,000 × $MWR_{C/S}$
= (0.1% / 86.3%) × 10,000 × 12/32
= 4.0 ppm/%, where:

fuel C = fuel carbon level (weight percent) for distillate fuel
= (100% - 0.1%S – 0.03% other) × (MW_H × H/C)/(MW_C + MW_H × H/C) [A]
= 86.3%
10,000 = conversion from percent to ppm
$MWR_{C/S}$ = molecular weight ratio of carbon to sulfur = 12/32

Scrubbers are effective at reducing SO_2 emissions and sulfate PM emissions from the exhaust. However, as discussed above, the effectiveness of the scrubber at removing PM emissions, other than sulfates, is dependent on the scrubber design. In addition to sulfate PM reductions, switching from residual fuel to distillate fuel results in reductions in organic PM and metallic ash particles in the exhaust. Clearly, scrubbers can be designed to provide similar reductions in such non-sulfate PM emissions if need be to provide equivalent reductions compared to fuel switching.

We would not consider an exhaust gas scrubber to be an acceptable control strategy for reducing NO_X emissions. In a typical diesel exhaust gas mixture, NO_X is composed of roughly 5-10% NO_2, with the majority of the remainder in the form of NO. NO_2 is soluble in water, and therefore may be removed by the water in the scrubber. It is possible to treat the exhaust upstream of the scrubber to convert more of the NO_X to NO_2, thereby facilitating the use of a scrubber to remove NO_2. However we are concerned that this would add to nitrogen loading of the water in which the ship is operating. As discussed in Chapter 2, nitrogen loading can lead to serious water quality impacts. The issue of NO_X scrubbing is addressed in the draft IMO EGCS guidelines by limiting the amount of NO_X that may be removed by the scrubber.

4.5 Technology for Producing/Distributing Lower Sulfur Fuel

4.5.1 Production of Lower Sulfur Marine Fuel

We project that the 1,000 ppm fuel sulfur limit, beginning in 2015, will likely result in the increased use of distillate fuel for operation in ECAs. As such, additional distillate fuel will likely be necessary to replace the residual fuel that would have been used without an ECA. Some engines already operate on distillate fuel; however, this distillate fuel may need to be further refined to meet the 1,000 ppm S limit.

[A] Fuel properties are based on properties in the IMO NO_X monitoring guidelines, MEPC.103(49) which includes a hydrogen to carbon (H/C) ratio for distillate fuel of 1.88 mol/mol. In addition, fuel is assumed to be composed of carbon, hydrogen, sulfur, and other, where other is assumed to be 0.03 weight % for distillate fuel. (MW_H =1.008, MW_C = 12.01)

4.5.1.1 Processing of Residual Stocks

IFO bunker grades are primarily comprised of residual stocks, such as Vacuum Residuals, Atmospheric Residuals, Visbreaker Residuals, and Fluidized Catalytic Cracking (FCC) clarified oil. These fuels also contain distillates that are added as cutter stocks, such as Light Cycle Oil (LCO), Vacuum Gas Oils (VGO), and kerosenes. As such, only the residual fuel blendstocks in IFO bunkers would need to be replaced or converted into distillate volumes to provide for additional lower sulfur distillate marine fuel. For converting residuals to distillates, refiners use two process technologies: Coking Units (Cokers) and Residual Hydrocrackers.

Coking units are used to convert the poorer quality residual feedstocks in IFO bunkers, such as vacuum residuals. The coking units crack these resids into distillates, using heat and residence time to make the conversion. The process produces petroleum coke and off gas as byproducts. Residual hydrocrackers are used to convert low and medium sulfur residual streams into distillates. Residual hydrocracking uses fluidized catalyst, heat and hydrogen to catalytically convert residual feedstocks into distillates and other light fuel products. The hydrocracking process upgrades low value residual stocks into high value distillate transportation fuels consuming large amounts of hydrogen.

For processing of residual blendstocks, vacuum tower distillation capacity is added to extract gas oils blendstocks that exist in residuals fuels used in current IFO bunker grades. The extracted gas oils are further processed in either distillate hydrotreaters or gas oil hydrocrackers to produce a distillate fuel that would meet a 1,000 ppm fuel sulfur limit. The use of additional vacuum towers capacity minimizes the volume of residual stocks which lowers processing costs, as less volume of fuel is processed in high cost residual coking and residual hydrocracker processes.

4.5.1.2 Distillate Stocks Processing

Conventional distillate hydrotreating technology is used to lower the sulfur levels of high sulfur distillate stocks. This technology removes sulfur compounds from distillate stocks using catalyst, heat and hydrogen. Since the ECA sulfur standard is 1,000 ppm, conventional distillate hydrotreating would likely be the technology chosen by refiners to make this distillate, rather than the ultra low sulfur technology that is used to remove sulfur to levels below 15 ppm. Conventional distillate hydrotreating refers to the design and conditions in the process, such as catalyst type, catalyst volume, reactor pressure, feed and reactor flow scheme used to lower sulfur levels to 500 ppm or higher.

Although the cutter stocks in IFO bunkers are distillate fuels, they would need to be desulfurized because the 1,000 ppm sulfur limit for the ECA is lower than the nominal sulfur levels for these blendstocks under the “business as usual” projections. The sulfur levels of distillate used directly as bunker fuel (MDO and MGO), are greater than 1,000 ppm, and thus would also need to be treated. Therefore, in addition to converting residuals to distillate fuels, existing distillates used as bunker fuel in MDO, MGO and IFO would also need to be hydrotreated. More distillate hydrotreating capacity would be required to lower the sulfur content of incremental distillate produced from cokers and residual hydrocrackers that do not meet low sulfur marine fuel standards.

For distillate stocks that are highly aromatic and high in sulfur, the use of technology for hydrocracking low sulfur gas oil is used to convert these blendstocks into No 2. grade diesel streams. Gas oil hydrocracking is a high volume gain process which produces diesel blendstocks that typically meet ECA sulfur standards, eliminating the need for further processing in hydrotreaters.

4.5.1.3 Supportive Processes

The increase in hydrotreating and hydrocracking requires new hydrogen and sulfur plant capacity. Extra hydrogen is required to react with and remove sulfur compounds in refinery hydrotreating processes. It is also needed to improve the hydrogen to carbon ratio of products made from converting IFO blend components to distillates, via processing in cokers and hydrocrackers.

4.5.2 Fuel Distribution Considerations

The existing nonroad, locomotive, and marine (NRLM) diesel fuel program requires that all marine diesel fuel meet a 15 ppm sulfur standard by June 1, 2014 except fuel produced by transmix processors which is allowed to meet a 500 ppm sulfur standard indefinitely, and fuel with a T90 distillation point greater than 700 ^{0}F when used in Category 2 or 3 marine diesel engines to which no EPA sulfur standard currently applies.[B] The proposed provisions in today's rule would adopt a 1,000 ppm sulfur standard for fuel sold for use in an emission control area (ECA) as defined by the International Maritime Organization under MARPOL Annex VI. The U.S. Government has proposed an amendment to MARPOL Annex VI to establish an ECA that would include the majority of U.S. coastal waters. Assuming the adoption of an amendment to MARPOL Annex VI establishing a U.S. ECA, the proposed 1,000 ppm C3 marine sulfur standard would become effective January 1, 2015.

Due to the nature of the refinery options to reduce the sulfur content of fuel used in C3 engines, we believe that the fuel manufactured to meet a 1,000 ppm sulfur specification would likely have a T90 below 700 ^{0}F, and thus would be subject to the requirements under the existing NRLM diesel program.[C] Therefore, changes are needed to existing NRLM diesel program to facilitate the adoption of a 1,000 ppm sulfur standard for C3 marine under MARPOL Annex VI. Without such changes, the implementation of a 1,000 ppm C3 diesel sulfur standard would actually result in the requirement for the use of 15 ppm diesel fuel in C3 marine engines.

The current provisions that allow transmix processors to continue to produce 500 ppm locomotive and marine (LM) diesel fuel after June 1, 2014 were put in place to allow an outlet for >15 ppm sulfur diesel fuel produced at transmix processors other than heating oil. These special provisions were deemed to be necessary due to challenges associated with desulfurizing diesel fuel produced at transmix processing facilities to a 15 ppm sulfur standard and the

[B] The existing marine diesel fuel standards and the proposed C3 marine sulfur standards are discussed in more detail in Section IV of today's preamble.
[C] The production of fuel meeting a 1,000 ppm sulfur standard for use in C3 marine engines is discussed in Section 4.5.1 of this DRIA.

geographically limited and seasonal nature of the heating oil market. Transmix processing facilities consist of a simple distillation column with no other facilities for modifying the resulting gasoline and diesel fractions such as a hydrotreater to remove sulfur.[D] The small throughput of transmix processing facilities is not sufficient to justify the installation of current sulfur removal units (such as a hydrotreater).

In the process of shipping products by pipeline, mixing takes place between batches of gasoline and distillate products that abut each other in the pipeline. This material (referred to as transmix) must be re-processed to make it suitable for use. The vast majority of transmix volume originates from pipeline shipments, although some is also generated during other fuel distribution activities such as when the same fuel handling and storage equipment is alternatively used for gasoline and distillate fuels. Transmix volumes typically gather towards the end of pipeline systems which are commonly distant from refineries. Transmix processors are typically located at these downstream pipeline locations to provide a means of coping with transmix volumes that would otherwise present logistical difficulties to return to refineries for reprocessing. Although transmix that is generated near refineries is sometimes returned to the refinery for reprocessing, introducing large volumes of transmix into the distillation column at a refinery can cause problems in the management of the output from this unit.[E] Hence, refiners would face difficulties in absorbing all of the transmix generated in the distribution system even absent the logistical hurdles.

The use of 500 ppm LM diesel fuel was limited to outside of the Northeast Mid-Atlantic (NE/MA) and Alaska area after 2014 because it was concluded that heating oil provided a sufficient outlet for >15 ppm diesel fuel from transmix processors within the NE/MA area and Alaska. To support the continued use 500 ppm LM diesel fuel outside the NE/MA area and AK, additional requirements were put in place to prevent distillate initially produced as heating oil to be inappropriately shifted into the 500 ppm LM diesel pool during distribution. Specifically, heating oil and 500 ppm LM diesel are required to be designated and tracked (D&T) throughout the distribution system up to the point where the fuel leaves the terminal. Handlers of these fuels in the distribution chain are further required to file a report with EPA on an annual basis to demonstrate that heating oil was not inappropriately shifted into the 500 ppm LM diesel pool. These requirements continue indefinitely after 2014 for all parties in the distribution chain that handle heating oil and/or 500 ppm LM diesel fuel. We estimated that a many as 1,000 parties in the distribution system may be affected by these recordkeeping and reporting requirements at an annual cost of approximately $2.6 million.[68]

Before heating oil leaves the terminal, the solvent yellow 124 (SY-124) marker is required to be added in order to continue to prevent its introduction in the 500 ppm LM diesel pool given that the D&T and reporting requirements were not practical to implement downstream of the terminal level. Given that most heating oil use takes place in the NE/MA area

[D] High octane gasoline blendstocks are sometimes blended into the gasoline fraction produced at a transmix processor to restore it to a marketable octane level. This is sometimes necessary because the heavier ends that normally exist in gasoline (which are high in octane) are typically cut into the distillate fraction during transmix distillation.

[E] Distillation columns at refineries are tuned to handle crude oil that has a much broader boiling range than transmix.

and AK, the exclusion of 500 ppm LM diesel fuel from the NE/MA and AK after June 1, 2014 and the accompanying exemption from heating oil marker requirement in these areas substantially limited the amount of heating oil that would need to be marked. This substantially limited the costs associated with installing equipment to store/inject the marker at the terminal and the cost of the marker itself. We estimated that 1.4 billion gallons of heating oil would need to be marked each year at an annual cost of $425 thousand.[69]

The accommodation of 1,000 ppm C3 diesel fuel within the framework of the NRLM program affords an opportunity to potentially simplify the requirements under the NRLM program. We believe that the creation of a 1,000 ppm C3 marine diesel grade in combination with the continued demand for heating oil may provide a sufficient outlet for >15 ppm diesel fuel produced by transmix processors. Thus, under the primary option in today's notice, we are proposing to eliminate the allowance for the continued production of 500 ppm LM diesel fuel by transmix processors. This would allow the tracking, reporting, and marker requirements for heating oil to be eliminated after June 1, 2014, which would result in a significant reduction in the cost of compliance for a number of parties in the fuel distribution system. Since there would be no limitation on the amount of 1,000 ppm C3 diesel that could be produced, and given the absence of a limited 500 ppm LM diesel pool, the sulfur content alone would be sufficient to differentiate 1,000 C3 diesel fuel from other distillate fuels (in order to facilitate compliance oversight by EPA).[F]

Removing the potential outlet to the locomotive and C2 marine markets, while opening a new outlet to the C3 marine market would affect the distribution pathways for >15 ppm diesel fuel produced at transmix processors. We believe that transmix generated near the coasts would have ready access to marine applications, and transmix generated in the mid-continent could be shipped via rail, pipeline, or other means to C3 marine and heating oil markets on the coasts. We requested comment on this, and plan to further evaluate whether some transmix processors might face difficulties in shipping their distillate product to market in the absence of an outlet to the locomotive and marine users.

There may be some increase in the cost of distributing some portion of the >15 ppm diesel fuel produced by transmix processors while in other cases there may be decrease in distribution costs. It is useful to compare the potential savings from the elimination of the D&T requirements needed to support the 500 ppm LM transmix provisions to the potential increase in distribution cost for such fuel if the outlet to the LM diesel fuel market was eliminated. To facilitate this comparison, we assumed that 430 million gallons a year of transmix generated 500 ppm diesel fuel would be used in LM applications. This is 40% of the total annual transmix volume. The remaining transmix is assumed to be consumed in the heating oil market or returned to a refinery for reprocessing. Dividing the annual potential savings (~$3 million) by the annual volume of transmix-generated 500 ppm distillate estimated to be used in LM results in approximately 1 cent per gallon. Thus, if the distribution costs for 500 ppm diesel fuel produced at transmix processors increased by 1 cent per gallon as a result of the proposed amendments, the

[F] Internal Revenue Service (IRS) red dye requirements to differentiate non-taxed diesel fuel will continue to apply.

overall net cost would be neutral. We believe that the overall impact to the distribution costs for 500 ppm transmix-generated diesel fuel would be less than 1 cent per gallon.

We anticipate that the introduction of a 1,000 ppm C3 marine fuel grade would not cause the need for a significant number of additional storage tanks or transport vessels (rail cars, tank trucks, and barges). Downstream of the producer, we expect the same distribution equipment would be used. In certain instances where the distribution pathway may need to be altered to accommodate a switch from the locomotive and C2 marine market to the C3 marine market, it may be necessary to introduce an additional trans-loading step from rail car to tank truck. However, we believe that such trans-loading could be accomplished at existing trans-loading facilities at rail yards. The improved flow-ability of 1,000 ppm diesel fuel over current C3 marine fuels (which sometimes requires heating to maintain flow-ability), may simplify the handling of C3 marine fuels. The likely fungibility of 1,000 ppm C3 marine fuels with heating oil may also facilitate its distribution in areas where heating oil is shipped in bulk (primarily the Northeast). Based on the above discussion, we expect that the introduction of a 1,000 ppm C3 marine fuel grade and the elimination of 500 ppm transmix processor LM diesel fuel post 2014 with the associated streamlining of the diesel program compliance requirements would result in a reduced costs to the industry as a whole.

We do not anticipate that the lack of access to 500 ppm LM diesel fuel produced at transmix processors would pose a difficulty to locomotive and C2 marine end users given the widespread availability of 15 ppm diesel fuel. Instead of being the consumers of fuel produced at transmix processors, locomotive and C2 marine operators would likely be an important means of bringing such fuel to the C3 market.

Two potential alternative options were identified to the primary proposed option discussed above. Under the first option, the NE/MA area would be expanded to cover all U.S. coastal areas included in the emission control area defined under MARPOL Annex VI. Consistent with the current provisions in the NE/MA area, 500 ppm LM diesel fuel produced by transmix processors could not be used in the expanded NE/MA area. This would afford a greater potential for transmix processors to market their >15 ppm diesel fuel by maintaining a substantial outlet to the LM market. We would likely pursue such an option only if additional input from industry indicates that the primary proposed option would substantially limit transmix processors ability to market >15 ppm diesel fuel. The adoption of this option would forgo the substantial simplification of EPA's diesel program requirements under the primary proposed option. Furthermore, additional tracking and volume balance requirements (similar to those for heating oil) would be needed for 1,000 ppm C3 marine fuel to prevent the inappropriate shifting of fuel manufactured as 1,000 ppm C3 marine fuel (but actually meeting a 500 ppm sulfur standard) to the limited 500 ppm LM diesel pool.

Under the second option, the existing provisions to facilitate the use of 500 ppm LM diesel fuel post 2014, including the existing NE/MA provisions, would be retained as is. This would require the most augmentation to the existing diesel fuel program in order to ensure that of fuel manufactured as 1,000 ppm C3 marine fuel would not be inappropriately shifted to the 500 ppm LM diesel pool. In addition to the need for C3 marine fuel tracking and balance provisions (as under the first alternative option), a unique marker would be needed to differentiate C3 marine fuel (or at least C3 marine fuel that had a sulfur content of 500 ppm and less) from 500

ppm LM diesel fuel downstream of the terminal level. We are not aware of any suitable markers for this task. Such a marker would need to be compatible with, and distinguishable from, the red dye required by IRS as well as well as other in-use fuel and fuel system components. Furthermore, we anticipate that the added cost and complexity of a new marker for C3 marine diesel fuel might be a substantial deterrent to the 1,000 ppm marine diesel fuel. If this were the case, 15 ppm might largely be used for the purpose, and transmix processors would find a more limited market for their >15 ppm distillate.

4.6 Impact on Safety, Noise, and Energy

We do not anticipate any impact on vessel safety or noise due to the engine-based emission control technologies which we anticipate manufacturers will use to meet the proposed Tier 2 and Tier 3 standards. Some of these technologies are incremental improvements to existing engine components, and many of these improvements have already been applied to similar engines. Based on numerous data from automotive, truck, and marine industries, we do not anticipate that SCR technology will impact vessel safety or noise.

No new impacts are anticipated on the energy supply due to the proposed rule. We anticipate that the Tier II NO_X standards required by Annex VI of the International Convention for the Prevention of Pollution from ships will result engine modifications which may result in approximately a 2% fuel penalty. The 2020 increase in fuel consumption (in U.S. inventory domain) due to 2% Tier II penalty is roughly 1,700 barrels per day (BPD) (250 BPD from U.S. vessels). The use of SCR to meet Tier III NO_X standards may provide the opportunity to offset this fuel penalty when vessels are operating in an ECA by recalibrating the engine when the SCR is operating and relying on the SCR unit to achieve the full NO_X reduction. Because we are not proposing requirements that would necessitate further engine or vessel modifications beyond what is anticipated to meet the Annex VI requirements, this rule would not significantly affect the energy use, production, or distribution beyond what is required by Annex VI.

Similarly, we are not proposing to establish new fuel sulfur standards beyond what is necessary under the Annex VI requirements for marine fuels in this action; therefore no increase in energy use during fuel refining is anticipated. However, under the coordinated strategy, increased demand for distillate fuel in the ECA would increase the volume of crude oil needed in global refinery processes. This is discussed in Chapter 5. As shown in Table 5-36, the total refinery crude throughput in 2020 would increase by nearly 0.1 million BPD, leading to a corresponding increase in crude oil supply.

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CHAPTER 5: ENGINEERING COST ESTIMATES

CHAPTER 5: Engineering Cost Estimates

In this chapter, we present the projected cost impacts associated with the coordinated emission control strategy for Category 3 vessels including the engine and fuel standards described in this proposal and those that would apply in the U.S. ECA.[A]

We estimate the costs of the coordinated strategy to be approximately $1.85 billion in 2020, increasing to $3.11 billion in 2030.[B] Of the 2020 costs, nearly 89 percent or $1.64 billion are attributable to ECA fuel sulfur provisions which include the costs incurred by both U.S. and foreign-flagged vessels. The total operational costs are estimated to be $1.82 billion in 2020, which include fuel sulfur controls, a two percent fuel consumption penalty associated with Tier 2 and global Tier II NO_X standards, and the use of urea on vessels equipped with selective catalytic reduction (SCR) to meet Tier 3 and global Tier III NO_X standards. The costs to apply engine controls to U.S.-flagged vessels are expected to be $31.9 million in 2020, increasing to $47.4 million in 2030 as more ships are built to comply with CAA Tier 3 NO_X limits.

When attributed by pollutant, at a discount rate of 3 percent from 2010 through 2040, the NO_X controls are expected to cost about $510 per ton of NO_X reduced, SO_X controls are expected to cost about $930 per ton of SO_X reduced, and the PM controls are expected to cost about $7,950 per ton of PM reduced ($500, $920, and $7,850 per ton of NO_X, SO_X, and PM respectively, at a net present value of 7 percent over the same period.) These costs are comparable to our other recently-adopted mobile source programs, and are one of the most cost effective programs in terms of NO_X and PM when compared to recent mobile and stationary programs. The coordinated strategy also provides very cost effective SO_X reductions comparable to the Heavy-Duty Nonroad diesel rulemaking.

The estimated costs presented in this chapter are for the entire coordinated strategy, including those requirements that are the subject of this proposal and those that are associated with the proposed ECA designation. The costs of the coordinated strategy consists of the costs associated with the MARPOL Annex VI global standards that we are implementing through APPS, some of which we are also adding to our CAA emission control program for U.S. vessels (Tier 2 and Tier 3 NO_X emission control hardware for U.S. vessels; operating costs for the Tier 2 NO_X requirements; controls for existing vessels; certain compliance requirements). Also included are the costs associated with the U.S. portion of the ECA package (Tier 3 operating costs; fuel sulfur hardware and operating costs). Note that the proposal to amend Annex VI to designate U.S. coasts is a separate action and is not part of this rulemaking. Also note that the costs associated with the Canadian portion of the ECA package are not included in the costs of the coordinated strategy.

[A] We use the term “engineering costs” to differentiate from “social costs.” Social costs are discussed in Chapter 7 of this RIA. For simplicity, the terms “cost” and “costs” throughout the discussion in this Chapter 5 should be taken as referring to “engineering costs.”

[B] The costs totals reported in this NPRM are slightly different than those reported in the ECA proposal. This is because the ECA proposal did not include costs associated with the Annex VI existing engine program, Tier II, or the costs associated with existing vessel modifications that may be required to accommodate the use of lower sulfur fuel. Further, the cost totals presented in the ECA package included Canadian cost estimates.

The regulatory changes proposed for Category 1 and 2 engines are not included in this cost analysis as they are intended to be compliance flexibilities and not result in increased compliance costs. Similarly, the technical amendments proposed for other engines, would not have significant economic impacts and are therefore not addressed here. Finally, compliance costs for gas turbine engines are not addressed separately because they would be similar to those for diesel marine engines.

A more detailed description of the components of the coordinated strategy that are included in this cost analysis is presented in Section 5.1of this chapter. Section 5.2 describes the methodology used to estimate the hardware and operating costs, including the development of a representative future fleet and predicted sales volumes to which these hardware and operating costs are applied. Sections 5.3 and 5.4 present the estimated hardware costs of the individual engine technologies we expect manufacturers to use to comply with the emissions standards for new and existing engines, along with a discussion of the associated fixed costs of these technologies such as research and development, tooling, and certification. Section 5.5 describes vessel hardware and fixed costs that may be incurred by some vessels to accommodate the use of lower sulfur fuel. Section 5.6 presents our estimate of changes in vessel operating costs that may result from the coordinated strategy, including estimated fuel production costs. Section 5.7 presents the total estimated cost of the coordinated strategy to U.S.- and foreign-flagged vessels, and finally Section 5.8presents the cost effectiveness of this program.

This analysis relies on a number of assumptions about the prices of various engine and fuel hardware components, as well as fuel consumption, the number of affected vessels, and their operation. As noted in the preamble for this proposal, we seek comment on all aspects of this analysis, including all of these assumptions and the methodology we used to estimate the costs of the program.

All costs presented in this chapter are in 2006 dollars.

5.1 Components of Coordinated Strategy Included in this Analysis

This analysis estimates the costs associated with all components of the coordinated strategy. These include the costs of the proposed Clean Air Act (CAA) Tier 2 and Tier 3 emission standards for U.S.-flagged vessels, operational costs associated with the global Tier II and Tier III standards for foreign-flagged vessels operating in the ECA, and the ECA fuel sulfur requirements. We also include Clean Air Act compliance costs that will apply only to new U.S. vessels for verification testing after engine installation (PLT). The fuel program changes are implementation provisions and do not impose compliance costs but, instead, may reduce the costs for fuel distributors of complying with EPA's distillate diesel standards.

While there is significant overlap between the coordinated strategy and our proposal for ECA designation, the total costs associated with these two programs are not identical. The differences between the two programs are set out in Table 5-1. The estimated costs for the coordinated strategy include hardware costs for new U.S.-flagged vessels to comply with the CAA Tier 2 and Tier 3 engine standards, and for existing U.S.-flagged vessels to comply with the MARPOL Annex VI existing engine requirements. Costs are also included for hardware changes associated with switching to 1,000 ppm sulfur fuel for certain new and existing U.S.-

flagged vessels. The cost analysis includes all of these hardware costs even though some of the benefits from using these emission control systems will occur outside the United States. Conversely, we do not include any new vessel Tier 3 or fuel hardware costs for foreign vessels that operate in U.S. waters even though a significant share of the benefits of the coordinated strategy will arise from foreign vessels that comply with the ECA engine and fuel sulfur limits while operating within the U.S. ECA. An alternative approach would be to allocate a portion of hardware costs of complying with the Tier 3 NO_X standards and the fuel sulfur limits to the coordinated strategy. For example, analysis of MARAD port entrance data shows that about 30 percent of the vessels that enter U.S. ports account for about 75 percent of the vessel entrances. This suggests it may be reasonable to allocate the hardware costs for 30 percent of the new foreign vessels to the coordinated strategy. Similarly, it may be reasonable to discount the share of estimated hardware costs included in the coordinated strategy costs for those U.S. vessels that do not operate primarily between two U.S. ports. As noted in the preamble for this proposal, we are requesting comment on the allocation of hardware costs and on whether the U.S. should adopt the alternative approach described above or some other method to allocate these costs.

The estimated costs for the coordinated strategy also includes operating costs for U.S. and foreign vessels while operating in the inventory modeling domain, which includes the proposed ECA. These increased operating costs include changes in fuel consumption rates, the differential increase in fuel costs, and the use of urea for engines equipped with SCR. There are also Clean Air Act compliance costs that will apply only to new U.S. vessels for verification testing after engine installation (PLT). The fuel program changes are implementation provisions and do not impose compliance costs but, instead, may reduce the costs for fuel distributors of complying with EPA's distillate diesel standards.

Estimated costs for the proposed ECA designation, on the other hand, include hardware costs for both U.S. and foreign vessels to meet the ECA Tier III NO_X and fuel sulfur limits and operating costs associated with using those systems within the ECA domain. Although we included the entire hardware cost for all vessels, these vessels will likely operate in other existing or yet-to-be-designated ECAs in Europe or Asia, and therefore it may have been more appropriate to allocate only a portion of those hardware costs.

Table 5-1 Costs Associated with the Coordinated Strategy and U.S./Canadian Proposal to IMO for ECA Designation

PROGRAM ELEMENT		COORDINATED STRATEGY AND U.S. ECA	CANADIAN ECA
Hardware – T2 (variable costs; fixed costs applied in 2010)	US vessels	$3,310,000	NA – not part of ECA
	Foreign Vessels	N/A – global std	NA – not part of ECA
Hardware – T3 (variable costs; fixed costs recovered in the year in which they occur: 2011-15)	US vessels (variable costs; fixed costs recovered in the year in which they occur: 2011-15)	$28,700,000	$100,000,000
	Foreign vessels: 30% of vessels making 75% of entrances to US ports[a]	$296,700,000	
	Foreign vessels: 70% of vessels making 25% of entrances to US ports[a]	$692,200,000	
Hardware – Fuel	US vessels (new vessel costs)	$804,000	$10,000,000
	Foreign vessels (new vessel costs)	$23,600,000	
Operating – T2 (inside full inventory modeling domain)	US vessels	$5,630,000	NA – not part of ECA
	Foreign vessels	$32,900,000	NA – not part of ECA
Operating – T3 (inside relevant part of ECA)	US vessels	$15,800,000	$30,000,000
	Foreign vessels	$127,000,000	
Operating – Fuel (inside relevant part of ECA)	US vessels	$210,000,000	$260,000,000
	Foreign vessels	$1,430,000,000	
Existing vessels – engine costs (all US vessels 1990-99 retrofit during first 5 years of program, 2011-15)	US vessels	$0	NA – not part of ECA
	Foreign vessels	N/A – global std	NA – not part of ECA
Existing vessels – vessel fuel switching costs (all US vessels 1999-90 retrofit during first 5 years of program, 2011-15)	US vessels	$0	Canada did not provide
	Foreign vessels	$0	Canada did not provide

Note:

[a] Note the RIA reports $1,010,000,000 in engine costs for foreign vessels; this includes the costs of production line testing which is not applicable to foreign vessels under our CAA program. This element is not included in the estimated costs for the Coordinated Strategy; we will revise the RIA.

The proposed CAA Tier 2 and Tier 3 NO_X standards will not result in costs to U.S. vessels above or beyond those costs that will already be experienced through compliance with the Tier II and Tier III NO_X standards contained in Annex VI. In addition, we are not proposing NO_X standards for foreign-flagged vessels, nor are we proposing requirements for the use of lower sulfur fuel. However, the U.S. Government was a key participant in the development of the new Annex VI NO_X emission standards and fuel sulfur limits. As such, we are interested in quantifying the costs and benefits associated with the coordinated strategy.

5.2 Methodology for Estimating Engine and Equipment Engineering Costs

To estimate the cost of the coordinated strategy for ensuring that all ships that affect U.S. air quality will be required to meet stringent NO_X and fuel sulfur requirements, we estimated the hardware and operational costs to both U.S.- and affected foreign-flagged ships separately. The hardware costs are only applied to U.S.-flagged vessels, and include those associated with the Annex VI existing engine program, Tier 2, Tier 3, and the use of lower sulfur fuel. For the sake of completeness, however, estimated hardware costs for foreign-flagged vessels associated with global Annex VI Tier III standards and additional hardware that may be required to accommodate the use of lower sulfur fuel are presented here as a separate analysis. Tier 2 hardware costs are expected to consist of changes to the engine block and the migration from mechanical fuel injection to common rail fuel injection systems. Tier 3 hardware costs include engine modifications, the migration from mechanical fuel injection to common rail fuel injection systems, and the installation of SCR. Hardware costs associated with the use of lower sulfur fuel are a result of applying additional tanks and equipment to enable a vessel to switch from residual fuel to lower sulfur fuel. These equipment costs were applied to those new vessels that may require such additional hardware, and also include the estimated cost of retrofitting the portion of the fleet that may require additional hardware to accommodate the use of lower sulfur fuel in 2015, when the fuel sulfur standards take effect. The total hardware costs also include a per engine cost of $10,000 associated with the proposed requirement to test each production engine (§1042.302).

The operational costs were applied to both U.S.- and foreign-flagged vessels and include additional operational costs associated with the applicable NO_X limits, and the use of lower sulfur fuel. The operational costs for NO_X controls consist of the additional fuel required due to an estimated two percent fuel penalty associated with the use of technology to meet Tier 2 standards for U.S.-flagged vessels and global Annex VI Tier II standards for foreign-flagged vessels, and the use of urea for ships equipped with an SCR unit. The operational costs associated with the use of lower sulfur fuel include both the differential cost of using lower sulfur fuel that meets ECA standards instead of using marine distillate fuel, and the differential cost of using lower sulfur fuel that meets ECA standards instead of using residual fuel.

To assess these potential cost impacts we must understand: the makeup of the fleet of ships expected to visit the U.S. when these requirements go into effect, the emission reduction technologies expected to be used, and the cost of these technologies. The total engine and vessel costs associated with the coordinated strategy are based on a cost per unit value applied to the number of affected vessels. Operational costs are based on fuel consumption values determined in the inventory analysis (Chapter 3). This section discusses an overview of the methodology used to develop the hardware and operational costs. This section also presents the methodology

used to develop a fleet of future vessels necessary to determine how to apply these hardware and engineering costs.

5.2.1 Engineering Cost Methodology

To determine the cost of applying emission reduction technology on a per vessel basis, ICF International (ICF) was contracted by the U.S. EPA to conduct a cost study of the various compliance strategies expected to be used to meet the new requirements. The resulting cost estimates were used to determine a $/kW equation which could be scaled according to engine speed and power to arrive at a per vessel cost. The per vessel hardware costs were then applied to the number of applicable new vessels estimated to be built in each year after the standards take effect.

5.2.1.1 Overview

There are a number of technologies available or expected to be available to meet CAA Tier 2 and Tier 3, global Tier II and Tier III, and Annex VI Existing Engine NO_X standards, and to accommodate the use of lower sulfur fuel. We expect that each manufacturer will evaluate all possible technology avenues to determine how to best balance costs while ensuring compliance, however, this analysis makes certain assumptions regarding how manufacturers will comply with the new emission and fuel standards. First, Tier 2 assumes that compliance is met through a combination of fuel injection system changes for some engines and the use of engine modifications for all engines. These engine modifications do not require additional hardware and therefore do not have any related variable costs associated with them. The fuel injection change (the migration from mechanical fuel injection to common rail fuel injection systems) is expected to apply to a certain fraction of engines for Tier 2, and an additional fraction for Tier 3. Tier 3 NO_X standards are projected to be met through the use of SCR systems. The fuel standards are assumed to be met through the use of lower sulfur fuel. An analysis was performed on the current global operating fleet to estimate the percentage of the fleet that may require additional hardware to accommodate the use of lower sulfur fuel, as some ships either already have or are expected to be built with the equipment necessary to accommodate the use of lower sulfur fuel.

Through our background work for this rulemaking and for the ECA application, we sought input from the regulated community regarding the expected future costs of applying the emission control technologies associated with the coordinated strategy. EPA contracted with ICF to research the fixed and variable costs associated with the technologies expected to be used to meet engine and fuel sulfur requirements, as applied to different engine types and sizes. A series of both slow-speed and medium-speed engine configurations were selected and used to provide an understanding of the costs to apply emission control technologies associated with the coordinated strategy. The engine configurations were selected based on a review of 2005 U.S. Army Corps of Engineers 'Entrances and Clearances' data which was used to determine the characteristics of engines on those vessels that call on U.S. ports most frequently. This data represents a broad range of propulsion power for each engine type (slow and medium speed engines). The costs developed for these engine configurations were used to develop a $/kW value that could be applied to any slow or medium speed engine. Using the average propulsion power by ship type presented in the inventory analysis (Chapter 3), the per vessel hardware costs

were then applied to the estimated number of applicable vessels built after the standards take effect, Table 5-2 lists these engine configurations. After ICF developed their initial cost estimates, they provided surveys to several engine and emission control technology manufacturers to determine the reasonableness of their approach and cost estimates. Input received from those surveyed was incorporated into the final cost estimates used in this analysis.

Table 5-2 Engine Configurations Used in the Cost Analyses

ENGINE TYPE	MEDIUM-SPEED			LOW-SPEED		
Engine Power (kW)	4,500	9,500	18,000	8,500	15,000	48,000
Cylinders	9	12	16	6	8	12
Liters/cylinder	35	65	95	380	650	1400
Engine Speed (rpm)	650	550	500	130	110	100
BSFC (g/kWh)	210			195		

5.2.1.2 Hardware Costs

The hardware cost estimates include variable costs (components, assembly, and associated markup) and fixed costs (tooling, research and development, redesign efforts, and certification.) For technologies sold by a supplier to an engine manufacturer, cost estimates are based on a direct cost to manufacture the system components plus a 29 percent markup to account for the supplier's overhead and profit.[1] Variable costs also include a 29 percent markup to account for both manufacturer and dealer overhead and carrying costs. Fixed costs are estimated to be incurred over a five-year period preceding the introduction of the standard.

Hardware costs associated with IMO's existing engine standards were applied to the portion of the existing U.S.-flagged fleet built between 1990 and 1999 expected to be subject to these standards in 2011 when the standards go into effect. These costs were taken over a five-year period beginning in 2011 where 20 percent of the subject fleet was estimated to undergo a rebuild event in each respective year. The existing engine program fixed costs were phased in over a five year period beginning in 2010 and applied on a per vessel basis using the estimated applicable fleet in each respective sales year.

Hardware costs associated with the CAA Tier 2 program were applied to all new U.S.-flagged vessels beginning in the year 2011 when the standards take effect. The fixed costs associated with Tier 2 standards are expected to be incurred over a five year period, however, as the Tier 2 standards take effect in 2011, it is assumed that manufacturers are nearing the end of their research and development efforts. To capture all of these costs, the fixed costs that would have been incurred during that five year phase-in period were all taken in the year 2010 and applied on a per vessel basis using the applicable future fleet of new U.S.-flagged vessels in 2010.

Hardware costs associated with Tier 3 are estimated for U.S. vessels and are applied as of 2016. Because of the global scope of the Tier III standards, and the fact that other ECAs exist today and more may exist in the future, we do not include hardware costs for Tier III emission controls on foreign-flagged vessels. However, for completeness, Section 5.2 presents these hardware cost estimates separately. The fixed costs associated with Tier 3 were phased in over a

five year period beginning in 2011. Hardware costs associated with the use of lower sulfur fuel are estimated separately for both new and existing vessels that may require additional hardware to accommodate the use of lower sulfur fuel. The fuel sulfur control related hardware costs for new vessels begin to apply in 2015, while all retrofit costs are expected to be incurred by 2015. The fixed costs for both new and existing vessels that may require additional hardware to accommodate the use of lower sulfur fuel are applied on a per vessel basis and are phased in over a five year period beginning as of 2010.

5.2.1.3 Operational Costs

The operational costs estimated here are comprised of three parts, (1) the estimated 2 percent increase in fuel consumption (see Chapter 4) expected to occur with the use of Tier 2 and global Tier II technologies on U.S.- and foreign-flagged vessels, (2) the differential cost of using lower sulfur, and (3) the use of urea with SCR as a Tier 3 and global Tier III NO_X emission reduction technology on both U.S.- and foreign-flagged vessels. The fuel consumption values were determined in the inventory analysis (see Chapter 3). The differential cost of using lower sulfur fuel is discussed in Section 5.5.4. The estimated costs of using of urea associated with Tier III NO_X standards are derived from a urea dosage rate that is 7.5 percent of the fuel consumption rate.

Operating costs per vessel vary depending on what year the vessel was built, for example, vessels built as of 2016 will incur operating costs associated with the use of urea necessary when using SCR as a Tier 3 and global Tier III NO_X emission control technology. Vessels built prior to 2016 will not incur the cost of using urea, but will incur operating costs associated with the differential cost of using lower sulfur fuel. Further, we have assumed that vessels built as of 2011 that meet Tier 2 and global Tier II standards will incur a 2 percent fuel consumption penalty. Therefore, an estimated fleet had to be developed over a range of years, and provide a breakout of ships by age in each year. We use the fuel consumption rates from the inventory analysis in Chapter 3 as the basis for estimating additional operating costs incurred prior to 2016 and for ships traveling in non-ECA areas within the U.S. after 2016

5.2.2 Development of 2010-2040 Fleets

To project future costs, we needed to first develop estimates of the number of ships that may visit U.S. ports in a baseline year. This baseline fleet was grown using the growth rates described in Chapter 3 to estimate an approximation of the fleet of ships by age and engine type that may visit U.S. ports in the future.

5.2.2.1 Baseline Fleet

To characterize the fleet of ships visiting U.S. ports we used U.S. port call data collected in 2002 for the inventory port analysis (see Chapter 3 of the draft RIA) which included only vessels with C3 engines where the engine size and type was identified. We used this data with the growth rates developed in the inventory analysis to estimate how many ships by ship type and engine type would visit U.S. ports in future years. Due to the long life of these vessels, and the fact that there has been no significant event that would have changed the composition of the world fleet since this baseline data was taken, it is reasonable to use 2002 data as the basis for

modeling the future fleet upon which to base hardware cost estimates. An analysis is presented in Section 5.1.2.2 which confirms the reasonableness of this assumption using 2007 MARAD data. The ships that called on the U.S. in 2002 were cross referenced with Lloyd's database using each ship's IMO number to determine the actual propulsion power, engine type, and ship type information for each ship. This allowed for ships without Category 3 engines to be removed from the analysis. To separate slow speed engines from medium speed engines where that information was not explicitly available, 2-stroke engines were assumed to be slow speed engines (SSD), and 4-stroke engines were assumed to be medium speed engines (MSD). The research performed for this cost analysis differentiated between SSD and MSD engines, and separate $/kW values were developed for each engine type. The separation by engine type was also necessary to allow for the use of the age distribution formula developed in the inventory analysis (Chapter 3) which provided a method to estimate how many vessels the hardware costs are applicable to in each year.

The ship type information gathered from this baseline data, for the purposes of both this analysis and the inventory, was categorized into one of the following ship types: Auto Carrier, Bulk Carrier, Container, General Cargo, Miscellaneous, Passenger, Refrigerated Cargo (Reefer), Roll-On Roll-Off (RoRo), and Tankers. The 2002 baseline fleet was also used to develop average ship characteristics shown in Tbale 5-3, these values were used to represent the characteristics of new (and future existing) vessels included in this cost analysis.

The 2002 port call data were sorted by IMO number to determine the total number of unique ships that visited all included U.S. ports in 2002. Table 5-4 shows the breakout by ship type of these approximately 6,700 ships. Next, to be consistent with the inventory analysis which provides different regional growth rates, the original port call data were separated into the same regions used by the inventory (South Pacific (SP), North Pacific (NP), East Coast (EC), Gulf Coast (GC), Alaska East (AE), Alaska West (AW), Hawaii East (HE), and West Hawaii (HW)). This was done by matching each port-of-call entry in the original port call data file with the corresponding region containing that port as per the inventory analysis.[2] This resulted in a fleet of ships for each region, each with a unique IMO number.

Table 5-3 Average Ship Characteristics

SHIP TYPE	ENGINE SPEED	AVERAGE PROPULSION POWER (KW)	AVERAGE AUXILIARY POWER (KW)	SERVICE SPEED (KNOTS)	AVERAGE DWT
Auto Carrier	Slow Speed	11,000	3,000	19	17,000
	Medium Speed	9,600	2,600	17	13,000
Bulk Carrier	Slow Speed	8,400	1,900	15	47,000
	Medium Speed	6,300	1,400	14	27,000
	Steam Turbine	6,400	1,400	15	19,000
Container	Slow Speed	27,000	6,000	22	45,000
	Medium Speed	14,000	3,000	19	19,000
	Steam Turbine	21,000	4,700	21	30,000
General Cargo	Slow Speed	7,700	2,000	15	26,000
	Medium Speed	5,200	1,300	15	8,700
	Steam Turbine	18,000	4,600	21	23,000
Passenger	Slow Speed	24,000	6,600	210	6,200
	Medium Speed	24,000	6,600	20	6,200
	Steam Turbine	27,000	7,600	19	13,000
	Gas Turbine	44,000	12,000	24	12,000
Reefer	Slow Speed	10,000	4,200	20	11,000
	Medium Speed	7,400	3,000	18	7,600
RoRo	Slow Speed	16,000	4,000	18	30,000
	Medium Speed	8,600	2,200	16	8,400
	Gas Turbine	47,000	12,000	24	37,000
	Steam Turbine	22,000	5,800	25	19,000
Tanker	Slow Speed	9,800	2,100	15	61,000
	Medium Speed	6,700	1,400	15	27,000
	Gas Turbine	7,600	1,600	15	40,000
	Steam Turbine	21,000	4,400	18	59,000
Misc.	Slow Speed	4,700	1,300	14	8,800
	Medium Speed	9,400	2,500	13	6,000
	Steam Turbine	13,000	3,500	21	17,000

Some ships may have visited ports in more than one region which could result in an overestimate of the hardware costs that are applied to each unique vessel as required. To prevent over-counting of vessels visiting the U.S., a factor was developed (see Equation 5-1) to account for this overlap. The number of unique ships in each region (identified by unique IMO numbers) was summed together to produce a total number of "unique" ships visiting all regions, this value was then reduced by the total number of unique ships that had visited U.S. ports in 2002 (from

the original baseline data) to eliminate the over-counting of ships that had visited multiple regions.

Equation 5-1 Regional Fleet Overlap Reduction Factor

$$\frac{\#Unique\_Auto\_Carriers\_in\_Total\_Port\_Call\_Data}{\sum Unique\_Auto\_Carriers\_by\_\mathrm{Re}gion} = \%\_Actual\_Unique\_\mathrm{Re}gional\_Auto\_Carriers$$

For example, a total of 300 unique auto carriers visited all included U.S. ports in 2002, yet when looking at unique ships on a regional basis and totaling all regions, 650 auto carriers appeared to visit. This implies that only 46 percent of auto carriers were "unique" and the additional 350 auto carriers were actually ships that had visited multiple regions. Therefore, only 46 percent of the auto carriers in each regional fleet were assumed to be "unique." The growth rates were only applied to the corrected count of "unique" ships in each region to estimate the regional fleet makeup in future years.

Table 5-4 2002 Baseline Fleet of Ships and Regional Overlap Factor

SHIP TYPE	TOTAL UNIQUE SHIP VISITS TO U.S. PORTS IN 2020	UNIQUE REGIONAL VISITING U.S. PORTS IN 2020	REGIONAL OVERLAP FACTOR
Auto Carrier	300	650	46%
Bulk	2,500	3,600	68%
Container	1,000	1,600	63%
Gen. Cargo	980	1,700	57%
Misc	24	50	49%
Pass	110	200	57%
Reefer	280	400	71%
RoRo	120	200	58%
Tanker	1,400	2,700	52%
Total	6,700	11,000	62%

5.2.2.2 Projected Fleet

Within each region, the ship types were further broken down by engine type. The unique ship fleet within each region was then grown by ship type and engine type using the appropriate growth rate (Chapter 3) to estimate the makeup of the future fleet. To be consistent with the inventory, we used the same flag fractions to estimate how many of these vessels were U.S.-flagged and how many were foreign-flagged.[3] However, the flag fractions developed by the inventory are based on installed power, while the cost estimate is based on the number of vessels that called U.S. ports. According to MARAD, U.S.-flagged ships averaged 36 calls per vessel per year while foreign-flagged ships averaged only eight calls per vessel per year.[4] To eliminate the potential over-counting of the actual number of U.S.-flagged ships using the installed power method, which does not account for the disparity in the number of visits per year by ship, the U.S.-flagged vessel fraction presented in the inventory was reduced by 75 percent for this cost analysis and was applied to estimate the number of U.S. vessels in the future fleet. This resulted in a more representative estimated fleet in 2007 of 265 existing and 22 new U.S.-flagged vessels. According to MARAD, at the end of 2007 there were 189 U.S.-flagged vessels and another 25

on order that were over 10,000 deadweight tons.[5,C] Table 5-5 shows the estimated 2020 fleet of ships expected to visit U.S. ports.

Table 5-5 Baseline 2002 and Estimated 2020 Fleet by Ship Type and Engine Type

SHIP TYPE	ENGINE SPEED	US FLAG	FOREIGN FLAG	TOTAL	US FLAG	FOREIGN FLAG	TOTAL
		2002			2020		
Auto Carrier	SSD	8	220	228	20	510	530
Auto Carrier	MSD	1	50	51	4	120	124
Bulk Carrier	SSD	70	2,300	2,370	150	4,900	5,050
Bulk Carrier	MSD	20	300	320	30	660	690
Bulk Carrier	ST	8	60	68	15	120	135
Container	SSD	30	890	920	70	2,100	2,170
Container	MSD	3	120	123	7	290	298
Container	ST	2	30	32	4	70	74
General Cargo	SSD	20	630	650	40	1,400	1,440
General Cargo	MSD	3	120	123	8	300	308
General Cargo	ST	1	20	21	3	40	43
Passenger	SSD	2	70	72	4	150	154
Passenger	MSD	1	30	31	2	80	82
Passenger	ST	1	5	6	1	10	11
Passenger	GT	0	2	3	0	5	5
Reefer	SSD	5	120	195	10	130	140
Reefer	MSD	2	60	62	5	130	135
RoRo	SSD	2	60	62	4	140	144
RoRo	MSD	1	30	31	2	60	62
RoRo	GT	0	1	1	0	2	2
RoRo	ST	0	2	3	0	5	5
Tanker	SSD	30	1,000	1,030	60	2,200	2,260
Tanker	MSD	10	300	340	20	800	820
Tanker	GT	1	20	21	1	50	51
Tanker	ST	5	50	55	7	110	117
Misc.	SSD	0	7	8	1	15	16
Misc.	MSD	0	4	4	1	10	10
Misc.	ST	0	1	2	1	3	3
Total:		220	6,500	6,730	470	14,410	14,880

[C] Note that the number reported by MARAD includes only vessels greater than 10,000 DWT while the average vessel characteristics developed from the baseline fleet of ships visiting U.S. ports in 2002, and reported in Table 5-3, include some vessels less than 10,000 DWT assumed to have C3 propulsion engines, and are considered in this analysis.

5.2.2.3 Current Distillate Carrying Capacity of the Existing Global Fleet

Although most ships primarily operate on residual fuel, they typically carry some amount of distillate fuel as well. Switching to the use of lower sulfur distillate fuel is the compliance strategy assumed here to be used by both new and existing ships in 2015 when the new lower sulfur fuel standards go into effect. To estimate the potential cost of this compliance, we first evaluated the distillate storage capacity of the current existing fleet to estimate how many ships may require additional hardware to accommodate the use of lower sulfur fuel. We performed this analysis on the entire global fleet listed in Lloyd's database as of 2008.[6] Of the nearly 43,000 vessels listed, approximately 20,000 vessels had provided Lloyd's with fuel tankage information, cruise speed, and propulsion engine power data. Using this information, we were able to estimate how far each individual vessel could travel on its existing distillate carrying capacity.

The cruise speed provided by Lloyd's was used to determine the vessel's maximum speed using Equation 5-2 while transit speed was assumed to be 12 knots, and maneuver speed 5.8 knots.[7] The load factor used at cruise speed was 83 percent, while both the transit and maneuver load factors were estimated by cubing the ratio their respective speeds to the ship's maximum speed. The same low load factors used in the inventory (for loads less than 20 percent) were used here to adjust the brake specific fuel consumption (BSFC) because diesel engines are less efficient at low loads and the BSFC tends to increase. It was also assumed that ships spend a total of four hours per call in both transit and maneuver speeds. The BSFC values used here are the same as reported in the inventory section, 195 g/kWh for SSDs, 210 g/kWh for MSDs, and 305 g/kW for steam and gas turbines. The fuel consumed by auxiliary engines was also taken into account and the same ratios used in the inventory section (Chapter 3) of auxiliary power by ship type were used here to estimate the total installed auxiliary engine power and load factors at cruise, transit, and maneuver speeds for each ship.

Equation 5-2: Maximum Speed

$$\frac{Lloyds\_speed}{0.94} * 0.83 = \max imum\_speed$$

To determine if the current distillate capacity of a particular ship was sufficient to call on the U.S. ECA without requiring additional hardware, we evaluated whether or not each ship could travel 1,140 nm, or the distance between the Port of Los Angeles and the Port of Tacoma. This distance was selected because it represents one of the longer trips a ship could travel without stopping at another port, and should overestimate the number of vessels that would require such a modification. The amount of fuel a ship will consume calling on a port and travelling a total distance of 1,140 nm was determined using the methodology described above. The total fuel used in each mode (cruise, transit and maneuver) by both main and auxiliary engines was summed and compared to the total amount of distillate fuel carried onboard. This provided an estimate of the number of ships that had sufficient distillate capacity onboard, and the number that did not, shown in Table 5-6. The resulting percentages of ships that were estimated to require a retrofit were then applied to the number of existing ships in the 2015 fleet to estimate the total cost of this compliance strategy for existing ships built prior to 2015. The same percentages were also applied to all new ships built as of 2015 to determine the number of

ships that may require additional hardware, beyond that of comparable new ships, to estimate the cost of this compliance strategy for new vessels.

Table 5-6 Ships that Can Travel 1,140 nm on Existing Distillate Carrying Capacity

SHIP TYPE	TOTAL # SHIPS	TOTAL # SHIPS THAT ONLY CARRY DISTILLATE	DISTILLATE ONLY SHIPS THAT MAY NEED A MODIFICATION		TOTAL # SHIPS THAT CARRY DISTILLATE + ANOTHER FUEL	SHIPS THAT CARRY DISTILLATE + ANOTHER FUEL THAT MAY NEED A MODIFICATION		TOTAL # SHIPS THAT CARRY NO DISTILLATE	% NO DISTILLATE	TOTAL OF ALL SHIPS THAT MAY NEED A MODIFICATION	
			#	%		#	%			#	%
General Cargo	4,600	1,900	9	0.5%	2,300	200	8.9%	370	8.2%	580	13%
Tanker	5,900	740	60	8.7%	4,900	1,600	33%	280	4.7%	1,900	33%
Container	1,900	45	1	2.2%	1,700	910	53%	140	7.3%	1000	55%
Bulk Cargo	3,600	230	7	3.1%	3,000	1,600	53%	400	11%	2,000	55%
RoRo	510	70	1	1.4%	380	30	7.6%	60	12%	90	18%
Auto Carrier	360	20	0	0.0%	310	20	7.1%	40	10%	60	16%
Misc.	1,600	1,100	4	0.4%	210	70	34%	210	14%	280	18%
Passenger	710	170	10	6.0%	460	270	59%	85	12%	360	51%
Reefer	530	60	0	0.0%	440	20	4.1%	25	4.8%	40	8.2%

5.3 Engineering Costs for Freshly Manufactured Engines

This section describes the projected variable and fixed costs to new engines. The component, tooling, labor and overhead costs are presented here separately for Tier 2 and Tier 3. First, the costs are presented as estimated for the six engine configurations described in Table 5-2. Those values were then plotted by engine type and the resulting curve fit and $/kW equation is presented next. Finally, the stream of costs from 2010 through the year 2040 are presented with a three and seven percent discount rate.

5.3.1 Tier 2 Variable Hardware Costs

Tier 2 NO_X standards are roughly 20 percent lower than the existing Tier 1 NO_X standards. To meet these standards, in-cylinder emission control approaches such as electronically controlled high pressure common rail fuel systems, turbocharger optimization, compression ratio changes and electronically controlled exhaust valves could be used. There are no variable costs associated with the engine modifications (such as injection timing and valve timing adjustments, increased compression ratio, and nozzle optimization) as the changes are not expected to require any additional hardware.[D] However, the migration of some engines from mechanically controlled mechanical fuel injection (MFI) to common rail fuel systems will require additional hardware including a control unit, common rail accumulators, low and high pressure pumps, injectors and wiring harnesses. The cost of the Tier 2 technology presented here was developed using Tier 1 technology as the baseline. Table 5-7 shows the per engine variable cost estimates for the six engine configurations used in this analysis, Figure 5-1 shows the cost

[D] MAN Diesel, "Exhaust Gas Emission Control Today and Tomorrow, August 19, 2008," available at http://www.manbw.com/article_009187.html

curve developed from these data points to determine a $/kW equation applicable to other engine sizes.

Table 5-7 Variable Costs for Going to Common Rail from Mechanical Fuel Injection Systems

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Cost to Engine Manufacturer						
Component Costs						
Electronic Control Unit	$3,500	$3,500	$3,500	$5,000	$5,000	$5,000
Common Rail Accumulators (each)	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Number of Accumulators	3	6	8	9	12	18
Low Pressure Pump	$2,000	$3,000	$4,000	$2,500	$3,500	$4,500
High Pressure Pump	$3,500	$4,500	$6,000	$4,500	$6,000	$8,000
Modified injectors (each)	$2,500	$2,500	$2,500	$3,500	$3,500	$3,500
Number of injectors	9	12	16	18	24	36
Wiring Harness	$2,500	$2,500	$2,500	$3,000	$3,000	$3,000
Total Component Cost	**$40,000**	**$55,500**	**$72,000**	**$96,000**	**$125,500**	**$182,500**
Assembly						
Labor (hours)	120	160	200	200	250	300
Cost ($23.85/hr)	$2,900	$3,800	$4,800	$4,800	$5,900	$7,100
Overhead @ 40%	$1,100	$1,500	$1,900	$1,900	$2,400	$2,900
Total Assembly Cost	**$4,000**	**$5,300**	**$6,700**	**$6,700**	**$8,300**	**$10,000**
Total Variable Cost	**$44,000**	**$60,800**	**$78,700**	**$102,700**	**$133,800**	**$192,500**
Markup @ 29%	$12,800	$17,700	$22,800	$29,800	$38,800	$55,800
Total Hardware RPE	**$56,800**	**$78,500**	**$101,500**	**$132,500**	**$172,600**	**$248,300**

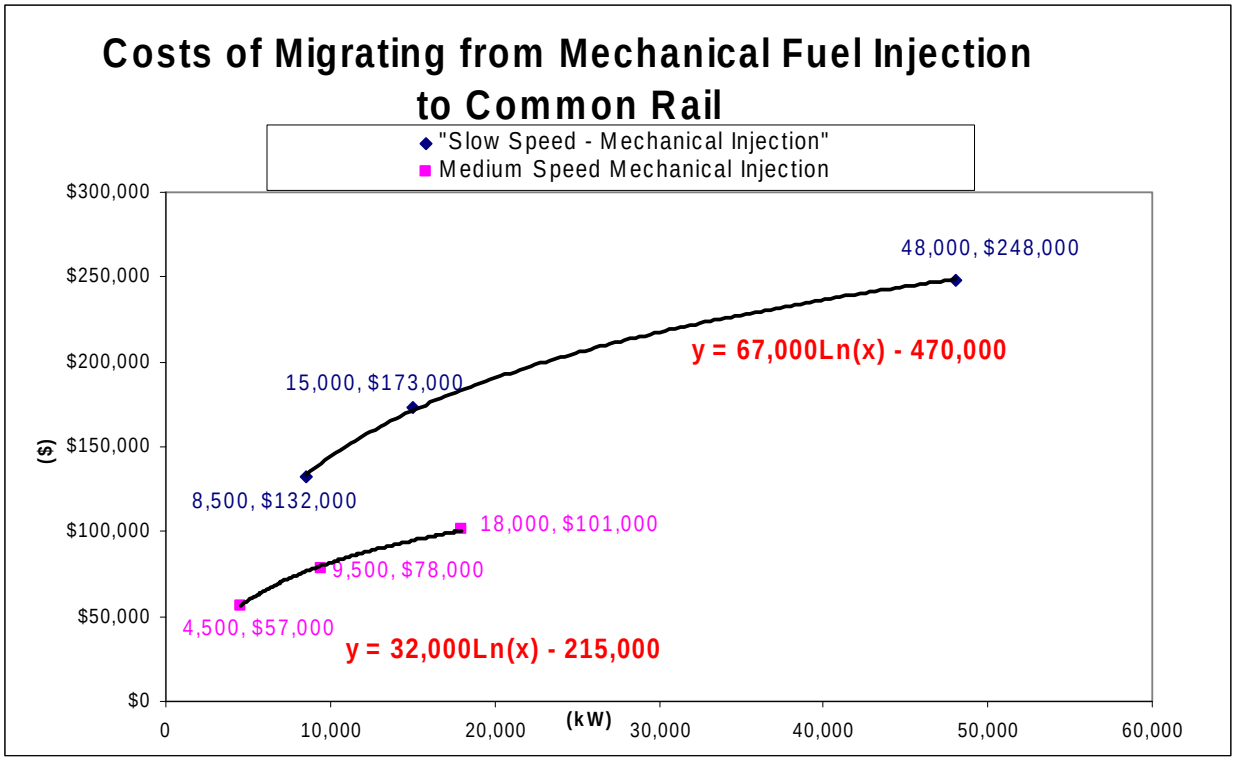

Figure 5-1 Variable Cost Curve-Fit for Mechanically Controlled MFI to Common Rail Fuel Injection Systems

It is estimated that approximately 20 percent of SSD and 60 percent of MSD will remain mechanically injected under the Tier 2 standards. We estimate that 5 percent of all SSD and 10 percent of MSD are already equipped with common rail fuel systems.[E] Table 5-8 shows the expected migration from MFI to common rail for Tier 2 and Tier 3 NO_X standards. Table 5-9 shows the total cost estimate of the Tier 2 program per year from 2010 through 2040, these costs are included in the total cost of the coordinated strategy. Also included here are the costs associated with the proposed requirement to test each production engine (§1042.302). We estimate that, on average, this requirement would add a one-time cost of $10,000 for each new engine.

Table 5-8 Mechanical Injection to Common Rail Technology Mix for Tier 2 and Tier 3

TECHNOLOGY MIX	ENGINE SPEED	PERCENT COMMON RAIL IN TIER 1	PERCENT MECHANICAL MFI TO COMMON RAIL	PERCENT ELECTRICAL MFI TO COMMON RAIL	TOTAL PERCENT COMMON RAIL
Tier 2 (Tier 1 is baseline)	SSD	5	75	0	80
	MSD	10	30	0	40
Tier 3	SSD	80	5	15	100
	MSD	40	10	30	80

[E] Conversations between Lou Browing of ICF and Amy Kopin of the U.S. EPA on 3/1/09.

Table 5-9 Estimated Tier 2 Variable Costs to U.S.-Flagged Vessels 2010-2040

TOTAL US FLAG - TIER 2 COSTS			
Year	SSD	MSD	Total
	Variable	Variable	
2010	$0	$0	$0
2011	$2,410,000	$164,000	$2,570,000
2012	$2,510,000	$170,000	$2,680,000
2013	$2,610,000	$176,000	$2,790,000
2014	$2,710,000	$183,000	$2,890,000
2015	$2,810,000	$190,000	$3,000,000
2016	$2,700,000	$139,000	$2,840,000
2017	$2,800,000	$144,000	$2,940,000
2018	$2,910,000	$150,000	$3,060,000
2019	$3,030,000	$155,000	$3,190,000
2020	$3,150,000	$161,000	$3,310,000
2021	$3,270,000	$167,000	$3,440,000
2022	$3,400,000	$174,000	$3,570,000
2023	$3,540,000	$181,000	$3,720,000
2024	$3,680,000	$188,000	$3,870,000
2025	$3,820,000	$195,000	$4,020,000
2026	$3,980,000	$203,000	$4,180,000
2027	$4,130,000	$211,000	$4,340,000
2028	$4,300,000	$219,000	$4,520,000
2029	$4,470,000	$227,000	$4,700,000
2030	$4,650,000	$236,000	$4,890,000
2031	$4,840,000	$246,000	$5,090,000
2032	$5,040,000	$256,000	$5,300,000
2033	$5,240,000	$266,000	$5,510,000
2034	$5,460,000	$277,000	$5,740,000
2035	$5,680,000	$288,000	$5,970,000
2036	$5,910,000	$299,000	$6,210,000
2037	$6,150,000	$311,000	$6,460,000
2038	$6,400,000	$324,000	$6,720,000
2039	$6,670,000	$337,000	$7,010,000
2040	$6,940,000	$351,000	$7,290,000
NPV @ 3%	$75,400,000	$4,040,000	$79,400,000
NPV @ 7%	$43,200,000	$2,380,000	$45,600,000

5.3.2 Tier 2 Fixed Costs

Tier 2 fixed costs are comprised of those associated with engine modifications shown in Table 5-10, and those associated with the migration from MFI to common rail shown in Table 5-11. The engine modification fixed cost estimates include modification of fuel injection timing, increasing the compression ratio, fuel injection nozzle optimization and Miller cycle effects. Retooling cost estimates include cylinder head and piston rod shim modifications to increase

compression ratios as well as to accommodate different injection nozzles. Differential costs for new common rail fuel injection systems that replace MFI systems include research and development, and retooling costs include modification of the cylinder head to accommodate the common rail fuel injection systems. The fixed costs associated with common rail are applied on a per vessel basis only to those engines expected to receive this technology; the fixed costs associated with the engine modifications are applied to all vessels. These costs are included in the total estimated cost of the coordinated strategy.

Table 5-10 Fixed Costs Estimated for Tier 2 Engine Modifications

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (1 year R&D)	$688,000	$688,000	$688,000	$688,000	$688,000	$688,000
Retooling Costs	$750,000	$750,000	$750,000	$1,000,000	$1,000,000	$1,000,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$7,200**	**$7,200**	**$7,200**	**$8,500**	**$8,500**	**$8,500**

Table 5-11 Fixed Costs for Mechanical Injection to Common Rail

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (1 year R&D)	$688,000	$688,000	$688,000	$688,000	$688,000	$688,000
Retooling Costs	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$8,500**	**$8,500**	**$8,500**	**$8,500**	**$8,500**	**$8,500**

5.3.3 Tier 3 Variable Hardware Costs

Tier 3 NO_X standards are approximately 80 percent lower than the existing Tier 1 NO_X standards. To meet these standards, it is expected that SCR will be used along with the additional migration from mechanical injection systems to common rail, and engine modifications. The variable costs associated with Tier 3 include the continued migration to

common rail (see Table 5-8 for the expected percentages migrating for Tier 3). Table 5-7 shows these variable costs. Table 5-12 shows the variable costs associated with the migration from electronically controlled mechanical fuel injection (EFI) to common rail. A cost estimate is presented for each of the six engine configurations used in this analysis. Figure 5-2 shows the cost curve developed from these data points to determine a $/kW equation applicable to other engine sizes and types.

The variable costs associated with the use of engine modifications for Tier 3 include the use of two stage turbochargers and electronic valve actuation, and are shown in Table 5-13, Figure 5-3 shows the cost curve used to determine a $/kW equation applicable to other engine sizes and types. The methodology used here to estimate the capacity of the SCR systems is based on the power rating of the propulsion engines only. Auxiliary engine power represents about 20 percent of the total installed power on a vessel; however, it would be unusual to operate both propulsion and auxiliary engines at 100 percent load. Typically, ships operate under full propulsion power only while at sea when the SCR is not operating; when nearing ports the auxiliary engine is operating at high loads while the propulsion engine is operating at very low loads.

Table 5-14 shows the variable costs associated with the use of SCR, these costs include the urea tank, the reactor, dosage pump, urea injectors, piping, bypass valve, the acoustic horn, a cleaning probe and the control unit and wiring. Detailed costs for the urea tank are shown in Table 5-15 and are based on the storage of urea sufficient for up to 250 hours of normal operation of the SCR. It is envisioned that the urea tank is constructed of 304 stainless steel one mm thick due to the corrosive nature of urea, at a cost of approximately $2,700 per metric ton (tonne).[F]

In this analysis, we estimated the average number of hours a ship may spend to call on a U.S. port: if the call was straight in and straight out at a distance of 200 nm, the average time spent was slightly over 35 hours. If the distance travelled was substantial, such as from the Port of Los Angeles to the Port of Tacoma, or 1140 nm, the average time spent travelling was approximately 75 hours. Therefore, the size of the tanks and corresponding $/kW value estimated here to carry enough urea for 250 hours of continuous operation may be an overestimate, and some owners may choose a smaller tank and to refill more often. Based on 250 hours of operation, a range of urea tank sizes from 20 m^3 to approximately 260 m^3 was estimated for the six different engine configurations used in this analysis.

To understand what impacts this may have on the cargo hauling capacity of the ship, we looked at the ISO standard containers used today. Currently, over two-thirds of the containers in use today are 40 feet long, total slightly over 77m^3 and are the equivalent of two TEU.[G] The urea tank size range estimates provided here reflect a cargo equivalence of 0.5-2 TEUs, based on a capacity sufficient for 250 hours of operation. The TEU capacity of container ships, for example, continues to increase and can be as high as 13,000 TEUs; while not all ports are equipped to handle ships of this size, feeder ships (ships that carry containers to ocean-going

[F] http://www.metalprices.com/FreeSite/metals/stainless_product/product.asp#Tables for 2006.
[G] www.iicl.org, Institute of International Container Lessors

vessels in smaller ports) have also increased in size to carry as much as 2,000 TEUs.[H] Based on a rate of approximately $1,300 per TEU to ship a container from Asia to the US,[I] a net profit margin of 10%, and an average of 16 trips per year, the estimated cost due to displaced cargo to call on a U.S.-Canada ECA may be $2,100.[J,K,L] The cost analysis presented here does not include displaced cargo costs due to the variability of tank sizes owners choose to install.

The cost of Tier 3 technology as presented here was developed using Tier 2 as a baseline. Figure 5-4 shows the shows the cost curve used to determine a $/kW equation applicable to other engine types and sizes. The total variable hardware costs of Tier 3 estimated here include the fuel injection changes, engine modifications, SCR, and the costs associated with the proposed requirement to test each production engine (§1042.302). We estimate that, on average, this requirement would add a one-time cost of $10,000 for each new engine. Table 5-16 shows the total variable hardware costs estimated from 2010 through 2040 of Tier 3 for U.S.-flagged vessels, and Table 5-17 shows the total variable hardware costs estimated from 2010 through 2040 of Tier 3 for foreign-flagged vessels.

[H] Kristensen, Hans Otto Holmegaard, "Preliminary Ship Design of Container Ships, Bulk Carriers, Tankers, and Ro-Ro Ships. Assessment of Environmental Impact from Sea-Borne Transport Compared with Landbased Transport," March, 2008.

[I] http://people.hofstra.edu/geotrans/eng/ch2en/conc2en/maritimefreightrates.html

[J] http://moneycentral.msn.com/investor/invsub/results/hilite.asp?Symbol=SSW

[K] http://moneycentral.msn.com/investor/invsub/results/hilite.asp?Symbol=SSW

[L] Based on a container ship carrying nearly 9,000 TEUs traveling from Hong Kong to the Port of Los Angeles (approximately 6,400 nm) with a cruise speed of 25 nm/hr, the round trip time is nearly 21 days and this trip could be made roughly 16 times per year.

Table 5-12 Variable Costs for EFI to Common Rail

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Costs to the Manufacturer						
Component Costs						
Electronic Control Unit	$500	$500	$500	$500	$500	$500
Common Rail Accumulators (each)	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Number of Accumulators	3	6	8	9	12	18
Low Pressure Pump	$1,000	$1,000	$1,000	$1,500	$1,500	$1,500
High Pressure Pump	$1,500	$1,500	$1,500	$2,000	$2,000	$2,000
Modified injectors (each)	$500	$500	$500	$750	$750	$750
Number of injectors	9	12	16	18	24	36
Wiring Harness	$500	$500	$500	$650	$650	$650
Total Component Cost	**$14,000**	**$21,500**	**$27,500**	**$36,150**	**$46,650**	**$67,650**
Assembly						
Labor (hours)	40	60	80	40	60	80
Cost ($23.85/hr)	$950	$1,430	$1,910	$950	$1,430	$1,910
Overhead @ 40%	$380	$570	$760	$380	$570	$760
Total Assembly Cost	**$1,330**	**$2,000**	**$2,670**	**$1,330**	**$2,000**	**$2,670**
Total Variable Cost	**$15,300**	**$23,500**	**$30,200**	**$37,500**	**$48,700**	**$70,300**
Markup @ 29%	$4,400	$6,800	$8,800	$10,900	$14,100	$20,400
Total Hardware RPE	**$19,700**	**$30,300**	**$39,000**	**$48,400**	**$62,800**	**$90,700**

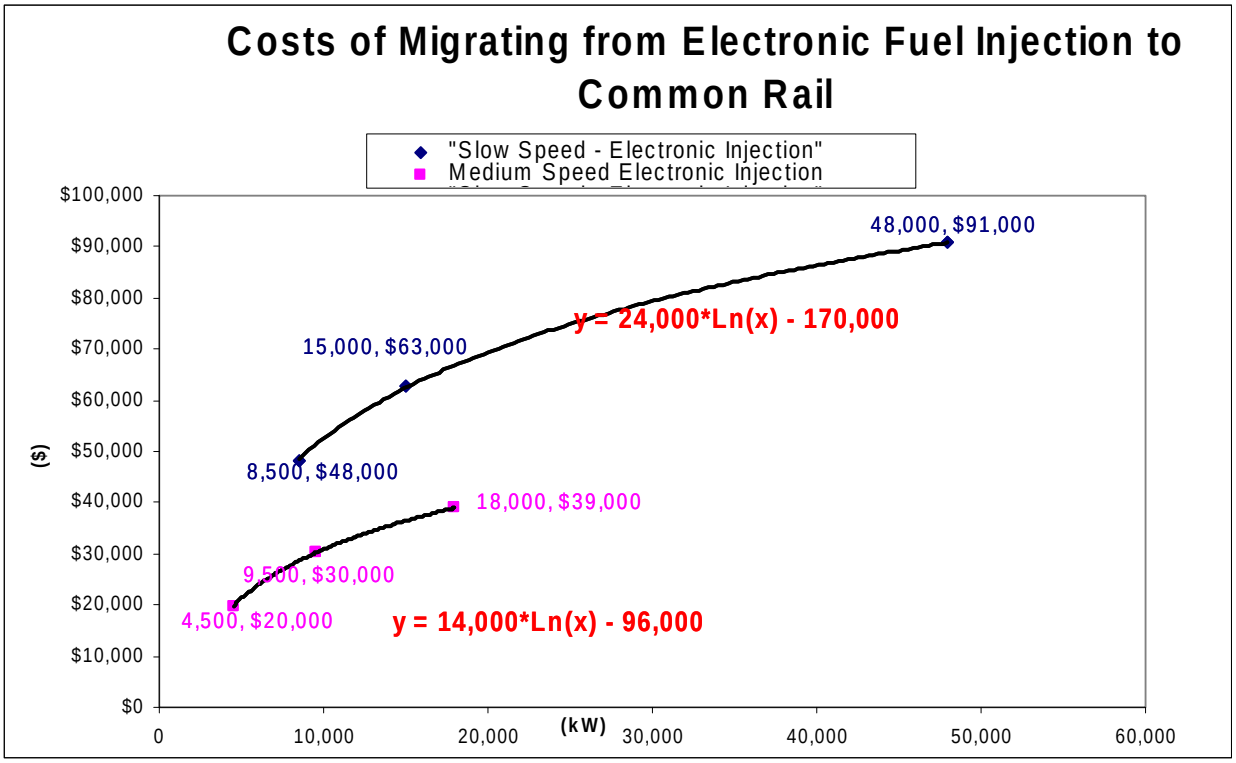

Figure 5-2 Variable Cost Curve-Fit for Electronically Controlled MFI to Common Rail Fuel Injection Systems

Table 5-13 Variable Costs for Engine Modifications Associated with Tier 3

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Costs to the Manufacturer						
Component Costs						
2 Stage Turbochargers (Incremental)	$16,250	$20,900	$46,750	$28,000	$42,000	$61,000
Electronic Intake Valves (each)	$285	$285	$285			
Intake Valves per Cylinder	2	2	2			
Electronic Exhaust Valves (each)	$285	$285	$285	$425	$425	$425
Exhaust Valves per Cylinder	2	2	2	4	4	4
Controller	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750
Wiring	$2,800	$2,800	$2,800	$2,800	$2,800	$2,800
Total Component Cost	**$33,000**	**$41,000**	**$72,000**	**$45,000**	**$62,000**	**$88,000**
Markup @ 29%	$10,000	$12,000	$21,000	$13,000	$18,000	$25,000
Total Hardware RPE	**$43,000**	**$53,000**	**$93,000**	**$58,000**	**$80,000**	**$113,000**

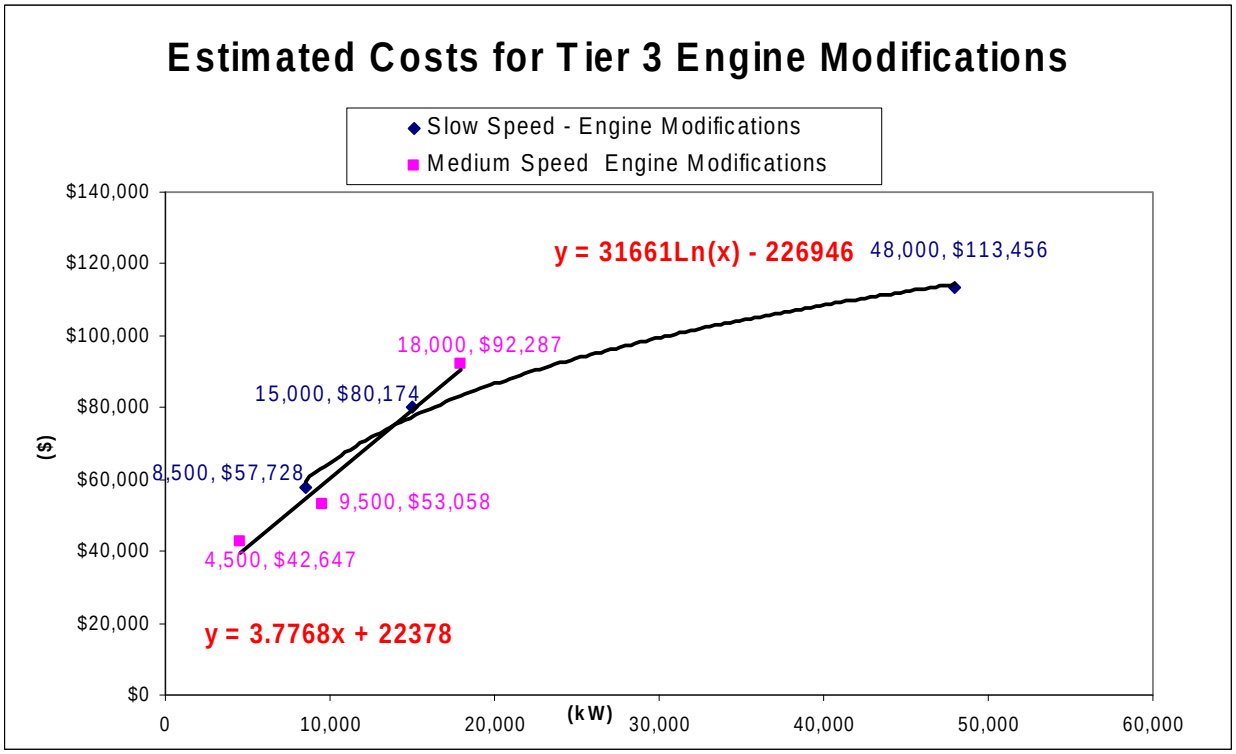

Figure 5-3 Variable Cost Curve-Fit for Engine Modifications Associated with Tier 3

Table 5-14 Variable Costs Associated with the Use of SCR

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Costs to the Supplier						
Component Costs						
Aqueous Urea Tank	$1,200	$1,900	$2,800	$1,700	$2,400	$4,600
Reactor	$200,000	$295,000	$400,000	$345,000	$560,000	$1,400,000
Dosage Pump	$9,500	$11,300	$13,000	$11,300	$13,000	$15,000
Urea Injectors (each)	$2,400	$2,400	$2,400	$2,400	$2,400	$2,400
Number of Urea Injectors	3	6	8	12	16	24
Piping	$4,700	$5,600	$6,600	$5,600	$7,500	$9,500
Bypass Valve	$4,700	$5,600	$6,600	$5,600	$6,600	$7,500
Acoustic Horn	$9,500	$11,300	$13,000	$11,700	$14,000	$16,400
Cleaning Probe	$575	$575	$575	$700	$700	$700
Control Unit/Wiring	$14,000	$14,000	$14,000	$19,000	$19,000	$19,000
Total Component Cost	**$251,000**	**$360,000**	**$476,000**	**$429,000**	**$662,000**	**$1,530,000**
Assembly						
Labor (hours)	1000	1200	1500	1200	1600	2000
Cost ($23.85/hr)	$23,900	$28,600	$35,800	$28,600	$38,200	$47,700
Overhead @ 40%	$9,500	$11,400	$14,300	$11,400	$15,300	$19,100
Total Assembly Cost	**$33,400**	**$40,000**	**$50,100**	**$40,000**	**$53,500**	**$66,800**
Total Variable Cost	$284,800	$399,700	$525,800	$469,400	$715,000	$1,597,100
Markup @ 29%	$82,600	$115,900	$152,500	$136,100	$207,300	$463,200
Total Hardware RPE	**$367,400**	**$515,600**	**$678,300**	**$605,500**	**$922,300**	**$2,060,300**

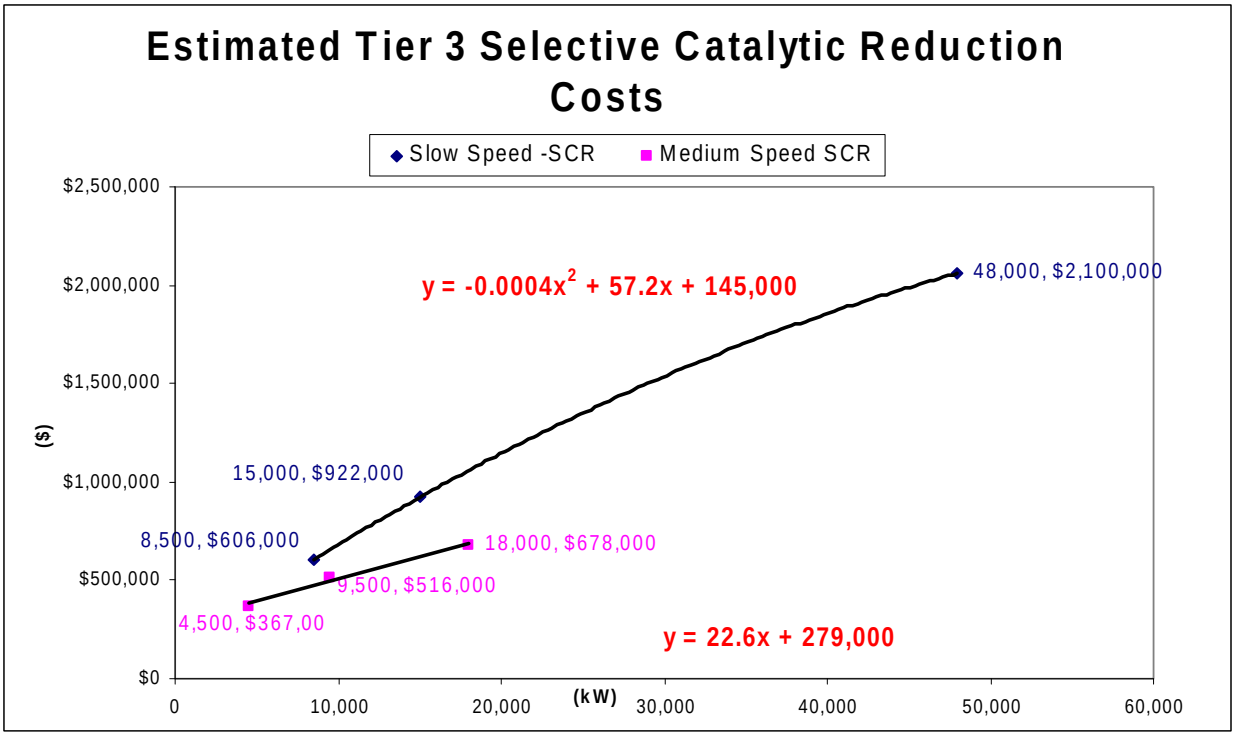

Figure 5-4 Variable Cost Curve-Fit for SCR Systems

Table 5-15 Variable Costs Associated with the Urea Tanks for use with SCR Systems

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Urea Tank Costs						
Urea Amount (kg)	12,910	27,255	51,642	22,645	39,961	127,875
Density (kg/m^3)	1,090	1,090	1,090	1,090	1,090	1,090
Tank Size (m^3)	14	30	57	21	37	117
Tank Material (m^3)	0.04	0.06	0.09	0.05	0.07	0.14
Tank Material Cost ($)	$758	$1,248	$1,909	$977	$1,426	$3,093
Assembly						
Labor (hours)	5	6	7	10	12	15
Cost ($23.85/hr)	$119	$143	$167	$238	$286	$358
Overhead @ 40%	$48	$57	$67	$95	$114	$143
Total Assembly Cost	$167	$200	$234	$334	$401	$501
Total Variable Cost	$925	$1,448	$2,143	$1,310	$1,826	$3,594
Markup @ 29%	$268	$420	$621	$380	$530	$1,042
Total Hardware RPE	$1,194	$1,868	$2,765	$1,690	$2,356	$4,636

Table 5-16 Estimated Tier 3 Costs to U.S.-Flagged Vessels 2010-2040 ($Millions)

TOTAL ESTIMATED US FLAG TIER 3 COSTS			
Year	SSD	MSD	Total
	Variable	Variable	
2010	$0.00	$0.00	$0.00
2011	$0.00	$0.00	$0.00
2012	$0.00	$0.00	$0.00
2013	$0.00	$0.00	$0.00
2014	$0.00	$0.00	$0.00
2015	$0.00	$0.00	$0.00
2016	$21.5	$2.98	$24.5
2017	$22.4	$3.09	$25.5
2018	$23.3	$3.21	$26.5
2019	$24.2	$3.33	$27.5
2020	$25.2	$3.46	$28.6
2021	$26.2	$3.59	$29.8
2022	$27.2	$3.73	$31.0
2023	$28.3	$3.87	$32.2
2024	$29.5	$4.02	$33.5
2025	$30.6	$4.18	$34.8
2026	$31.9	$4.35	$36.2
2027	$33.2	$4.52	$37.7
2028	$34.5	$4.69	$39.2
2029	$35.9	$4.88	$40.8
2030	$37.4	$5.07	$42.5
2031	$38.9	$5.28	$44.2
2032	$40.5	$5.49	$46.0
2033	$42.2	$5.71	$47.9
2034	$43.9	$5.94	$49.8
2035	$45.7	$6.18	$51.9
2036	$47.6	$6.43	$54.0
2037	$49.6	$6.69	$56.3
2038	$51.6	$6.96	$58.6
2039	$53.8	$7.25	$61.0
2040	$56.0	$7.54	$63.5
NPV @ 3%	$509	$69.3	$579
NPV @ 7%	$261	$35.6	$297

Table 5-17 Estimated Tier 3 Costs to Foreign Flagged Vessels 2010-2040 ($Millions)

TOTAL FOREIGN FLAG			
Year	SSD	MSD	Total
	Variable	Variable	
2010	$0	$0	$0
2011	$0	$0	$0
2012	$0	$0	$0
2013	$0	$0	$0
2014	$0	$0	$0
2015	$0	$0	$0
2016	$754	$89	$843
2017	$784	$93	$877
2018	$817	$97	$914
2019	$850	$101	$951
2020	$885	$105	$991
2021	$922	$110	$1,032
2022	$960	$115	$1,075
2023	$1,000	$120	$1,119
2024	$1,040	$125	$1,165
2025	$1,080	$130	$1,210
2026	$1,130	$136	$1,266
2027	$1,180	$142	$1,322
2028	$1,230	$148	$1,378
2029	$1,280	$154	$1,434
2030	$1,330	$161	$1,491
2031	$1,390	$168	$1,558
2032	$1,450	$175	$1,625
2033	$1,510	$183	$1,693
2034	$1,570	$191	$1,761
2035	$1,640	$199	$1,839
2036	$1,710	$208	$1,918
2037	$1,780	$217	$1,997
2038	$1,850	$227	$2,077
2039	$1,930	$237	$2,167
2040	$2,020	$247	$2,267
NPV @ 3%	$18,100	$2,180	$20,280
NPV @ 7%	$9,260	$1,110	$10,370

5.3.4 Tier 3 Fixed Costs

The Tier 3 fixed costs presented here include those associated with the use of SCR, including research and development costs, marine society approval, and retooling for the redesign of the exhaust system to accommodate the SCR unit, and are shown in Table 5-18. The migration to common rail from for Tier 3 is primarily from EFI which includes modification of the cylinder head to accommodate common rail fuel injection systems, these costs are shows in

Table 5-18. The fixed costs associated with the migration from MFI to common rail are shown above in Table 5-11. Finally, Tier 3 also includes the fixed costs associated with the engine modifications which include the use of two stage turbochargers and electronic valve actuation; the retooling costs represent turbocharger redesign and valve actuation modifications. These costs are applied to U.S.-flagged vessels and are included in the total cost estimate of the coordinated strategy.

Table 5-18 Fixed Costs Associated with the use of SCR for Tier 3

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (1 year R&D)	$1,376,000	$1,376,000	$1,376,000	$1,376,000	$1,376,000	$1,376,000
Retooling Costs	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$16,900**	**$16,900**	**$16,900**	**$16,900**	**$16,900**	**$16,900**

Table 5-19 Fixed Costs Associated with the Migration of EFI to Common Rail

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (0.5 year R&D)	$344,000	$344,000	$344,000	$344,000	$344,000	$344,000
Retooling Costs	$500,000	$500,000	$500,000	$500,000	$500,000	$500,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$4,200**	**$4,200**	**$4,200**	**$4,200**	**$4,200**	**$4,200**

Table 5-20 Fixed Costs Associated with Engine Modifications Used for Tier 3

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (1 year R&D)	$688,000	$688,000	$688,000	$688,000	$688,000	$688,000
Retooling Costs	$1,000,000	$1,000,000	$1,000,000	$1,320,000	$1,320,000	$1,320,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$8,500**	**$8,500**	**$8,500**	**$10,000**	**$10,000**	**$10,000**

5.4 Engineering Costs for Existing Engines

The October 2008 amendments to MARPOL Annex VI include NO_X standards that apply to existing engines on ships constructed on or after January 1, 1990 but prior to January 1, 2000 for marine diesel engines with a per cylinder displacement of at least 90 liters and a power output of over 5,000 kW. Subject engines must be retrofit with components that reduce NO_X approximately 20 percent and be certified to confirm the engine meets Tier I standards.

5.4.1 Variable Costs for the Annex VI Existing Engine Program

Most manufacturers will comply with the existing engine standard by providing retrofit kits which contain modified fuel injectors and possibly modified injection timing. The costs for the retrofit kit include new fuel injectors plus three months of research and development to modify the timing, and consist only of the incremental cost associated with the required emission reductions. A Marine Society approval certificate is also estimated to be included. As part of the IMO regulations, the retrofit kit cannot exceed $375 Special Drawing Rights (SDR)/metric ton of NO_X reduced. The currency value of the SDR is determined by summing the values in U.S. dollars, based on market exchange rates, of a basket of major currencies (the U.S. dollar, Euro, Japanese yen, and pound sterling). The SDR currency value is calculated daily and the valuation basket is reviewed and adjusted every five years, the conversion rate used in this analysis is $1.49 per SDR. Table 5-21 presents the estimated variable costs associated with the existing engine program. The costs are presented only for the engine configurations used in this analysis that are subject to the program.

Table 5-21 Variable Costs Associated with the Existing Engine Program

SPEED	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**16**	**6**	**8**	**12**
Liters/cylinder	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**500**	**130**	**110**	**100**
Hardware Cost to Engine Manufacturer				
Component Costs				
Number of Injectors	16	18	24	36
Improved Fuel Valves (each)	$235	$235	$375	$470
Total Component Cost	**$3,760**	**$4,230**	**$9,000**	**$16,920**
Assembly				
Labor (hours)	120	168	216	312
Cost ($23.85/hr)	$2,860	$4,010	$5,150	$7,440
Overhead @ 40%	$1,150	$1,600	$2,060	$2,980
Total Assembly Cost	**$4,010**	**$5,610**	**$7,210**	**$10,420**
Total Variable Cost	**$7,770**	**$9,840**	**$16,210**	**$27,340**
Markup @ 29%	$2,250	$2,850	$4,700	$7,930
Total Hardware RPE	**$10,020**	**$12,690**	**$20,910**	**$35,270**

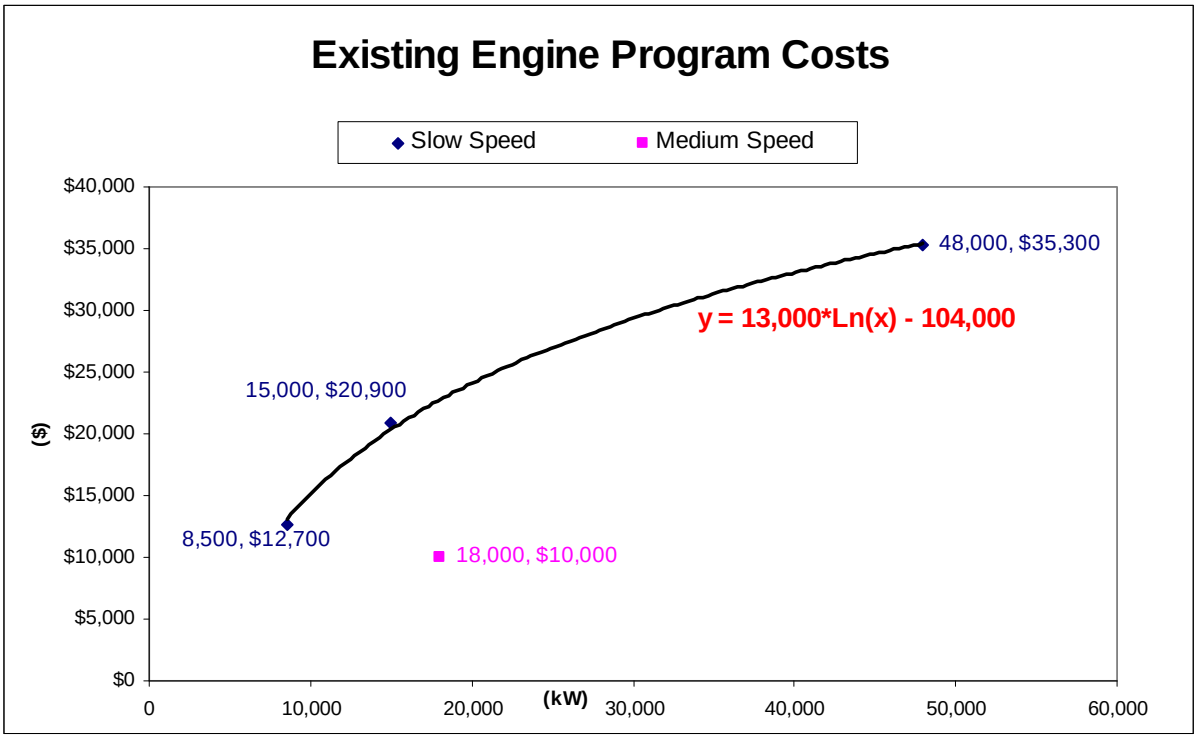

Figure 5-5 Variable Cost Curve Fit for Existing Engine Program

5.4.2 Fixed Costs for the Annex VI Existing Engine Program

The fixed costs associated with the existing engine program are presented below in Table 5-22 and include the costs for research and development and marine society approval. These costs as applied to U.S.-flagged vessels are included in the total cost estimate of the coordinated strategy.

Table 5-22 Fixed Costs Associated with the Existing Engine Program

SPEED	**MEDIUM**	**LOW**	**LOW**	**LOW**
Engine Power (kW)	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**16**	**6**	**8**	**12**
Liters/cylinder	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**500**	**130**	**110**	**100**
Fixed Costs				
R&D Costs (0.25 year R&D)	$172,000	$172,000	$172,000	$172,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40
Years to recover	5	5	5	5
Fixed cost/engine	**$880**	**$880**	**$880**	**$880**

5.4.3 Total Estimated Costs of the Annex VI Existing Engine Program

The costs for the existing engine program for Tier 0 (pre-control) engines were developed in the same manner modeled in the inventory (Chapter 3) as being applicable to 80 percent of 1990 through 1999 model year engines greater than 90 liters per cylinder (L/cyl) and 5,000 kW starting in 2011, with a five year phase-in. In this cost analysis, the research and development fixed costs were phased in from 2010-2014, while the certification fixed costs were applied in 2010. To estimate the cost of the existing engine program to U.S.-flagged vessels, we had to determine how many ships built between 1990-1999 there would be in each year from 2011 through 2015 using the age distribution analysis from the inventory. The $/kW values were then applied to the portion of the fleet each year between 2011 and 2015 expected to be subject to these standards. Table 5-23 presents the total estimated costs of the existing engine program to U.S.-flagged vessels; these costs are included in the total cost estimate of the coordinated strategy.

Table 5-23 Total Estimated Costs of the Existing Engine Program to U.S.-Flagged Vessels

TOTAL US FLAG			
Year	SSD	MSD	Total
2010	$0	$0	$0
2011	$145,000	$6,800	$152,000
2012	$139,000	$5,500	$144,000
2013	$132,000	$4,600	$137,000
2014	$126,000	$3,600	$129,000
2015	$128,000	$3,000	$131,000
2016	$0	$0	$0

5.5 Engineering Costs for Vessels

5.5.1 Freshly Manufactured Vessels

5.5.1.1 Variable Costs

The vessel costs associated with the coordinated strategy are those that may be incurred if additional hardware is required to accommodate the use of lower sulfur fuel. This section discusses the costs that may be incurred by some newly built ships if additional fuel tank equipment, beyond that installed on comparable new ships, is required to meet lower sulfur fuel standards in the ECA. Based on existing vessel fleet data, we estimate that nearly one-third of new vessels may need additional equipment installed to accommodate additional lower sulfur fuel storage capacity. The size of the tank is dependent on the frequency with which the individual ship owner prefers to fill the lower sulfur fuel tank.

Costs include additional distillate fuel storage tanks, an LFO fuel separator, an HFO/LFO blending unit, a 3-way valve, an LFO cooler, filters, a viscosity meter, and various pumps and piping, these costs are shown in Table 5-24. The estimates of the additional tank costs are shown in Table 5-25. Distillate tanks are assumed to be constructed of cold rolled steel one mm thick, double walled, and estimated to carry capacity sufficient for 250 hours of propulsion and auxiliary engine operation. Similar to the urea tank size estimation presented in this analysis, this is most likely an overestimate of the amount of lower sulfur fuel a ship owner would need to carry, resulting in an overestimate of the total cost to existing and new vessels. The tank size based on 250 hours of operation and based on the six different engine configuration used in this analysis ranges from 240 m^3 to nearly 2,000 m^3. This would be the equivalent of 6-50 TEUs. This cost analysis does not reflect the costs of displaced cargo as there are other design options such as partitioning of a residual fuel tank to allow for lower sulfur fuel capacity which would reduce the amount of additional space required, nor does this analysis reflect the possibility that some ships may have already been designed to carry smaller amounts of distillate fuel in separate tanks for purposes other than continuous propulsion.

The costs were developed for each of the six different engine sizes and types used in this analysis. These values were used to develop a curve fit, Figure 5-6, used to determine a $/kW equation applicable to other engine sizes and types. Table 5-27 presents the total estimated variable hardware costs for U.S.-flagged vessels associated with the installation of additional equipment to enable the use of lower sulfur fuel, these costs are included in the total estimated cost of the coordinated strategy. While the estimated costs to new foreign-flagged vessels are presented here in Table 5-28, they are not included as a part of the total cost of the coordinated strategy as this technology will be used globally and will result in emissions reductions in many other countries.

Table 5-24 Variable Costs Associated with the use of Lower Sulfur Fuel - New Vessels

Speed	**Medium**	**Medium**	**Medium**	**Low**	**Low**	**Low**
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Cost to Supplier						
Component Costs						
Additional Tanks	$3,400	$5,500	$8,300	$4,600	$6,500	$13,700
LFO Separator	$2,800	$3,300	$3,800	$3,800	$4,200	$4,700
HFO/LFO Blending Unit	$4,200	$4,700	$5,600	$4,700	$5,600	$6,600
3-Way Valve	$950	$1,400	$1,900	$1,400	$1,900	$2,800
LFO Cooler	$2,400	$2,800	$3,300	$2,800	$3,800	$4,700
Filters	$950	$950	$950	$950	$950	$950
Viscosity Meter	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400
Piping/Pumps	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Total Component Cost	**$18,100**	**$22,100**	**$27,300**	**$21,600**	**$26,400**	**$36,900**
Assembly						
Labor (hours)	240	320	480	320	480	600
Cost ($23.85/hr)	$5,700	$7,600	$11,400	$7,600	$11,400	$14,300
Overhead @ 40%	$2,300	$3,100	$4,600	$3,100	$4,600	$5,700
Total Assembly Cost	**$8,000**	**$10,700**	**$16,000**	**$10,700**	**$16,000**	**$20,000**
Total Variable Cost	$26,100	$32,700	$43,300	$32,300	$42,400	$56,900
Markup @ 29%	$7,600	$9,500	$12,600	$9,400	$12,300	$16,500
Total Hardware RPE	**$33,700**	**$42,200**	**$55,900**	**$41,700**	**$54,700**	**$73,400**

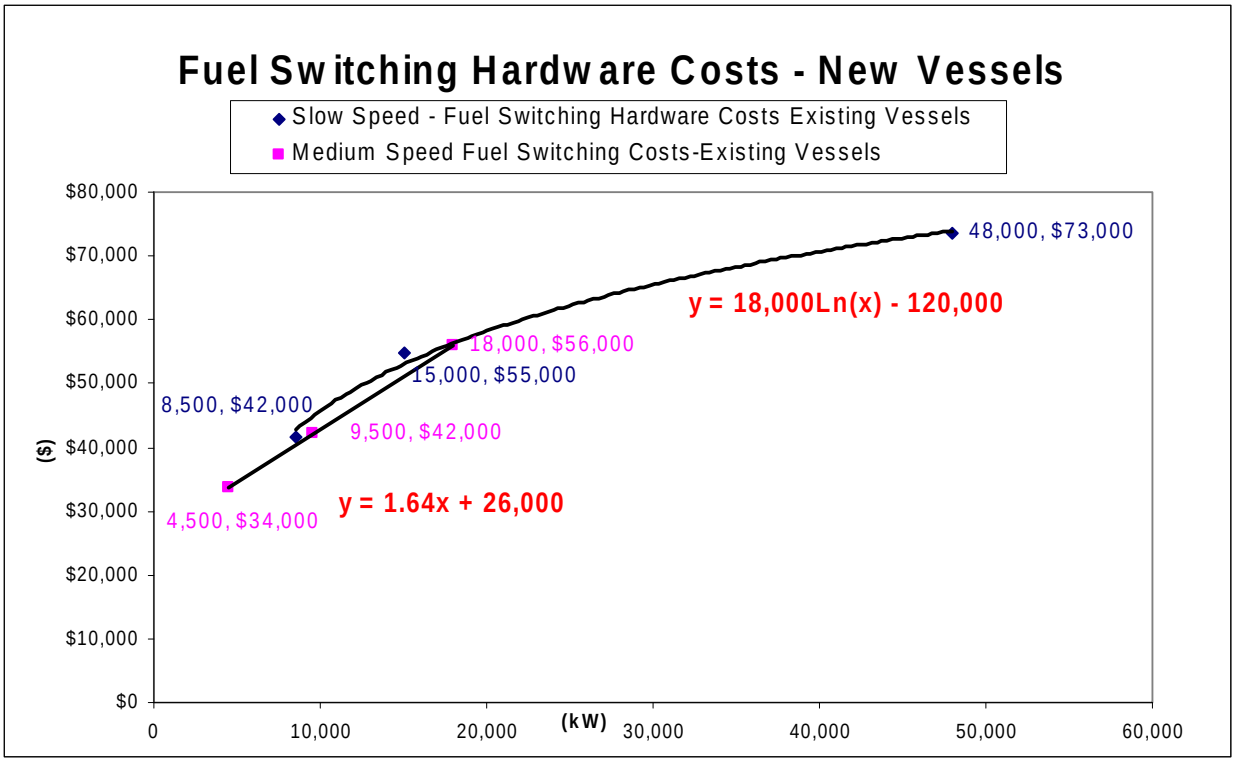

Figure 5-6 Variable Cost Curve Fit for Fuel Switching Vessels Costs to New Vessels

Table 5-25 Variable Cost to New Vessels Associated with Fuel Switching - Extra Tankage

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Propulsion						
BSFC (g/kWh)	210	210	210	195	195	195
Load factor	73%	73%	73%	73%	73%	73%
Auxiliary						
Power (kW)	1,000	2,200	4,100	1,900	3,400	10,900
BSFC (g/kWh)	227	227	227	227	227	227
Load factor	31%	31%	31%	31%	31%	31%
Combined						
Fuel Amount (kg)	190,000	401,000	760,000	336,000	592,000	1,896,000
Density (kg/m^3)	960	960	960	960	960	960
Tank Size (m^3)	238	501	950	350	617	1,975
Tank Material (m^3)	0.46	0.75	1.15	0.59	0.87	1.88
Tank Material Cost ($)	$2,500	$4,100	$6,200	$3,200	$4,700	$10,100
Assembly						
Labor (hours)	5	6	7	10	12	15
Cost ($23.85/hr)	$119	$143	$167	$238	$286	$358
Overhead@40%	$48	$57	$67	$95	$114	$143
Total Assembly Cost	$167	$200	$234	$334	$401	$501
Total Variable Cost	$2,600	$4,300	$6,500	$3,500	$5,100	$10,600
Markup @ 29%	$800	$1,200	$1,900	$1,000	$1,500	$3,100
Total Hardware RPE	$3,400	$5,500	$8,400	$4,500	$6,600	$13,700

5.5.1.2 Fixed Engineering Costs

The fixed vessel costs associated with the use of switching to lower sulfur fuel are shown in Table 5-26. These costs include research and development, and marine society approval; it assumed there would not be any new retooling costs incurred. These costs as applied to U.S.-flagged vessels are included in the total estimated cost of the coordinated strategy.

Table 5-26 Fixed Costs for Fuel Switching Hardware Costs on New Vessels

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (0.25 year R&D)	$172,000	$172,000	$172,000	$172,000	$172,000	$172,000
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$880**	**$880**	**$880**	**$880**	**$880**	**$880**

5.5.1.3 Total Cost to New Vessels

Total vessel hardware cost estimates associated with the coordinated strategy were developed from the number of new ships expected to require additional hardware to accommodate the use of lower sulfur fuel (approximately one-third as discussed in Section 5.2.2.3). All new vessels were considered to have the average characteristics (including propulsion power) shown in Table5-3. The variable and fixed cost estimates developed for the six engine configurations shown above were used to develop $/kW equations that were applied to the number of new ships, by ship and engine type, expected to require this additional hardware. The total estimated hardware costs to new U.S.-flagged vessels are shown below in Table5-27, these costs are included in the total cost associated with the coordinated strategy. The total estimated hardware costs to foreign-flagged vessels are shown in Table 5-27, however, these costs are only shown here for the sake of completeness and are not included in the total cost estimate of the coordinated strategy.

Table 5-27 Total Estimated New Vessel Hardware Costs - U.S.-Flagged

TOTAL US FLAG					
Year	SSD	MSD	Gas Turbine	Steam Turbine	Total
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	$0	$0	$0
2015	$499,000	$38,100	$3,900	$125,000	$666,000
2016	$518,000	$39,500	$4,100	$129,000	$691,000
2017	$539,000	$41,000	$4,300	$133,000	$717,000
2018	$560,000	$42,500	$4,500	$138,000	$745,000
2019	$582,000	$44,100	$4,700	$143,000	$774,000
2020	$605,000	$45,800	$4,900	$148,000	$804,000
2021	$628,000	$47,500	$5,200	$153,000	$834,000
2022	$653,000	$49,300	$5,400	$158,000	$866,000
2023	$679,000	$51,200	$5,700	$163,000	$899,000
2024	$706,000	$53,100	$5,900	$169,000	$934,000
2025	$734,000	$55,200	$6,200	$175,000	$970,000
2026	$764,000	$57,300	$6,500	$181,000	$1,010,000
2027	$794,000	$59,500	$6,800	$187,000	$1,050,000
2028	$826,000	$61,800	$7,200	$194,000	$1,090,000
2029	$859,000	$64,200	$7,500	$200,000	$1,130,000
2030	$894,000	$66,700	$7,900	$207,000	$1,180,000
2031	$930,000	$69,300	$8,200	$215,000	$1,220,000
2032	$968,000	$72,100	$8,600	$222,000	$1,270,000
2033	$1,010,000	$74,900	$9,000	$230,000	$1,320,000
2034	$1,050,000	$77,900	$9,500	$238,000	$1,380,000
2035	$1,090,000	$81,000	$9,900	$246,000	$1,430,000
2036	$1,140,000	$84,200	$10,400	$255,000	$1,490,000
2037	$1,180,000	$87,600	$10,900	$264,000	$1,540,000
2038	$1,230,000	$91,100	$11,400	$274,000	$1,610,000
2039	$1,280,000	$94,800	$12,000	$283,000	$1,670,000
2040	$1,330,000	$98,600	$12,600	$293,000	$1,730,000
NPV @ 3%	$12,600,000	$946,000	$109,000	$2,960,000	$16,600,000
NPV @ 7%	$6,610,000	$497,000	$56,000	$1,570,000	$8,730,000

Table 5-28 Total Estimated New Vessel Hardware Costs – Foreign Flagged

TOTAL FOREIGN FLAG					
Year	SSD	MSD	Gas Turbine	Steam Turbine	Total
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	$0	$0	$0
2015	$16,500,000	$1,090,000	$127,000	$1,630,000	$19,300,000
2016	$17,200,000	$1,140,000	$133,000	$1,690,000	$20,200,000
2017	$17,800,000	$1,190,000	$140,000	$1,760,000	$20,900,000
2018	$18,600,000	$1,240,000	$147,000	$1,830,000	$21,800,000
2019	$19,300,000	$1,290,000	$154,000	$1,900,000	$22,600,000
2020	$20,100,000	$1,350,000	$161,000	$1,970,000	$23,600,000
2021	$20,900,000	$1,410,000	$169,000	$2,050,000	$24,500,000
2022	$21,800,000	$1,470,000	$177,000	$2,130,000	$25,600,000
2023	$22,700,000	$1,530,000	$186,000	$2,220,000	$26,600,000
2024	$23,600,000	$1,600,000	$194,000	$2,310,000	$27,700,000
2025	$24,600,000	$1,670,000	$204,000	$2,400,000	$28,900,000
2026	$25,600,000	$1,740,000	$214,000	$2,490,000	$30,000,000
2027	$26,600,000	$1,820,000	$224,000	$2,590,000	$31,200,000
2028	$27,700,000	$1,890,000	$235,000	$2,700,000	$32,500,000
2029	$28,900,000	$1,980,000	$246,000	$2,810,000	$33,900,000
2030	$30,100,000	$2,060,000	$258,000	$2,920,000	$35,300,000
2031	$31,300,000	$2,160,000	$271,000	$3,040,000	$36,800,000
2032	$32,600,000	$2,250,000	$284,000	$3,160,000	$38,300,000
2033	$34,000,000	$2,350,000	$298,000	$3,290,000	$39,900,000
2034	$35,400,000	$2,450,000	$312,000	$3,420,000	$41,600,000
2035	$36,900,000	$2,560,000	$327,000	$3,560,000	$43,300,000
2036	$38,500,000	$2,670,000	$343,000	$3,710,000	$45,200,000
2037	$40,100,000	$2,790,000	$360,000	$3,860,000	$47,100,000
2038	$41,800,000	$2,920,000	$377,000	$4,010,000	$49,100,000
2039	$43,500,000	$3,050,000	$395,000	$4,180,000	$51,100,000
2040	$45,400,000	$3,180,000	$414,000	$4,350,000	$53,300,000
NPV @ 3%	$424,000,000	$28,900,000	$3,590,000	$41,200,000	$497,000,000
NPV @ 7%	$221,000,000	$15,000,000	$1,850,000	$21,600,000	$260,000,000

5.5.2 Existing Vessels Hardware Costs

5.5.2.1 Existing Vessel Variable Costs

Existing vessels are required to meet the ECA lower sulfur fuel standards beginning in 2015. The existing vessel hardware costs associated with the coordinated strategy are those that may be incurred if additional hardware is required to accommodate the use of lower sulfur. Based on the methodology described above in Section 5.1.2.2, it is estimated that over two-thirds of vessels would not require additional hardware. For the remaining vessels, the hardware requirements would be similar to those discussed in Section 5.4.1, and would most likely include

additional distillate fuel storage tanks, an LFO fuel separator, an HFO/LFO blending unit, a 3-way valve, an LFO cooler, filters, a viscosity meter, and various pumps and piping. This cost analysis does not reflect other design options such as partitioning of a residual fuel tank to allow for lower sulfur fuel capacity which would reduce the amount of additional space required, nor does this analysis reflect the possibility that some ships may have already been designed to carry smaller amounts of distillate fuel in separate tanks for purposes other than continuous propulsion.

Similar to the costs to new vessels, the existing vessel hardware cost analysis assumes sufficient capacity for 250 hours of main and auxiliary engine operation, which may be an overestimate of the amount of fuel necessary to call on U.S. ports. The variable costs associated with existing vessels are shown in Table 5-29. Retrofitting a vessel is expected to require more effort than making upgrades during new vessel construction, to address this, additional labor is allocated for installing equipment to accommodate the use of lower sulfur fuel on existing ships. The cost of the extra tanks is assumed to be the same as that for new vessels, shown in Table -24. The costs were developed for each of the six different engine sizes and types used in this analysis, and are shown plotted in Figure 5-7 from which a curve fit was developed to obtain an equation for the $/kW cost of this technology that could be applied to other engine types and sizes.

Table 5-29 Variable Costs Associated with the use of Lower Sulfur Fuel - Existing Vessels

SPEED	**MEDIUM**	**MEDIUM**	**MEDIUM**	**LOW**	**LOW**	**LOW**
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Hardware Cost to Supplier						
Component Costs						
Additional Tanks	$3,400	$5,500	$8,300	$4,600	$6,500	$13,700
LFO Separator	$2,800	$3,300	$3,800	$3,800	$4,200	$4,700
HFO/LFO Blending Unit	$4,200	$4,700	$5,600	$4,700	$5,600	$6,600
3-Way Valve	$950	$1,400	$1,900	$1,400	$1,900	$2,800
LFO Cooler	$2,400	$2,800	$3,300	$2,800	$3,800	$4,700
Filters	$950	$950	$950	$950	$950	$950
Viscosity Meter	$1,400	$1,400	$1,400	$1,400	$1,400	$1,400
Piping/Pumps	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Total Component Cost	**$18,100**	**$22,100**	**$27,300**	**$21,600**	**$26,400**	**$36,900**
Assembly						
Labor (hours)	480	640	960	640	960	1200
Cost ($23.85/hr)	$11,400	$15,300	$22,900	$15,300	$22,900	$28,600
Overhead @ 40%	$4,600	$6,100	$9,200	$6,100	$9,200	$11,400
Total Assembly Cost	**$16,000**	**$21,400**	**$32,100**	**$21,400**	**$32,100**	**$40,000**
Total Variable Cost	$34,100	$43,400	$59,300	$43,000	$58,400	$77,000
Markup @ 29%	$9,900	$12,600	$17,200	$12,500	$17,000	$22,300
Total Hardware RPE	**$44,000**	**$55,000**	**$76,500**	**$55,500**	**$75,400**	**$99,300**

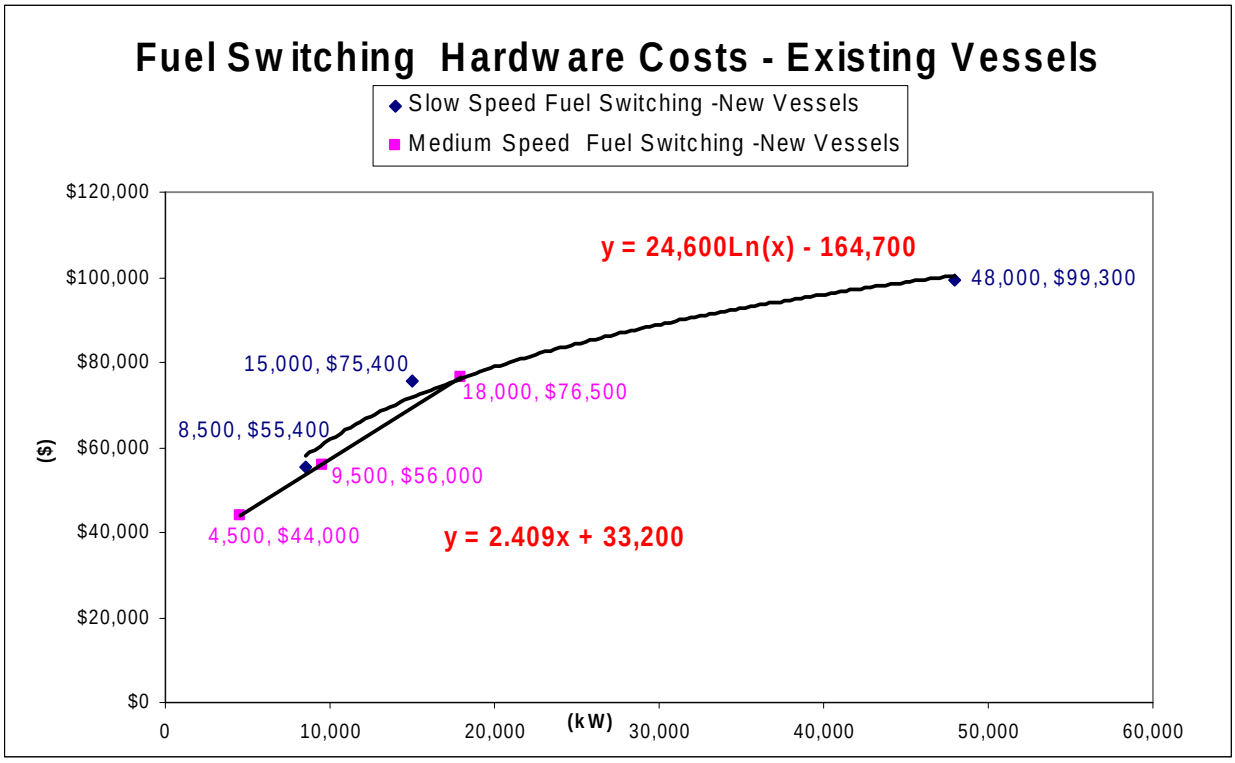

Figure 5-7 Variable Cost Curve Fit for Fuel Switching Vessels Costs to Existing Vessels

5.5.2.2 Fixed Engineering Costs

The fixed costs associated with the use of switching to lower sulfur fuel for existing vessels are shown in Table 5-30, and are similar to the cost for new vessels; however, additional research and development is provided to test systems on existing ships. The fixed costs are applied to U.S.-flagged vessels and are included in the total estimated cost of the coordinated strategy.

Table 5-30 Fixed Costs for Fuel Switching Hardware Costs on Existing Vessels

SPEED	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW
Engine Power (kW)	**4,500**	**9,500**	**18,000**	**8,500**	**15,000**	**48,000**
Cylinders	**9**	**12**	**16**	**6**	**8**	**12**
Liters/cylinder	**35**	**65**	**95**	**380**	**650**	**1400**
Engine Speed (rpm)	**650**	**550**	**500**	**130**	**110**	**100**
Fixed Costs						
R&D Costs (0.33 year R&D)	$227,040	$227,040	$227,040	$227,040	$227,040	$227,040
Marine Society Approval	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Engines/yr.	40	40	40	40	40	40
Years to recover	5	5	5	5	5	5
Fixed cost/engine	**$1,160**	**$1,160**	**$1,160**	**$1,160**	**$1,160**	**$1,160**

5.5.2.3 Total Costs to Existing Vessels

The total estimated cost to existing vessels includes both variable and fixed costs. Analysis of these costs to both U.S.-flagged and foreign-flagged vessels that affect U.S. emissions was completed and while U.S.-flagged costs are included in the total estimated cost of the coordinated strategy, foreign-flagged costs are presented only for the benefit of ship owners. The fuel sulfur standards take effect in 2015, and for the purposes of simplification all vessels were assumed to be modified by 2015 therefore all hardware costs were applied in 2015. The cost to existing U.S.-flagged vessels is estimated to be $10.4 million in 2015. The cost to foreign-flagged vessels in 2015 is estimated to be $317 million. Table 5-31 shows the estimated costs to U.S- and foreign-flagged vessels through 2015 included all fixed and variable costs.

Table 5-31 Estimated Costs to Existing Vessels - U.S. and Foreign Flagged

TOTAL US FLAG			
Year	Fixed	Variable	Total
2010	$155,700	$0	$155,700
2011	$161,500	$0	$161,500
2012	$167,600	$0	$167,600
2013	$173,800	$0	$173,800
2014	$180,300	$0	$180,300
2015	$0	$10,400,000	$10,400,000
TOTAL FOREIGN FLAG			
Year	Fixed	Variable	Total
2010	$4,671,000	$0	$4,671,000
2011	$4,855,000	$0	$4,855,000
2012	$5,048,000	$0	$5,048,000
2013	$5,249,000	$0	$5,249,000
2014	$5,458,000	$0	$5,458,000
2015	$0	$316,900,000	$316,900,000

5.6 Operating Costs

5.6.1 Tier II Fuel Consumption Impacts

We estimate a two percent fuel consumption penalty associated with the engine modifications made to comply with Tier II standards. The two percent fuel penalty estimate is based on the use of modifications to the fuel delivery system to achieve Tier II NO_X reductions, and does not reflect the possibility that there may be other technologies available to manufacturers that could offset this fuel penalty (see Chapter 4 for more details). Additionally, Tier III will provide an opportunity to re-optimize engines for fuel economy when using aftertreatment such as SCR to provide NO_X reductions. To estimate the cost of this fuel penalty, we applied the two percent to the total fuel consumed presented in the inventory (Chapter 3) and the fuel prices described in Section 5.5.4. The engines must continue to meet Tier II standards globally after 2015; therefore, this fuel penalty is projected even for Tier III engines. However, for engines equipped with SCR, we assume that the fuel penalty will not be incurred when the engine is operating in the ECA where Tier III standards apply because the use of SCR

aftertreatment affords the opportunity to advance the fuel injection timing for fuel efficiency while using the exhaust aftertreatment technology to achieve Tier III NO_X levels. These operational costs were applied to both U.S.- and foreign-flagged vessel operations estimated in the inventory analysis and are shown in Table 5-32 below, these costs are included in the total estimated cost of the coordinated strategy.

Table 5-32 Operational Costs Associated with Tier II

YEAR	U.S. FLAG		FOREIGN FLAG		TOTAL			
	Residual Fuel (Tonnes)	Distillate Fuel (Tonnes)	Residual Fuel (Tonnes)	Distillate Fuel (Tonnes)	Residual Fuel (Tonnes)	Distillate Fuel (Tonnes)	CO2 Emissions (Tonnes)	Distillate and Residual Fuel Costs[a]
2010	0	0	0	0	0	0	0	$0
2011	516	14	3,361	107	3,878	121	12,729	$1,306,556
2012	2,519	63	16,596	515	19,115	577	62,682	$6,431,250
2013	4,873	118	31,985	983	36,858	1,101	120,825	$13,249,217
2014	7,184	174	47,257	1,449	54,441	1,623	178,450	$19,567,804
2015	2,127	7,172	3,709	57,335	5,836	64,507	223,903	$32,201,585
2016	2,604	8,302	4,591	66,590	7,196	74,892	261,286	$37,530,731
2017	3,055	7,890	5,468	63,265	8,523	71,155	253,615	$36,240,842
2018	3,706	7,971	6,692	64,206	10,399	72,176	262,837	$37,367,120
2019	4,307	7,897	7,862	63,702	12,169	71,599	266,634	$37,708,847
2020	0	12,035	0	70,273	0	82,309	261,988	$38,513,853
2021	0	12,454	0	71,154	0	83,608	266,125	$39,121,913
2022	0	12,905	0	72,466	0	85,371	271,737	$39,946,889
2023	0	12,739	0	67,999	0	80,739	256,991	$37,779,189
2024	0	12,578	0	63,722	0	76,301	242,865	$35,702,589
2025	0	12,779	0	62,561	0	75,340	239,807	$35,253,126
2026	0	12,564	0	58,117	0	70,681	224,979	$33,073,186
2027	0	12,264	0	53,759	0	66,022	210,149	$30,893,155
2028	0	11,918	0	48,529	0	60,447	192,404	$28,284,583
2029	0	12,100	0	47,729	0	59,829	190,436	$27,995,257
2030	0	12,173	0	45,646	0	57,819	184,039	$27,054,822
2031	0	12,802	0	47,703	0	60,505	192,586	$28,311,283
2032	0	13,980	0	54,026	0	68,006	216,464	$31,821,543
2033	0	14,711	0	56,740	0	71,451	227,429	$33,433,355
2034	0	14,967	0	55,524	0	70,491	224,371	$32,983,936
2035	0	15,412	0	55,390	0	70,802	225,362	$33,129,589
2036	0	15,844	0	55,446	0	71,290	226,916	$33,358,073
2037	0	16,128	0	52,665	0	68,793	218,969	$32,189,713
2038	0	16,367	0	51,713	0	68,080	216,698	$31,855,940
2039	0	17,026	0	52,845	0	69,871	222,401	$32,694,254
2040	0	17,320	0	52,368	0	69,688	221,816	$32,608,299
NPV @ 3%	26,400	193,000	113,000	944,000	139,000	1,140,000	4,060,000	$580,000,000
NPV @ 7%	21,800	103,000	97,100	549,000	119,000	653,000	2,460,000	$346,000,000

Note:
[a]These fuel costs were estimated using $462/tonne of distillate through 2014, $468/tonne of distillate as of 2015, $322/tonne for residual through 2012, and $346/tonne for residual fuel as of 2013.

The impacts of this estimated increase in fuel consumption on U.S. energy security are small. U.S. energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs. Most discussion of U.S. energy security revolves around the topic of the economic costs of the U.S. dependence on oil imports. The Tier 2 standards modestly increase consumption of petroleum in

ocean-going vessels. This increase in petroleum consumption increases both financial and strategic risks associated with a potential disruption in supply or a spike in cost of oil. As a result, the Tier 2 standards have a modest adverse impact on U.S. energy security. In the recent RFS2 proposal, EPA estimated that the macroeconomic disruption component for energy security at $4.74 per barrel or oil, or alternatively, $0.11/gallon. In the case of ocean-going vessels, there is no energy security-related monopsony component since the oil consumed in the vessels in purchased outside the U.S.

5.6.2 Tier III Urea Consumption

In addition to the SCR hardware costs discussed above in Section 5.2.4, ships built asof 2016 would also incur operating costs associated with SCR's use of urea. The urea costs are based on a price of $1.52 per gallon with a density of 1.09 g/cc. The cost per gallon was derived for a 32.5 percent urea solution delivered in bulk to the ship through research completed by ICF combined with historical urea price information.[8,9,10,11] This cost analysis uses a urea dosing rate that is 7.5 percent of the BSFC to estimate how much urea would be used by different engine types and sizes. These operational costs were applied to both U.S. and foreign-flagged vessels, and are shown in Table 5-33 below. These costs are included in the total estimated cost of the coordinated strategy.

Table 5-33 Operation Costs Associated with the use of Urea with SCR for Tier 3 –U.S.- and Foreign-Flagged

YEAR	U.S.-FLAG	FOREIGN-FLAG	TOTAL
2010	$0	$0	$0
2011	$0	$0	$0
2012	$0	$0	$0
2013	$0	$0	$0
2014	$0	$0	$0
2015	$0	$0	$0
2016	$934,000	$7,110,000	$8,040,000
2017	$4,320,000	$34,500,000	$38,800,000
2018	$8,220,000	$66,100,000	$74,300,000
2019	$12,100,000	$97,500,000	$110,000,000
2020	$15,800,000	$127,000,000	$143,000,000
2021	$19,500,000	$157,000,000	$177,000,000
2022	$22,700,000	$183,000,000	$206,000,000
2023	$27,700,000	$225,000,000	$253,000,000
2024	$32,300,000	$263,000,000	$295,000,000
2025	$36,500,000	$297,000,000	$334,000,000
2026	$40,800,000	$333,000,000	$374,000,000
2027	$44,900,000	$367,000,000	$412,000,000
2028	$49,500,000	$406,000,000	$456,000,000
2029	$53,900,000	$441,000,000	$495,000,000
2030	$58,500,000	$480,000,000	$539,000,000
2031	$62,300,000	$512,000,000	$574,000,000
2032	$66,000,000	$543,000,000	$609,000,000
2033	$70,100,000	$577,000,000	$647,000,000
2034	$74,900,000	$618,000,000	$693,000,000
2035	$79,700,000	$658,000,000	$738,000,000
2036	$85,100,000	$702,000,000	$787,000,000
2037	$91,300,000	$753,000,000	$844,000,000
2038	$97,100,000	$801,000,000	$898,000,000
2039	$103,000,000	$847,000,000	$950,000,000
2040	$109,000,000	$896,000,000	$1,010,000,000
NPV @ 3%	$660,000,000	$5,410,000,000	$6,070,000,000
NPV @ 7%	$299,000,000	$2,450,000,000	$2,750,000,000

5.6.3 Operation on Lower-Sulfur Fuel

The increased operating costs associated with the use of lower sulfur fuel, as discussed in Section 5.5.4, were applied to the fuel consumption values presented in the inventory. The costs in 2014 and 2015 represent operation on 1.0 percent sulfur residual fuel in the proposed ECA. Costs for 2015 and later represent operation on 0.1 percent sulfur distillate fuel in the proposed ECA. These costs were applied to both U.S.- and foreign-flagged vessels and are presented in the Table 5-34 below, and are included in the total estimated cost of the coordinated strategy.

Table 5-34 Operational Costs Associated with the use of Lower Sulfur Fuel (in $thousands)

YEAR	US FLAG	FOREIGN FLAG	TOTAL
2010	$0	$0	$0
2011	$0	$0	$0
2012	$0	$0	$0
2013	$30,700	$201,000	$232,000
2014	$31,800	$209,000	$241,000
2015	$176,000	$1,160,000	$1,340,000
2016	$180,000	$1,210,000	$1,390,000
2017	$190,000	$1,260,000	$1,450,000
2018	$200,000	$1,310,000	$1,510,000
2019	$200,000	$1,370,000	$1,570,000
2020	$210,000	$1,430,000	$1,640,000
2021	$220,000	$1,490,000	$1,710,000
2022	$230,000	$1,550,000	$1,780,000
2023	$240,000	$1,620,000	$1,860,000
2024	$250,000	$1,690,000	$1,940,000
2025	$260,000	$1,760,000	$2,020,000
2026	$270,000	$1,840,000	$2,110,000
2027	$280,000	$1,920,000	$2,200,000
2028	$290,000	$2,000,000	$2,290,000
2029	$300,000	$2,090,000	$2,390,000
2030	$310,000	$2,180,000	$2,500,000
2031	$330,000	$2,280,000	$2,600,000
2032	$340,000	$2,380,000	$2,720,000
2033	$350,000	$2,480,000	$2,840,000
2034	$370,000	$2,600,000	$2,960,000
2035	$380,000	$2,710,000	$3,100,000
2036	$400,000	$2,830,000	$3,240,000
2037	$420,000	$2,960,000	$3,380,000
2038	$440,000	$3,100,000	$3,540,000
2039	$450,000	$3,240,000	$3,700,000
2040	$470,000	$3,390,000	$3,870,000
NPV @ 3%	$4,500,000	$31,000,000	$35,500,000
NPV @ 7%	$2,370,000	$16,300,000	$18,600,000

5.6.4 Projected Fuel Costs

This section presents our analysis of the impact of the proposed ECA on marine fuel costs. We project that the 1,000 ppm fuel sulfur limit, beginning in 2015, will likely result in the use of distillate fuel for operation in ECAs.[M] As such, the primary cost of the fuel sulfur limit

[M] As an alternative, an exhaust gas cleaning device (scrubber) may be used. This analysis does not include the effect on distillate fuel demand of this alternative approach. It is expected that scrubbers would only be used in the case where the operator determines that the use of a scrubber would result in a cost savings relative to using

will be that associated with switching from heavy fuel oil to higher-cost distillate fuel, when operating in the ECA. Some engines already operate on distillate fuel and would not be affected by fuel switching costs. On the other hand, distillate fuel costs may be affected by the need to further refine the distillate fuel to meet the 1,000 ppm S limit. To investigate these effects, studies were performed on the impact of a U.S/Canadian ECA on global fuel production and costs. These studies, which are summarized below, include economic modeling to project bunker fuel demand and refinery modeling to assess the impact of a U.S./Canada ECA on fuel costs. Detailed documentation of these studies may be found in the docket.

5.6.4.1 Bunker Fuel Demand Modeling

To assess the affect of an ECA on the refining industry, we needed to first understand and characterize the fuels market and more specifically the demand for the affected marine fuels both currently and in the future. Research Triangle Institute (RTI) was contracted to conduct a fuels study using an activity-based economic approach.[12] The RTI study established baseline bunker fuel demand, projected a growth rate for bunker fuel demand, and established future bunker fuel demand volumes. The basis for this work was the Global Insights economic model which projects international trade for different categories of commodities. Demand for marine fuels was derived from the demand of transportation of various types of cargoes by ship, which, in turn, was derived from the demand for commodities produced in one region of the world and consumed in another. The flow of commodities was matched with typical vessels for that trade (characterized according to size, engine power, age, specific fuel consumption, and engine load factors). Typical voyage parameters were assigned, including average ship speed, round trip mileage, tons of cargo shipped, and days in port. Fuel consumption for each trade route and commodity type was thus a function of commodity projections, ship characteristics, and voyage characteristics.

The bunker demand model included operation off the coasts of the contiguous United States and southeastern Alaska. The bunker demand volumes for this modeling in the Canadian portion of the North American ECA was based on fuel consumed by ships en route to and from Canadian ports based on estimates from Environment Canada.

The affected fuel volumes used in the WORLD model are slightly higher than what we now estimate for the proposed ECA. This difference is because the RTI evaluation of affected fuel volumes was performed before the ECA was defined and was performed independently of the emission inventory modeling described in Chapter 3. However, we believe it is reasonable to use the fuel cost increases, on a per-tonne basis, from the WORLD modeling to estimate the impact of the proposed ECA. In earlier work,[13] EnSys modeled a number of fuel control scenarios where the volume of affected fuel was adjusted to represent (1) different ECAs or (2) various penetration scenarios of exhaust gas scrubbers (as an alternative to fuel switching). This work suggests that the differences in fuel volume between these scenarios have only a small effect on fuel cost. Although this earlier work was based on the older crude oil and refinery costs used in the expert group study, it is sufficient for observing the sensitivity of fuel cost

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distillate fuel. Therefore we are only estimating the cost of compliance using distillate fuel here as we believe this is the most likely approach.

increases to small changes (on a global scale) in affected fuel volume. In addition, the larger affected fuel volume, used in the WORLD modeling, directionally increases the projected fuel cost increases, and therefore allows for a conservative analysis.

5.6.4.2 Bunker Fuel Cost Modeling

5.6.4.2.1 Methodology

To assess the impacts of the proposed ECA on fuel costs, the World Oil Refining Logistics and Demand (WORLD) model was run by Ensys Energy & Systems, the owner and developer of the refinery model. The WORLD model is the only such model currently developed for this purpose, and was developed by a team of international petroleum consultants. It has been widely used by industries, government agencies, and OPEC over the past 13 years, including the Cross Government/Industry Scientific Group of Experts, established to evaluate the effects of the different fuel options proposed under the revision of MARPOL Annex VI.[14] The model incorporates crude sources, global regions, refinery operations, and world economics. The results of the WORLD model have been shown to be comparable to other independent predictions of global fuel, air pollutant emissions and economic predictions.

WORLD is a comprehensive, bottom-up model of the global oil downstream that includes crude and noncrude supplies; refining operations and investments; crude, products, and intermediates trading and transport; and product blending/quality and demand. Its detailed simulations are capable of estimating how the global system can be expected to operate under a wide range of different circumstances, generating model outputs such as price effects and projections of refinery operations and investments.

5.6.4.2.2 Assessment of the Impact of Marine Fuel Standards

During the development of the amendments to MARPOL Annex VI, a Cross Government/Industry Scientific Group of Experts was established, by IMO, to evaluate the effects of the different fuel options that were under consideration at the time. This expert group engaged the services of EnSys to assess the impact of these fuel options using the WORLD model. The final report from this study presents great detail on the capabilities of the WORLD model and provides support for why the WORLD model was chosen as the appropriate tool for modeling the economic impacts of the different fuel options.[15] The following description of the WORLD model is taken from the expert group study:

WORLD is a linear programming model that simulates the activities and economics of the world regional petroleum industry against short, medium or long term horizons. It models and captures the interactions between:

- crude supply;
- non-crudes supply: Natural gas Liquids (NGLs), merchant MTBE, biofuels, petrochemical returns, Gas To Liquid fuels (GTLs), Coal to Liquid fuels (CTLs);
- refining operations;
- refining investment;
- transportation of crudes, products and intermediates;

- product blending/quality;
- product demand; and
- market economics and pricing.

The model includes a database representing over 180 world crude oils and holds detailed, tested, state-of-the-art representation of fifty-plus refinery processes. These representations include energy requirements based on today's construction standards for new refinery units. It allows for advanced representation of processes for reformulated, ultra-lower sulfur/aromatics fuels and was extended for detailed modeling of marine fuels for the aforementioned EPA and API studies. The model contains detailed representations of the blending and key quality specifications for over 50 different products spread across the product spectrum and including multiple grades of gasolines, diesel fuels/gasoils (marine and non-marine) and residual fuels (marine and non-marine).

The refining industry is a co-product industry. This means that changes in production of one product also affect production volume and/or production costs of other products. As necessary, the model will adjust refinery throughputs and operations, crude and product trade patterns to ensure that a specified product demand slate is met, without surplus or deficit of any product.

To evaluate the impact of changes to marine fuels specifications as a result of any of the options under consideration, the model is run with a future demand scenario for all products. The first run, the base case, assumes marine fuels in line the current Annex VI regulation. The second run is done with marine fuel specifications in line with the option under consideration. Both runs are optimized independently. Since the only thing that is altered between the cases is the change in the projected marine fuels regulation, the difference between both cases is therefore a true assessment of the actual cost and other implications of the change to the marine fuels requirements under consideration. Thus, the incremental refining investment costs, incremental marine fuel costs and incremental refinery/net CO_2 emissions are all directly attributable to, and must be allocated to, the change in regulation.

Prior to the expert group study, EnSys made updates to the WORLD model to be able to perform the analysis of the impacts of different marine fuel options. As part of this effort, the refinery data, capacity additions, technology assumptions, and costs were reviewed. EnSys reviewed relevant regulations to ensure that the WORLD model was correctly positioned to undertake future analyses of marine fuels ECAs. In developing these updates, a number of issues had to be considered:

- the costs of refining, including the capital expenditures required to reduce bunker fuel sulfur content and the potential for process technology improvements;
- likely market reactions to increased bunker fuel costs, such as fuel grade availability, impacts on the overall transportation fuels balance, and competition with land-based diesel and residual fuels for feedstocks that can upgrade fuels;
- the effects of emissions trading; and

- the potential for low- and high-sulfur grade bunker sources and consumption to partially shift location depending on supply volume, potential, and economics.

The analytical system thus had to be set up to allow for alternative compliance scenarios, particularly with regard to (a) adequately differentiating bunker fuel grades; (b) allowing for differing degrees to which the ECA or other standards in a region were presumed to be met by bunker fuel sulfur reductions, rather than by other means such as scrubbing or emissions trading; and (c) allowing for all residual fuel bunker demand to be reallocated to marine diesel. Beyond any international specifications, the analytical system needed to be able to accommodate future consideration of regional, national, and local specifications.

The primary approach taken to manage these issues was to

- expand the number of bunker grades in the model to three distillates and four residual grades,[N]
- allow for variation where necessary in (regional) sulfur standards on specific bunker grades, and
- enable residual bunker demand to be switched to marine diesel.

Other updates to the WORLD model included product transportation matrices covering tanker, interregional pipeline, and minor modes were expanded to embody the additional distillate and residual bunker grades, adjustments to the yield patterns of the residuum desulfurization, and blocking of paraffinic streams from residual fuel blends. The details of compliance in any particular region must be estimated external to the main WORLD model. As discussed above, we provided our estimates of affected fuel volumes to Ensys.

5.6.4.2.3 Updates for ECA Analysis

To determine the impact of a North American ECA, the WORLD model was employed using the same basic approach as for the IMO expert group study. Modeling was performed for 2020 in which the control case included a fuel sulfur level of 1,000 ppm in the U.S. and Canadian EEZs.[16] The baseline case was modeled as "business as usual" in which ships continue to use the same fuel as today. This approach was used for two primary reasons. First, significant emission benefits are expected in an ECA, beginning in 2015, due to the use of 1,000 ppm S fuel. These benefits, and costs, would be much higher in the early years of the program before the 5,000 ppm S global standard goes into effect. By modeling this scenario, we are able to observe the impact of the proposed ECA in these early years. Second, there is no guarantee that the global 5,000 ppm S fuel sulfur standards will begin in 2020. The global standard may be delayed until 2025, subject to a fuel availability review in 2018. In addition, the 35,000 ppm S

[N] Specifically, the following seven grades were implemented: MGO, plus distinct high- and low-sulfur blends for MDO and the main residual bunker grades IFO 180 and IFO 380. The latest international specifications applying to these fuels were used, as were tighter sulfur standards for the low-sulfur grades applicable in SECAs.

global standard, which begins in 2012, is higher than the current residual fuel sulfur average of 27,000 ppm S.

In the modeling for the expert group study, crude oil prices were based on projections released by the U.S. Energy Information Administration (EIA) in 2006.[17] Since that time, oil prices have fluctuated greatly. Using new information, EIA has updated its projections of oil price for 2020.[18,19] In response to this real-world effect, the ECA modeling was conducted using the updated oil price estimates. Specifically, we used a crude oil price of $51.55 for the reference case, and $88.14/bbl for the high price case, both expressed in real (2006) dollars. These crude oil prices were input to the WORLD model which then computed residual and distillate marine oil prices for 2020. The net refinery capital impacts are imputed based on the differences in the costs to the refining industry that occur between the Base Cases and ECA cases in 2020. The incremental global refining investment over the Base Case is projected to cost an additional $3.83 billion, with $1.48 billion being used for debottlenecking projects and $1.96 billion used for new units. For the high priced crude case, the incremental capital investments for an ECA is $3.44 billion over the base case, with new units accounting for $2.49 billion while debottlenecking costs are $0.72 billion. For both of the crude oil price cases, refinery investments represent a marginal increase of about 2% over the corresponding total base case investments required in 2020. Additionally, the majority of these ECA investments occur in the U.S./Canada refining regions, though smaller amounts also occur in other world regions. In addition to increased oil price estimates, the updated model accounts for increases in natural gas costs, capital costs for refinery upgrades, and product distribution costs.

5.6.4.3 Results of Fuel Cost Study

5.6.4.3.1 Incremental Refinery Capital Investments Associated with Desulfurization

The primary refining cost of desulfurization is associated with converting IFO bunker oil into a distillate fuel with a DMA specification. The other significant refining costs are those related to desulfurizing distillate stocks. The bulk of the refinery investments occur in regions located outside of the U.S. and Canada, because capital investments in these regions are approximately 9 and 23 percent of the overall capital for the reference and high priced crude cases, respectively. Table 5-35 summarizes the overall capital investments made for both conversion of IFO bunker oil into distillate as well as desulfurization in refineries in the various U.S. regions (East Coast, West Coast and Gulf Coast) and overseas. These cost estimates are based on the WORLD modeling results.

Table 5-35 Incremental Refinery Capital Investment Made in 2020 (2006 dollars)

	REFINERY INVESTMENTS ($ BILLION)					
	Base Case $52/bbl Crude	**NA ECA $52/bbl Crude**	**Delta**	**Base Case $88/bbl Crude**	**NA ECA $88/bbl Crude**	**Delta**
USEC	1.4	1.2	-0.2	1.0	0.9	-0.1
USGCCE	14.5	14.8	0.3	26.2	27.3	1.2
USWCCW	1.4	1.6	0.2	1.4	1.5	0.2
Refinery Investments Total USA+Canada	17.3	17.6	0.3	28.6	29.8	1.3
Refinery Investments Total Other Regions	85.2	88.1	2.9	110.5	115.0	4.4
Total World	102.5	105.7	3.2	139.1	144.8	5.7
Type of Modification						
Debottleneck	0.7	0.7	0.0	1.4	1.4	0.0
Major New Units	97.8	100.8	3.0	132.1	138.0	6.0
Total World	102.5	105.7	3.2	139.1	144.8	5.7

Notes:
USEC is United States East Coast, USGCCE is United States Gulf Coast and Eastern Canada, USWCCW is United States West Coast and Western Canada, $Bn is Billion U.S. Dollars. The results presented are investments made in 2020 to add new refinery processing capacity to what exists in the 2008 base case plus known projects.

Refinery investments in North America, Greater Caribbean and South American regions account for greater than half of all investments for the reference case, while investments made in China and Middle Eastern Gulf regions account for close to 40 percent of remaining investments. This accounts for greater than 90 percent of investments for the reference case. For the high price case, investments in the U.S., Canada, Greater Caribbean and South American refiner regions again account for greater than half of all investments made, while European north and China regions account for greater than 44 percent of the remaining investments. Table 5-36 summarizes overall incremental investments made in all world refining regions for the reference and high price case.

Table 5-36 World Region Refining Investments for ECA Made in 2020

	REFERENCE CASE		HIGH PRICED CASE	
	Capital, $ Billion	% of Capital	Capital, $ Billion	% of Capital
USEC	-0.167	-5.2%	-0.095	-1.7%
USGICE	0.277	8.7%	1.159	20.3%
USWCCW	0.176	5.5%	0.224	3.9%
GrtCAR	0.253	7.9%	0.828	14.5%
SthAM	0.810	25.4%	0.870	15.3%
AfWest	0.004	0.1%	0.002	0.0%
AfN-EM	0.143	4.5%	-0.006	-0.1%
Af-E-S	0.007	0.2%	0.006	0.1%
EUR-No	0.011	0.4%	1.239	21.7%
EUR-So	-0.006	-0.2%	-0.035	-0.6%
EUR-Ea	0.021	0.7%	-0.014	-0.2%
CaspRg	0.157	4.9%	-0.001	0.0%
RusFSU	0.185	5.8%	0.036	0.6%
MEGulf	0.754	23.6%	0.119	2.1%
PacInd	-0.115	-3.6%	0.069	1.2%
PacHi	0.177	5.5%	0.000	0.0%
China	0.490	15.3%	1.305	22.9%
RoAsia	0.018	0.6%	-0.002	0.0%
Total	3.20	100.0%	5.70	100.0%

Notes:
USEC = US East Coast, USGICE= US Gulf Coast, Interior & Canada East, USWCCW= US West Coast & Canada West, GrtCAR= Greater Caribbean, SthAM= South America, AfWest=African West, AFN- EM= North Africa/Eastern Mediterranean, AF-E-S=Africa East and South, Eur-No=Europe North, EUR-So= Europe South, EUR-EA= Europe East, CaspRg= Caspian Region, RusFSU= Russia & Other Former Soviet Union, MEGulf= Middle East Gulf, Pac Ind= Pacific Industrialized, PacHi= Pacific High Growth / Industrializing, RoAsia= Rest of Asia

5.6.4.3.2 Capacity and Throughput Changes for the Reference Case

The WORLD model used a total of 140 thousand barrels per stream day (KBPSD) of coking capacity to convert residual stocks to distillates. Of this amount, 110 KBPSD is existing spare or "slack" capacity available in U.S. and Canada refiner regions. This capacity is available based on projections that refiners add excess coking capacity in the base case. The remaining balance of coking capacity, or 30 KBPSD, is new capacity added to refiner regions outside of United States and Canada, equivalent to one additional coker. In addition to utilizing more coking capacity, the WORLD model also increased residual hydrocracking capacity by 50 KBPSD to convert residual stocks into distillates. These one to two additional hydrocrackers were added to refiner regions located outside of United States and Canada. Overall, considering the use of cokers and residual hydrocrackers, the total refiner process capacity is 190 KBPSD for residual stocks processing, mirroring the amount needed to process the residual volumes contained in IFO180 and IFO 380 bunker grades. To remove any gas oils in residual blendstocks

such as atmospheric and vacuum tower residuals, the model utilized 60 KBPSD of existing vacuum tower capacity, 50 KBPSD in U.S. and Canada and 10 KBPSD in other refiner regions.

Crude throughput is increased by 54 KBPSD, primarily to account for increased energy usage in refinery processes such as hydro crackers and hydrotreaters. Crude throughput is also increased to offset liquid volume loss from residual stocks that are converted to petroleum coke in coking units. Table 5-37 summarizes overall crude and non crude throughputs for the base and ECA cases.

Table 5-37 Refiner Crude and Non Crude Throughputs

		REFERENCE BASE CASE	REFERENCE ECA CASE	DELTA	HIGH BASE CASE	HIGH ECA CASE	DELTA
Crude Throughput	MMBPD	86.7	86.7	0.1	75.6	75.6	0.0
Non Crude Supply							
NGL ETHANE	MMBPD	1.7	1.7	0.0	1.7	1.7	0.0
NGLs C3+	MMBPD	6.3	6.3	0.0	6.1	6.1	0.0
PETCHEM RETURNS	MMBPD	1.0	1.0	0.0	0.8	0.8	0.0
BIOMASS	MMBPD	1.5	1.5	0.0	3.0	3.0	0.0
METHANOL (EX NGS)	MMBPD	0.1	0.1	0.0	0.1	0.1	0.0
GTL LIQUIDS (EX NGS)	MMBPD	0.3	0.3	0.0	0.6	0.6	0.0
CTL LIQUIDS (EX COAL)	MMBPD	0.5	0.5	0.0	0.8	0.8	0.0
HYDROGEN (EX NGS)	MMBPD	1.0	1.0	0.0	0.8	0.9	0.1
Total Non Crude Supply	MMBPD	12.3	12.3	0.0	14.0	14.0	0.0
TOTAL Supply	MMBPD	99.3	99.4	0.1	90.2	90.3	0.1

The model added 70 KBPSD of new ultra lower sulfur gas oil hydrocracking capacity in refiner regions outside of the U.S. and Canada. The distillate produced from these units has a sulfur content low enough to meet ECA standards and therefore does not require further processing in hydrotreaters. The model also reduced throughput by 40 KBPSD in existing base case capacity for Conventional Gas Oil Hydrocrackers located in U.S. and Canada refiner regions.

The model added 160 KBPSD of new conventional distillate hydrotreating capacity, 140 KBPSD to U.S. and Canada refiner regions and 20 KBPSD in refining regions in other areas of the world. In addition to new units, the model used 150 KBPSD of “slack” distillate conventional hydrotreating capacity, 90 KBPSD of this located in U.S. and Canada and 60 KBPSD in other world refiner regions. Considering this, the total net use of conventional distillate hydrotreating for the reference case is 310 KBPSD above the base case, mirroring incremental demand of lower sulfur distillate for ECA. The model used 70 KBPSD of slack capacity for vacuum gas oil/residual hydrotreating in addition to distillate hydrotreating. Of this amount, 40 KBPSD is in U.S. and Canada and 30 KBPSD in other world refiner regions.

The increased hydrotreating and hydrocracking capacity requires new hydrogen and sulfur plant capacity and was added to refiner regions that use more distillate hydrotreating and

hydrocracking. Other minor refinery process modifications were required by the model in 2020, although these were not substantial (see Table 5-38).

Table 5-38 Refinery Secondary Processing Capacity Additions in 2020 Reference Case (Million barrels per stream day)

	USE OF BASE CAPACITY			NEW CAPACITY			**BASE PLUS NEW CAPACITY**		
	US/CAN	Rest of World	Total	US/CAN	Rest of World	Total	US/CAN	Rest of World	Total
Total Additions Over Base	0.00	0.05	0.05	0.00	0.05	0.05	0.00	0.05	0.05
Total Crude Capacity Used 2020	0.02	0.04	0.05	0.02	0.04	0.05	0.017	0.037	0.054
Vacuum Distillation	0.05	0.01	0.06	0.00	(0.02)	(0.02)	0.05	(0.01)	0.04
Coking	0.11	0.00	0.12	0.00	0.02	0.02	0.11	0.03	0.14
Catalytic Cracking	(0.07)	0.01	(0.06)	0.00	(0.01)	(0.01)	(0.07)	0.00	(0.07)
Hydro-Cracking (TOTAL)	(0.04)	0.00	(0.04)	0.00	0.12	0.12	(0.04)	0.12	0.08
- Gasoil Conventional	(0.04)	0.00	(0.04)	0.00	0.00	0.00	(0.04)	0.00	(0.04)
- Gasoil ULS	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.07	0.07
- Resid LS	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01
- Resid MS	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.04	0.04
Catalytic Reforming with Revamp	0.01	0.00	0.02	0.00	0.07	0.07	0.01	0.07	0.08
Hydrotreating (Total)	0.13	0.08	0.21	0.11	0.05	0.17	0.24	0.14	0.37
- Gasoline – ULS	0.00	(0.00)	(0.00)	(0.03)	0.03	(0.00)	(0.03)	0.02	(0.01)
Distillate -New Conv/LS	0.09	0.06	0.15	0.14	0.02	0.16	0.23	0.08	0.31
- VGO/Resid	0.04	0.03	0.06	0.00	0.00	0.00	0.04	0.03	0.07
Hydrogen, (MMSCFD)	0	70	70	8	211	218	8	280	288
Sulfur Plant, (TPD)	500	500	1000	10	130	140	510	630	1140

While coking and hydrocracking (residual and gas oil) processes primarily produce distillates, to a lesser extent, some low octane gasoline blendstocks are also manufactured, requiring refiners to install additional catalytic reforming unit capacity. As such, in the U.S. and Canada regions approximately 10 KPBSD of existing spare CCR capacity is used while approximately 70 BPSD of new CCR capacity is added to other WORLD refiner regions that added cokers and hydrocrackers.

5.6.4.3.3 Capacity and Throughput Changes for the High Price Crude Oil Case

For the high priced case, the high cost of crude and high capital costs for processing units push the model to reduce installation of new processing units. The price of natural gas is also reduced relative to the price of crude which induces the model to use more natural gas and reduce the use of crude. Under these conditions, the model uses less crude, more natural gas and installs less capital for refinery processing units. As a result, the model favors the use of more

hydrocracking processing which adds hydrogen (made from natural gas) to residual and gas oils, producing lower sulfur distillates stocks that do not require further processing in hydrotreaters. The model also uses more synthetic crudes and less heavy sour crudes, which reduce the amounts of residual stocks that need upgrading.

Crude throughput is increased by 29 KBPSD, which is less than the reference case, as the model preferentially uses natural gas over crude and reduces the use of cokers and hydrotreating. Table 5-39 shows crude and non crude inputs for the high priced case.

The WORLD model used a total of 80 KBPSD of "slack" coking capacity to convert residual stocks to distillates. Of this amount, 70 KBPSD was used in the U.S. and Canada regions and 10 KBPSD in regions in other areas of the world. The model also added 80 KBPSD of new low and medium sulfur residual hydrocracking capacity to convert residual stocks into distillates—20 KBPSD in the U.S. and Canada and 60 KBPSD in other world refiner regions. Overall, considering the use of cokers and residual hydrocrackers, the total refiner process capacity for residual stocks processing for use in the ECA is 160 KBPSD for the high priced case.

To extract gas oils from residual blendstocks, the model utilized 90 KBPSD of existing vacuum tower capacity—80 KBPSD in the U.S. and Canada and 10 KBPSD on other refiner regions. In addition, the model added 120 KBPSD of new ultra lower sulfur gas oil hydrocracking capacity in refiner regions outside of the U.S. and Canada. The distillate fuel produced from these units meet ECA sulfur standards. The model also used 30 KBPSD of slack capacity in the U.S. and Canada refiner regions for hydrocracking of conventional gas oil.

The model added 40 KBPSD of new conventional distillate hydrotreating capacity to the U.S. and Canada refiner regions and 20 KBPSD of new capacity to refining regions in other areas of the world. While the model also used 40 KBPSD of "slack" conventional distillate hydrotreating capacity in the U.S. and Canada, other world refiner regions decreased use of base case or slack capacity by 80 KBPSD. Considering the use of the new and slack capacity, a total net use of capacity is 20 KBPSD of conventional distillate hydrotreating capacity. The model also used 60 KBPSD of existing slack capacity for vacuum gas oil/residual distillate hydrotreaters, with 20 KBPSD used in the U.S. and Canada refiner regions and 40 KBPSD in other world refining regions.

The use of additional hydrocracking and hydrotreater capacity requires installation of new hydrogen plant capacity. New sulfur plant capacity is required in refiner regions to process the offgas produced from incremental use of hydro cracking and hydrotreating (see Table 5-39 below).

Table 5-39 Refinery Secondary Processing Capacity Additions in 2020 High Priced Case (Million barrels per stream day)

	USE OF BASE CAPACITY			NEW CAPACITY			BASE PLUS NEW CAPACITY		
	US/CAN	Rest of World	Total	US/CAN	Rest of World	Total	US/CAN	Rest of World	Total
Total Additions Over Base Case	0.00	(0.05)	(0.05)	0.00	(0.05)	(0.05)	0.00	(0.05)	(0.05)
Total Crude Capacity Used in 2020	0.05	(0.02)	0.03	0.05	(0.02)	0.03	0.054	(0.024)	0.029
Vacuum Distillation	0.08	0.10	0.18	0.00	0.00	0.00	0.08	0.10	0.18
Coking	0.07	0.01	0.08	0.00	(0.00)	(0.00)	0.07	0.00	0.08
Catalytic Cracking	(0.03)	(0.05)	(0.09)	0.00	0.00	0.00	(0.03)	(0.05)	(0.09)
Hydro-Cracking (Total)	0.03	0.00	0.03	0.02	0.18	0.20	0.05	0.18	0.22
- Gasoil Conventional	0.03	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.03
- Gasoil ULS	0.00	0.00	0.00	0.00	0.12	0.12	0.00	0.12	0.12
- Resid LS	0.00	0.00	0.00	0.02	0.03	0.05	0.02	0.03	0.05
- Resid MS	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.03	0.03
Catalytic Reforming with Revamp	0.00	0.02	0.02	(0.05)	0.02	(0.03)	(0.05)	0.04	(0.00)
Hydrotreating (Total)	0.06	(0.04)	0.02	0.04	0.02	0.06	0.11	(0.03)	0.08
- Gasoline – ULS	0.00	0.00	0.00	0.00	(0.01)	(0.01)	0.00	(0.01)	(0.01)
Distillate -New Conv/LS	0.04	(0.08)	(0.03)	0.04	0.02	0.06	0.08	(0.06)	0.02
- VGO/Resid	0.02	0.03	0.05	0.00	0.00	0.00	0.02	0.04	0.06
Hydrogen, (MMSCFD)	0	0	0	243	325	568	243	325	568
Sulfur Plant, (TPD)	580	300	880	0	120	120	580	420	1000

5.6.4.3.4 Overall Increases Due to Fuel Switching and Desulfurization

Global fuel use in 2020 by international shipping is projected to be 500 million metric tonnes per year (tonnes/yr). The main energy content effects of bunker grade shifts were captured in the WORLD modeling by altering the volume demand and, at the same time, consistency was maintained between the bunker demand figures in tonnes and in barrels. The result was that partial or total conversion of IFO to distillate was projected to lead to a reduction in the total global tonnes of bunker fuel required but also led to a projected increase in the barrels required. These effects are evident in the WORLD case results. Because only a small portion of global marine fuel is consumed in the ECA, the overall impact on global fuel production is small. Global fuel use in 2020 by ships is projected to be 500 million metric tonnes/yr. Of this amount, 90 million metric tonnes of fuel is used for U.S./Canadian trade, or about 18 percent of total global fuel use. In the proposed ECA, less than 20 million metric tonnes of fuel will be consumed in 2020, which is less than 4 percent of total global marine fuel use. Of the amount of fuel to be consumed in the proposed ECA in 2020, about 4 million metric tonnes of distillate will be consumed in the Business as Usual (BAU) case, which is about 20 percent of the amount of

total fuel to be consumed in the proposed ECA.[O] As would be expected, since the shift in fuel volumes on a world scale is relatively small, the WORLD model predicts the overall global impact of an ECA to also be small.

There are two main components to projected increased marine fuel cost associated with an ECA. The first component results from the shifting of operation on residual fuel to operation on higher cost distillate fuel. This is the dominant cost component. The WORLD model computed costs based on a split between the costs of residual and distillate fuels. However, there is a small cost associated with desulfurizing the distillate to meet the 1,000 ppm S standard in the ECA. Based on the WORLD modeling, the average increase in costs associated with switching from marine residual to distillate will be $145 per tonne.[P] This is the cost increase that will be borne by the shipping companies purchasing the fuel. Of this amount, $6 per tonne is the cost increase associated with distillate desulfurization. In other words, we estimate a cost increase of $6/tonne for distillate fuel used in an ECA.

The above cost estimates are based on EIA's "reference case" projections for crude oil price in 2020. We also performed a sensitivity analysis using EIA's "high price" scenario. Under this scenario, the increase in fuel costs for switching from residual to distillate fuel is $237 per tonne. The associated increase in distillate fuel cost is $7 per tonne.

Table 5-40 summarizes the reference and high price fuel cost estimates with and without an ECA. In the baseline case, fuel volumes for operation are 18% marine gas oil (MGO), 7% marine diesel oil (MDO), and 75% IFO. In the ECA, all fuel volumes are modeled as MGO.

Table 5-40 Estimated Marine Fuel Costs

FUEL	UNITS	REFERENCE CASE		HIGH PRICE CASE	
		Baseline	ECA	Baseline	ECA
MGO	$/bbl	$ 61.75	$ 62.23	$ 102.70	$ 103.03
	$/tonne	$ 464	$ 468	$ 772	$ 775
MDO	$/bbl	$ 61.89	$ 62.95	$ 102.38	$ 103.70
	$/tonne	$ 458	$ 466	$ 757	$ 767
IFO	$/bbl	$ 49.87	$ 49.63	$ 83.14	$ 82.52
	$/tonne	$ 322	$ 321	$ 538	$ 534

[O] For this analysis, the U.S. included the lower contiguous states and southeastern Alaska.

[P] Note that distillate fuel has a higher energy content, on a per tonne basis, than residual fuel. As such, there is an offsetting cost savings, on a per tonne basis, for switching to distillate fuel. Based on a 5 percent higher energy content for distillate, the net equivalent cost increase is estimated as $123 for each tonne of residual fuel that is being replaced by distillate fuel ($200/tonne for the high price case).

5.7 Summary of Final Program Engineering Costs

5.7.1 Engineering Costs for Freshly Manufactured Engines

The total engine costs presented here include the fixed and variable costs of CAA Tier 2 and Tier 3 technologies to U.S.-flagged vessels, and are included in the total estimated cost of the coordinated strategy. The costs associated with the existing engine program are not included here but are presented in Section 5.3.1. The engine related costs to new U.S.-flagged vessels through 2040 at a 3 percent discount rate is estimated to be $0.66 billion, and $0.35 billion at a 7 percent discount rate.

Table 5-41 Total U.S.-Flagged Engine Costs for Freshly Manufactured Engines

YEAR	FIXED	VARIABLE	TOTAL
2010	$309,000	$0	$309,000
2011	$837,000	$2,580,000	$3,420,000
2012	$869,000	$2,680,000	$3,550,000
2013	$902,000	$2,780,000	$3,680,000
2014	$936,000	$2,890,000	$3,830,000
2015	$972,000	$3,000,000	$3,970,000
2016	$0	$27,400,000	$27,400,000
2017	$0	$28,400,000	$28,400,000
2018	$0	$29,600,000	$29,600,000
2019	$0	$30,700,000	$30,700,000
2020	$0	$31,900,000	$31,900,000
2021	$0	$33,200,000	$33,200,000
2022	$0	$34,500,000	$34,500,000
2023	$0	$35,900,000	$35,900,000
2024	$0	$37,400,000	$37,400,000
2025	$0	$38,800,000	$38,800,000
2026	$0	$40,400,000	$40,400,000
2027	$0	$42,000,000	$42,000,000
2028	$0	$43,700,000	$43,700,000
2029	$0	$45,500,000	$45,500,000
2030	$0	$47,400,000	$47,400,000
2031	$0	$49,300,000	$49,300,000
2032	$0	$51,300,000	$51,300,000
2033	$0	$53,400,000	$53,400,000
2034	$0	$55,600,000	$55,600,000
2035	$0	$57,900,000	$57,900,000
2036	$0	$60,200,000	$60,200,000
2037	$0	$62,700,000	$62,700,000
2038	$0	$65,300,000	$65,300,000
2039	$0	$68,000,000	$68,000,000
2040	$0	$70,800,000	$70,800,000
NPV @ 3%	$4,440,000	$658,000,000	$663,000,000
NPV @ 7%	$3,990,000	$342,000,000	$346,000,000

5.7.2 Engineering Costs for Vessels

The vessel costs presented here are associated with the use of lower sulfur fuel to meet the 2015 fuel sulfur standards for U.S.-flagged vessels. The costs here include additional equipment that may be required to accommodate the use of lower sulfur fuel on both new and existing vessels. The total cost to U.S.-flagged ships through 2040 at a 3 percent discount rate is $0.26 billion, or $0.17 billion at a seven percent discount rate.

Table 5-42 U.S.-Flagged Vessel Engineering Costs

YEAR	FIXED	VARIABLE	TOTAL
2010	$166,000	$0	$166,000
2011	$172,000	$0	$172,000
2012	$179,000	$0	$179,000
2013	$185,000	$0	$185,000
2014	$192,000	$0	$192,000
2015	$0	$11,100,000	$11,100,000
2016	$0	$691,000	$691,000
2017	$0	$717,000	$717,000
2018	$0	$745,000	$745,000
2019	$0	$773,000	$773,000
2020	$0	$803,000	$803,000
2021	$0	$834,000	$834,000
2022	$0	$866,000	$866,000
2023	$0	$899,000	$899,000
2024	$0	$934,000	$934,000
2025	$0	$970,000	$970,000
2026	$0	$1,010,000	$1,010,000
2027	$0	$1,050,000	$1,050,000
2028	$0	$1,090,000	$1,090,000
2029	$0	$1,130,000	$1,130,000
2030	$0	$1,180,000	$1,180,000
2031	$0	$1,220,000	$1,220,000
2032	$0	$1,270,000	$1,270,000
2033	$0	$1,320,000	$1,320,000
2034	$0	$1,370,000	$1,370,000
2035	$0	$1,430,000	$1,430,000
2036	$0	$1,490,000	$1,490,000
2037	$0	$1,540,000	$1,540,000
2038	$0	$1,610,000	$1,610,000
2039	$0	$1,670,000	$1,670,000
2040	$0	$1,740,000	$1,740,000
NPV @ 3%	$842,000	$25,600,000	$26,500,000
NPV @ 7%	$781,000	$16,200,000	$16,900,000

5.7.3 Total Increased Operating Costs

The total increase operating costs associated with the coordinated strategy are $42 billion at a 7 percent discount rate in 2040, and $22 billion at a 3 percent discount rate. The operational costs include Tier 2 and global Tier II fuel consumption increases, the use of urea with SCR for Tier 3 and Tier III equipped vessels, and the increased costs associated with the use of lower sulfur fuel. Table 5-43 presents the operating costs for both U.S.- and foreign-flagged vessels, and the total for the coordinated strategy.

Table 5-43 Total Operational Costs ($Thousands)

TOTAL OPERATING COSTS			
Year	U.S.-Flag	Foreign Flag	Total
2010	$0	$0	$0
2011	$0	$1,000	$1,000
2012	$1,000	$6,000	$7,000
2013	$32,000	$213,000	$245,000
2014	$34,000	$226,000	$260,000
2015	$180,000	$1,188,000	$1,368,000
2016	$189,000	$1,250,000	$1,439,000
2017	$199,000	$1,326,000	$1,525,000
2018	$210,000	$1,409,000	$1,619,000
2019	$221,000	$1,500,000	$1,721,000
2020	$233,000	$1,590,000	$1,823,000
2021	$246,000	$1,680,000	$1,926,000
2022	$258,000	$1,767,000	$2,025,000
2023	$272,000	$1,877,000	$2,149,000
2024	$286,000	$1,983,000	$2,269,000
2025	$300,000	$2,086,000	$2,386,000
2026	$315,000	$2,200,000	$2,515,000
2027	$330,000	$2,312,000	$2,642,000
2028	$345,000	$2,429,000	$2,774,000
2029	$362,000	$2,553,000	$2,915,000
2030	$378,000	$2,681,000	$3,059,000
2031	$395,000	$2,814,000	$3,209,000
2032	$413,000	$2,948,000	$3,361,000
2033	$431,000	$3,084,000	$3,515,000
2034	$451,000	$3,244,000	$3,695,000
2035	$471,000	$3,394,000	$3,865,000
2036	$494,000	$3,558,000	$4,052,000
2037	$517,000	$3,738,000	$4,255,000
2038	$541,000	$3,925,000	$4,466,000
2039	$566,000	$4,112,000	$4,678,000
2040	$591,000	$4,311,000	$4,902,000
NPV @ 3%	$5,260,000	$36,900,000	$42,200,000
NPV @ 7%	$2,730,000	$19,000,000	$21,700,000

5.7.4 Total Engineering and Operating Costs Associated with the Final Program

The total engineering hardware and operational costs associated with the coordinated strategy and included in the total cost of the coordinated strategy are described in Table 5-44 and presented in Table 5-45. The total cost of the program through 2040 at a 3 percent discount rate is $43 billion, or $22 billion at a 7 percent discount rate.

Table 5-44 U.S.- and Foreign-Flagged Costs Included in Total

COSTS INCLUDED IN THE TOTAL COORDINATED STRATEGY COST ESTIMATE[A,B]	
U.S.-Flagged Vessels	*Foreign-Flagged Vessels*
Annex VI Existing Engine Program Hardware Costs (No Estimated Fuel Consumption Penalty)	Not Included
Tier 2 Hardware Costs	Not Included
Tier 2 Operational Costs (based on an estimated 2 percent fuel consumption penalty)	Tier 2 Operational (based on an estimated 2 percent fuel consumption penalty)
Tier 3 Hardware Costs	Not Included (Presented as a separate analysis, not included in total cost)
Tier 3 Operational Costs (based on the use of urea with SCR)	Tier 3 Operational (based on the use of urea with SCR)
Lower Sulfur Fuel Hardware Costs (New and Existing Vessels)	Not Included (Presented as a separate analysis, not included in total cost)
Lower Sulfur Fuel Operational Costs (based on the differential price of lower sulfur fuel)	Lower Sulfur Fuel Operational Costs (based on the differential price of lower sulfur fuel)

Notes:
[a] The cost totals reported in this NPRM are slightly different than those reported in the ECA proposal, because the ECA proposal did not include costs associated with the Annex VI existing engine program, Tier II, or the costs associated with existing vessel modifications that may be required to accommodate the use of lower sulfur fuel. Further, the cost totals presented in the ECA package included Canadian cost estimates.
[b] For a more detailed explanation of these costs, see Chapter 5 of the draft RIA.

Table 5-45 Total Costs Associated with the Coordinated Strategy ($Thousands)

YEAR	FIXED	VARIABLE	OPERATIONAL	TOTAL
2010	$485	$0	$0	$485
2011	$1,020	$2,730	$1,310	$5,060
2012	$1,060	$2,820	$6,430	$10,300
2013	$1,100	$2,920	$245,000	$249,000
2014	$1,140	$3,020	$261,000	$265,000
2015	$972	$14,200	$1,370,000	$1,380,000
2016	$0	$28,100	$1,440,000	$1,470,000
2017	$0	$29,200	$1,530,000	$1,550,000
2018	$0	$30,300	$1,620,000	$1,650,000
2019	$0	$31,500	$1,720,000	$1,750,000
2020	$0	$32,700	$1,820,000	$1,850,000
2021	$0	$34,000	$1,930,000	$1,960,000
2022	$0	$35,400	$2,030,000	$2,060,000
2023	$0	$36,800	$2,150,000	$2,180,000
2024	$0	$38,300	$2,270,000	$2,310,000
2025	$0	$39,800	$2,390,000	$2,430,000
2026	$0	$41,400	$2,510,000	$2,550,000
2027	$0	$43,100	$2,640,000	$2,680,000
2028	$0	$44,800	$2,770,000	$2,820,000
2029	$0	$46,600	$2,910,000	$2,960,000
2030	$0	$48,500	$3,060,000	$3,110,000
2031	$0	$50,500	$3,210,000	$3,260,000
2032	$0	$52,600	$3,360,000	$3,410,000
2033	$0	$54,700	$3,520,000	$3,570,000
2034	$0	$56,900	$3,690,000	$3,750,000
2035	$0	$59,300	$3,870,000	$3,930,000
2036	$0	$61,700	$4,060,000	$4,120,000
2037	$0	$64,300	$4,260,000	$4,320,000
2038	$0	$66,900	$4,470,000	$4,530,000
2039	$0	$69,700	$4,680,000	$4,750,000
2040	$0	$72,600	$4,910,000	$4,980,000
NPV @ 3%	$5,320	$685,000	$42,200,000	$42,900,000
NPV @ 7%	$4,800	$359,000	$21,700,000	$22,100,000

5.8 Cost Effectiveness

One tool that can be used to assess the value of the coordinated strategy is the measure of cost effectiveness; a ratio of engineering costs incurred per ton of emissions reduced. This analysis involves a comparison of our proposed program to other measures that have been or could be implemented. As summarized in this section, the coordinated strategy represents a highly cost effective mobile source control program for reducing NO_X, PM and SO_X emissions.

We have estimated the cost per ton based on the net present value of 3 percent and 7 percent of all hardware costs incurred by U.S.-flagged vessels, and all operational costs incurred by both U.S.- and foreign-flagged vessels, and all emission reductions generated from the year 2010 through the year 2040. The baseline case for these estimated reductions is the existing set of engine standards for C3 marine diesel engines and existing fuel sulfur limits. Note that $PM_{2.5}$ is estimated to be 92 percent of the more inclusive PM_{10} emission inventory for marine vessels. In Chapter 3, 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, Table5-46 shows the annual emissions reductions associated with the coordinated strategy, these annual tons are undiscounted. A description of the methodology used to estimate these annual reductions can be found in Chapter 3 of the draft RIA.

Table 5-46 Estimated Emissions Reductions Associated with the Coordinated Strategy (Short tons)

CALENDAR YEAR	REDUCTIONS (TONS)		
	NO_X	SO_X	PM
2010	47,000	0	0
2011	54,000	0	0
2012	70,000	0	0
2013	88,000	390,000	48,400
2014	105,000	406,000	50,400
2015	123,000	641,000	68,000
2016	150,000	668,000	70,800
2017	209,000	695,000	73,700
2018	279,000	724,000	76,800
2019	349,000	755,000	80,000
2020	409,000	877,000	94,100
2021	488,000	916,000	98,200
2022	547,000	954,000	102,000
2023	634,000	995,000	107,000
2024	714,000	1,040,000	111,000
2025	790,000	1,080,000	116,000
2026	866,000	1,130,000	121,000
2027	938,000	1,170,000	126,000
2028	1,020,000	1,220,000	131,000
2029	1,100,000	1,280,000	137,000
2030	1,180,000	1,330,000	143,000
2031	1,260,000	1,390,000	149,000
2032	1,330,000	1,450,000	155,000
2033	1,410,000	1,510,000	162,000
2034	1,500,000	1,580,000	169,000
2035	1,590,000	1,650,000	177,000
2036	1,690,000	1,720,000	184,000
2037	1,810,000	1,800,000	193,000
2038	1,920,000	1,880,000	201,000
2039	2,020,000	1,970,000	210,000
2040	2,130,000	2,050,000	220,000
NPV at 3%	14,400,000	19,100,000	2,100,000
NPV at 7%	6,920,000	10,100,000	1,090,000

The net estimated reductions by pollutant, using a net present value of 3 percent from 2010 through 2040 are 14.4 million tons of NO_X, 19.1 million tons of SO_X, and 2.1 million tons of PM (6.9 million, 10.1 million, and 1.1 million tons of NO_X, SO_X, and PM, respectively, at a net present value of 7 percent over the same period.)

Using the above cost and emission reduction estimates, we estimated the lifetime (2010 through 2040) cost per ton of pollutant reduced. For this analysis, all of the hardware costs associated with the Annex VI existing engine program, and Tier 2 and Tier 3 NO_X standards as well as the operational costs associated with the CAA Tier 2 and Tier 3, and global Tier II and Tier III NO_X standards were attributed to NO_X reductions. The costs associated with lower

sulfur fuel operational costs as applied to all vessels visiting U.S. ports and the hardware costs associated with accommodating the use of lower sulfur fuel on U.S.-flagged vessels were associated with SOX and PM reductions. In this analysis, we have allocated half of the costs associated with the use of lower sulfur fuel to PM and half to SO_X, because the costs incurred to reduce SO_X emissions directly reduce emissions of PM as well. Using this allocation of costs and the emission reductions shown in Table5-46, we can estimate the lifetime cost per ton reduced associated with each pollutant. The resultant estimated cost effectiveness numbers are shown in Table 5-47. Using a net present value of 3 percent, the discounted lifetime cost per ton of pollutant reduced is $510 for NO_X, $930 for SO_X, and $7,950 for PM ($500, $920, and $7,850 per ton of NO_X, SO_X, and PM, respectively, at a net present value of 7 percent.) As shown in Table 5-47, these estimated discounted lifetime costs are similar to the annual long-term (2030) cost per ton of pollutant reduced.

Table 5-47 Coordinated Strategy Estiamted Aggregate Discounted Cost per Ton and Long-Term Annual Cost per Ton[a, b]

POLLUTANT	2010 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 3%	2010 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 7%	LONG-TERM COST PER TON (FOR 2030)
NO_X	$510	$500	$520
SO_X	$930	$920	$940
PM	$7,950	$7,850	$8,060

Notes:
[a] These costs are in 2006 U.S. dollars.
[b] The $/ton numbers presented here vary from those presented in the ECA proposal due to the net present value of the annualized reductions being applied from 2015-2020, and the use of tonnes rather than of short tons.

These results for the coordinated strategy compare favorably to other air emission control programs. Table 5-48 compares the coordinated strategy to other air programs. This comparison shows that the coordinated strategy will provide a cost-effective strategy for generating substantial NO_X, SO_X, and PM reductions from ocean-going vessels. The results presented in Table 5-48 are lifetime costs per ton discounted at a net present value of 3 percent, with the exception of the stationary source program and locomotive/marine retrofits, for which annualized costs are presented. While results at a net present value of 7 percent are not presented, the results would be similar. Specifically, the coordinated strategy falls within the range of values for other recent programs.

Table 5-48 Estimated $/ton for the Coordinated Strategy Compared to Previous Mobile Source Programs for NO_X, SO_X, and PM_{10}

SOURCE CATEGORY[20,a]	IMPLEMENTATION DATE	NO_X COST/TONNE	SO_X COST/TONNE	PM_{10} COST/TONNE
OGV Coordinated Strategy NPRM, 2009	2011	510	930	7,950
Nonroad Small Spark-Ignition Engines 73 *Fed Reg* 59034, October 8, 2008	2010	330-1200[b,c]	-	-
Stationary Diesel (CI) Engines [b] 71 *Fed Reg* 39154, July 11, 2006	2006	580 – 20,000	-	3,500 – 42,000
Locomotives and C1/C2 (Both New and Retrofits) [c] 73 *Fed Reg* 25097, May 6, 2008	2015	730[b]	-	8,400 (New) 45,000 (Retrofit)[b]
Heavy Duty Nonroad Diesel Engines[c] 69 *Fed Reg* 38957, June 29, 2004	2015	1,100[b]	780	13,000
Heavy Duty Onroad Diesel Engines [c] 66 *Fed Reg* 5001, January 18, 2001	2010	2,200[b]	5,800	14,000

Notes:

[a] Table presents aggregate program-wide cost/ton over 30 years, discounted at a 3 percent NPV, except for stationary CI Engines and LocoMarine retrofits, for which annualized costs of control for individual sources are presented. All figures are in 2006 U.S. dollars per short ton.

[b] Includes NO_X plus non-methane hydrocarbons (NMHC). NMHC are also ozone precursors, thus some rules set combined NO_X +NMHC emissions standards. NMHC are a small fraction of NO_X so aggregate cost/ton comparisons are still reasonable.

[c] Low end of range represents costs for marine engines with credit for fuel savings, high end of range represents costs for other nonroad SI engines without credit for fuel savings.

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[4] http://www.marad.dot.gov/documents/Vessel_Calls_at_US_Ports_Snapshot.pdf

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[9] http://www.adblueonline.co.uk/air_1/bulk_delivery

[10] http://www.factsaboutscr.com/documents/IntegerResearch-Ureapricesbackto2005levels.pdf

[11] http://www.fertilizerworks.com/fertreport/index.html

[12] Research Triangle Institute, 2008. "Global Trade and Fuels Assessment—Future Trends and Effects of Designating Requiring Clean Fuels in the Marine Sector"; Research Triangle Park, NC; EPA420-R-08-021; November.

[13] Research Triangle Institute, 2008. "Global Trade and Fuels Assessment—Future Trends and Effects of Designating Requiring Clean Fuels in the Marine Sector"; Research Triangle Park, NC; EPA420-R-08-021; November.

[14] International Maritime Organization, Note by the Secretariat, "Revision of MARPOL Annex VI and NO_X Technical Code; Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Scientific Group of Experts," Subcommittee on Bulk Liquids and Gases, 12th Session, Agenda Item 6, BLG 12/INF.10, December 28, 2007.

[15] International Maritime Organization, Note by the Secretariat, "Revision of MARPOL Annex VI and NO_X Technical Code; Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Scientific Group of Experts," Subcommittee on Bulk Liquids and Gases, 12th Session, Agenda Item 6, BLG 12/INF.10, December 28, 2007.

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CHAPTER 6: COST-BENEFIT ANALYSIS

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 EPA's coordinated strategy to address emissions from Category 3 engines and ocean-going vessels throughout the period from initial implementation through 2030. We provide estimated costs for the entire coordinated strategy, including the Annex VI Tier II NO_X requirements and the ECA controls that will be mandatory for U.S. and foreign vessels through the Act to Prevent Pollution from Ships. However, unlike the cost analysis, this benefits analysis does not allocate benefits between the components of the program (the requirements in this rule and the requirements that would apply through MARPOL Annex VI and ECA implementation). This is because the benefits of the coordinated strategy will be fully realized only when the U.S. ECA is in place and both U.S. and foreign vessels are required to use lower sulfur fuel and operate their Tier 3 NOx controls while in the designated area, and therefore it makes more sense to consider the benefits of the coordinated strategy as a whole..

The components of the coordinated strategy would apply stringent NO_X and SO_X standards to virtually all vessels that affect U.S. air quality, and impacts on human health and welfare would be substantial. As presented in Chapter 2, the coordinated strategy for controlling emissions from Category 3 engines and ocean-going vessels is expected to provide very large reductions in NO_X (a precursor to ozone formation and secondarily-formed $PM_{2.5}$), SO_X (a precursor to secondarily-formed $PM_{2.5}$) and directly-emitted $PM_{2.5}$. These pollutants contribute to on-land concentrations of $PM_{2.5}$ and ozone that cause harm to human health and the environment. This chapter presents the reductions in adverse health impacts that can be expected to occur from the adoption of a coordinated strategy to control ship emissions that includes implementation of the proposed CAA standards and the ECA designation described in this proposal.

Exposure to ozone and $PM_{2.5}$ is linked to adverse human health impacts such as premature deaths as well as other important public health and environmental effects. The most conservative premature mortality estimates (Pope et al., 2002 for $PM_{2.5}$ and Bell et al., 2004 for ozone)[1,2] suggest that implementation of the coordinated strategy would reduce approximately 13,000 premature mortalities in 2030 and yield approximately $110 billion in total benefits. The upper end of the premature mortality estimates (Laden et al., 2006 for $PM_{2.5}$ and Levy et al., 2005 for ozone)[3,4] suggest that implementation of the coordinated strategy would increase the estimate of avoided premature mortalities to approximately 32,000 in 2030 and yield approximately $280 billion in total benefits.[A] Thus, even taking the most conservative premature mortality assumptions, the health impacts of the coordinated strategy presented in this proposal are clearly substantial.

The health impacts modeling presented in this chapter is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality. The

[A] These benefits use a 3% discount rate. Using a 7% discount rate, the benefits are approximately 10% less.

health impact estimates for the coordinated strategy are based on an analytical structure and sequence consistent with health impacts analyses performed by the United States Environmental Protection Agency (EPA) for its recent analyses in support of the final Ozone National Ambient Air Quality Standard (NAAQS) and the final PM NAAQS as well as all of its recent mobile source emission control programs.[5,6] For a more detailed discussion of the principles of health impacts analysis used here, we refer the reader to those NAAQS documents.

To model the ozone and PM air quality impacts of the coordinated strategy, we used the Community Multiscale Air Quality (CMAQ) model (see Chapter 2). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[B] BenMAP is a computer program developed by the EPA that integrates a number of the modeling elements used in previous analyses (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

The range of total ozone- and PM-related benefits associated with the coordinated strategy to control ship emissions is presented in Table 6-1. 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 6-1) to estimates of PM-related premature mortality. These estimates represent EPA's preferred approach to characterizing the best estimate of benefits associated with the coordinated strategy. As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve to reflect the Agency's most current interpretation of the scientific and economic literature. This analysis, therefore, incorporates four important changes from recent RIAs released by the Office of Transportation and Air Quality (OTAQ):

- As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve over time to reflect the Agency's most current interpretation of the scientific and economic literature. For a period of time (2004-2008), the Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature. The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002)[7] meta-analysis of 33 studies and $10 million represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[8] meta-analysis of 46 studies. The mean estimate of $5.5 million (2000$)[C] was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006)[9] meta-analysis. However, the Agency neither changed its official guidance on the use of VSL

[B] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/benmodels.html.

[C] In this analysis, we adjust the VSL to account for a different currency year (2006$) and to account for income growth to 2020 and 2030. After applying these adjustments to the $5.5 million value, the VSL is $7.7m in 2020 and $7.9 in 2030.

in rule-makings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

During this time, the Agency continued work to update its guidance on valuing mortality risk reductions, including commissioning a report from meta-analytic experts to evaluate methodological questions raised by EPA and the SAB on combining estimates from the various data sources. In addition, the Agency consulted several times with the Science Advisory Board Environmental Economics Advisory Committee (SAB-EEAC) on the issue. With input from the meta-analytic experts, the SAB-EEAC advised the Agency to update its guidance using specific, appropriate meta-analytic techniques to combine estimates from unique data sources and different studies, including those using different methodologies (i.e., wage-risk and stated preference) (U.S. EPA-SAB, 2007).[10]

Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore, the Agency has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000) while the Agency continues its efforts to update its guidance on this issue.[D] This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[E]

The Agency is committed to using scientifically sound, appropriately reviewed evidence in valuing mortality risk reductions and has made significant progress in responding to the SAB-EEAC's specific recommendations. The Agency anticipates presenting results from this effort to the SAB-EEAC in the Fall 2009 and that draft guidance will be available shortly thereafter.

- Since 2004, the Office of Air and Radiation (OAR) has employed an interim approach to the Value of a Statistical Life (VSL) that differs from the default methodology defined in EPA's prevailing Economic Guidelines and was not reviewed by the Agency's Science Advisory Board (SAB). At the time, OAR agreed to use this as an interim value while updates to the mortality risk valuation guidance were completed. OAR used a range of $1 million to $10 million (2000$) to arrive at the VSL: the lower end of the range was based on a meta-analysis of 33 studies by Mrozek and Taylor (2002),[11] and the upper end of the range was based on a meta-analysis of 46 studies by Viscusi and Aldy (2003).[12] An average of these figures is $5.5 million (2000$). Based on recent SAB review and a desire for consistency in the application of the VSL within the Agency, we believe it is no longer appropriate to

[D] In the (draft) update of the Economic Guidelines, EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. Therefore, this report does not represent final agency policy. The 2000 guidelines can be downloaded here: http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html, and the draft updated version (2008) of the guidelines can be downloaded here: http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE-0516?OpenDocument

[E] In this analysis, we adjust the VSL to account for a different currency year (2006$) and to account for income growth to 2020 and 2030. After applying these adjustments to the $6.3 million value, the VSL is $8.9m in 2020 and $9.1m in 2030.

continue to use this as an interim value, especially while the Agency awaits a systematic review of the recent valuation literature to inform a revision to the mortality risk valuation guidance.[F] Instead, EPA has decided to apply the VSL that was vetted and endorsed by the Agency when the 2000 Guidelines for Preparing Economic Analyses were drafted. OAR will now apply a VSL that is consistent with the value used by all other branches of the Agency that quantify and monetize mortality incidence. This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[G]

- In recent analyses, OTAQ has estimated $PM_{2.5}$-related benefits assuming that a threshold exists in the PM-related concentration-response functions (at 10 $\mu g/m^3$) below which there are no associations between exposure to $PM_{2.5}$ and health impacts. For the benefits analysis of the coordinated strategy, however, we have revised this assumption. EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. Based on our review of the body of scientific literature, EPA applied the no-threshold model in this analysis, which is consistent with the approach taken in the recently published Portland Cement MACT RIA.[H] EPA's draft Integrated Science Assessment (ISA),[13] which was recently reviewed by EPA's Clean Air Scientific Advisory Committee (CASAC),[14,15] concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. Although this document does not represent final agency policy that has undergone the full agency scientific review process, it provides a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs. It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis. Because the Portland Cement RIA was completed while CASAC was reviewing the PM ISA, we solicited comment on the use of the

[F] EPA is in the process of revisiting this Guidance and has recently engaged the SAB-EEAC on several issues including the use of meta-analysis as a means of combining estimates and approaches for assessing mortality benefits when changes in longevity may vary widely (U.S. EPA, 2006). The Agency is committed to using the best available science in its analyses and will revise this guidance in response to SAB recommendations (see U.S. EPA, 2007 for recent SAB recommendations).
U.S. Environmental Protection Agency (U.S. EPA). 2006. Willingness to Pay for Environmental Health Risk Reductions when there are Varying Degrees of Life Expectancy: A White Paper. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE-0495?OpenDocument
U.S. Environmental Protection Agency (U.S. EPA). 2007. SAB Advisory on EPA's Issues in Valuing Mortality Risk Reduction. http://yosemite.epa.gov/sab/sabproduct.nsf/4128007E7876B8F0852573760058A978/$File/sab-08-001.pdf

[G] For a description of both approaches, please refer to Appendix B of the 2008 draft of EPA's Guidelines for Preparing Economic Analyses. It can be downloaded at http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf

[H] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP has been extended until September 4, 2009.[I] As explained in the recently published Portland Cement MACT RIA,[J] EPA's preferred benefits estimation approach assumes a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels. This approach reflects EPA's most current interpretation of the scientific literature on $PM_{2.5}$ and mortality. Please see Section 6.4.1.3 of the RIA for more discussion of the treatment of thresholds in this analysis.

- For the coordinated strategy, we rely on two empirical (epidemiological) studies of the relationship between ambient $PM_{2.5}$ and premature mortality (the extended analyses of the Harvard Six Cities study by Laden et al (2006) and the American Cancer Society (ACS) cohort by Pope et al (2002)) to anchor our benefits analysis, though we also present the $PM_{2.5}$-related premature mortality benefits associated with the estimates supplied by the expert elicitation as a sensitivity analysis. This approach was recently adopted in the Portland Cement MACT RIA. Since 2006, EPA has calculated benefits based on these two empirical studies and derived the range of benefits, including the minimum and maximum results, from an expert elicitation of the relationship between exposure to $PM_{2.5}$ and premature mortality (Roman et al., 2008).[16] Using alternate relationships between $PM_{2.5}$ and premature mortality supplied by experts, higher and lower benefits estimates are plausible, but most of the expert-based estimates have fallen between the two epidemiology-based estimates (Roman et al., 2008). Assuming no threshold in the empirically-derived premature mortality concentration response functions used in the analysis of the coordinated strategy, only one expert falls below the empirically-derived range while two of the experts are above this range (see Tables 6-5 and 6-6). Please refer to the Portland Cement MACT RIA for more information about the preferred approach and the evolution of the treatment of threshold assumptions within EPA's regulatory analyses.
- The range of ozone benefits associated with the coordinated strategy is estimated based on risk reductions derived from several sources of ozone-related mortality effect estimates. This analysis presents six alternative estimates for the association based upon different functions reported in the scientific literature. We use three multi-city studies,[17,18,19] including the Bell, 2004 National Morbidity, Mortality, and Air Pollution Study (NMMAPS) that was used as the primary basis for the risk analysis in the ozone Staff Paper[20] and reviewed by the Clean Air Science Advisory Committee (CASAC).[21] We also use three studies that synthesize ozone mortality data across a large number of individual studies.[22,23,24] This approach is consistent with recommendations provided by the NRC in their ozone mortality report (NRC, 2008),[25] "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously

[I] Readers interested in commenting on the use of the no-threshold model for benefits analysis should direct their comments to Docket ID No. EPA–HQ–OAR–2002–0051 (available at http://www.regulations.gov) before the comment period closes.

[J] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

published studies." The NRC goes on to note that there are uncertainties within each study that are not fully captured by this range of estimates.

Table 6-1 Estimated 2030 Monetized PM-and Ozone-Related Health Benefits of a Coordinated U.S. Strategy to Control Ship Emissions[a]

2030 TOTAL OZONE AND PM BENEFITS – PM MORTALITY DERIVED FROM AMERICAN CANCER SOCIETY ANALYSIS AND SIX-CITIES ANALYSIS[A]			
Premature Ozone Mortality Function	Reference	Total Benefits (Billions, 2006$, 3% Discount Rate)[b,c]	Total Benefits (Billions, 2006$, 7% Discount Rate)[b,c]
Multi-city analyses	Bell et al., 2004	$110 - $280	$100 - $250
	Huang et al., 2005	$120 - $280	$110 - $250
	Schwartz, 2005	$120 - $280	$110 - $250
Meta-analyses	Bell et al., 2005	$120 - $280	$110 - $250
	Ito et al., 2005	$120 - $280	$110 - $260
	Levy et al., 2005	$120 - $280	$110 - $260

Notes:

[a] Total includes premature mortality-related and morbidity-related 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 either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).

[b] 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 6-2.

[c] 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.

The benefits in Table 6-1 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM and ozone 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 eutrophication in coastal areas. These are listed in Table 6-2. As a result, the health benefits quantified in this chapter are likely underestimates of the total benefits attributable to the implementation of the coordinated strategy to control ship emissions.

Table 6-2 Unquantified and Non-Monetized Potential Effects of a Coordinated U.S. Strategy to Control Ship Emissions

POLLUTANT/ EFFECTS	EFFECTS NOT INCLUDED IN ANALYSIS - CHANGES IN:
Ozone Health[a]	Chronic respiratory damage[b] Premature aging of the lungs[b] Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
Ozone Welfare	Yields for -commercial forests -some fruits and vegetables -non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Ecosystem functions Exposure to UVb (+/-)[e]
PM Health[c]	Premature mortality - short term exposures[d] Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
PM Welfare	Residential and recreational visibility in non-Class I areas Soiling and materials damage Damage to ecosystem functions Exposure to UVb (+/-)[e]
Nitrogen and Sulfate 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 Existence values for currently healthy ecosystems Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
CO Health	Behavioral effects
HC/Toxics Health[f]	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) 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)

HC/Toxics Welfare	Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

Notes:
[a] 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.
[b] 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.
[c] 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.
[d] While some of the effects of short-term exposures are likely to be captured in the estimates, there may be premature mortality due to short-term exposure to PM not captured in the cohort studies used in this analysis. However, the PM mortality results derived from the expert elicitation do take into account premature mortality effects of short term exposures.
[e] May result in benefits or disbenefits.
[f] Many of the key hydrocarbons related to this rule are also hazardous air pollutants listed in the Clean Air Act.

6.2 Quantified Human Health Impacts

Tables 6-3 and 6-4 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the coordinated strategy for both 2020 and 2030. For each endpoint presented in Tables 6-3 and 6-4, we provide both the mean estimate and the 90% confidence interval.

Using EPA's preferred estimates, based on the ACS and Six-Cities studies and no threshold assumption in the model of mortality, we estimate that the coordinated strategy would result in between 5,300 and 14,000 cases of avoided $PM_{2.5}$-related premature deaths annually in 2020 and between 13,000 and 32,000 avoided premature deaths annually in 2030. As a sensitivity analysis, when the range of expert opinion is used, we estimate between 1,900 and 18,000 fewer premature mortalities in 2020 and between 4,500 and 42,000 fewer premature mortalities in 2030.

The range of ozone benefits associated with the coordinated strategy is based on risk reductions estimated using several sources of ozone-related mortality effect estimates. This analysis presents six alternative estimates for the association based upon different functions reported in the scientific literature, derived from both the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Bell et al., 2004) and from a series of recent meta-analyses (Bell et al., 2005, Ito et al., 2005, and Levy et al., 2005). This approach is not inconsistent with recommendations provided by the NRC in their recent report (NRC, 2008) on the estimation of ozone-related mortality risk reductions, "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously published studies."

For ozone-related premature mortality, we estimate a range of between 61 to 280 fewer premature mortalities as a result of the coordinated strategy in 2020 and between 220 to 980 in 2030. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from coordinated strategy, as well as increases in total population and the average age (and thus baseline mortality risk) of the population.

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 6-5 and 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.

In 2020, the effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. Only one expert falls below this range, while two of the experts are above this range. This same relationship occurs in 2030, as well. 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 6-3 Estimated $PM_{2.5}$-Related Health Impacts Associated with a Coordinated U.S. Strategy to Control Ship Emissions[a]

Health Effect	2020 Annual Reduction in Ship-Related Incidence (5^{th}% - 95^{th}%ile)	2030 Annual Reduction in Ship-Related Incidence (5^{th}% - 95^{th}%ile)
Premature Mortality – Derived from Epidemiology Literature[b]		
Adult, age 30+, ACS Cohort Study (Pope et al., 2002)	5,300 (2,100 – 8,500)	13,000 (5,000 – 20,000)
Adult, age 25+, Six-Cities Study (Laden et al., 2006)	14,000 (7,400 – 20,000)	32,000 (18,000 – 47,000)
Infant, age <1 year (Woodruff et al., 1997)	20 (0 – 55)	37 (0 – 100)
Chronic bronchitis (adult, age 26 and over)	3,800 (700 – 6,900)	8,500 (1,600 – 15,000)
Non-fatal myocardial infarction (adult, age 18 and over)	8,800 (3,200 – 14,000)	22,000 (8,100 – 35,000)
Hospital admissions - respiratory (all ages)[c]	1,200 (590 – 1,800)	2,900 1,400 – 4,200)
Hospital admissions - cardiovascular (adults, age >18)[d]	2,700 (2,000 – 3,200)	7,100 (5,000 – 8,300)
Emergency room visits for asthma (age 18 years and younger)	3,500 (2,000 – 4,900)	8,100 (4,800 – 11,000)
Acute bronchitis, (children, age 8-12)	8,500 (0 – 17,000)	19,000 (0 – 37,000)
Lower respiratory symptoms (children, age 7-14)	100,000 (49,000 – 150,000)	220,000 (110,000 – 330,000)
Upper respiratory symptoms (asthmatic children, age 9-18)	77,000 (24,000 – 130,000)	170,000 (54,000 – 290,000)
Asthma exacerbation (asthmatic children, age 6-18)	95,000 (10,000 – 260,000)	210,000 (23,000 – 580,000)
Work loss days	720,000 (630,000 – 810,000)	1,500,000 (1,300,000 – 1,700,000)
Minor restricted activity days (adults age 18-65)	4,300,000 (3,600,000 – 4,900,000)	9,000,000 (7,600,000 – 10,000,000)

Notes:

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope et al., 2002) and the Six-Cities Study (Laden et al., 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).

[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 6-4 Estimated Ozone-Related Health Impacts Associated with a Coordinated U.S. Strategy to Control Ship Emissions[a]

Health Effect	2020 Annual Reduction in Ship-Related Incidence (5^{th}% - 95^{th}%ile)	2030 Annual Reduction in Ship-Related Incidence (5^{th}% - 95^{th}%ile)
Premature Mortality, All ages[b]		
Multi-City Analyses		
Bell et al. (2004) – Non-accidental	61 (23 – 98)	220 (71 – 370)
Huang et al. (2005) – Cardiopulmonary	100 (43 – 160)	370 (140 – 610)
Schwartz (2005) – Non-accidental	93 (34 – 150)	340 (100 – 570)
Meta-analyses:		
Bell et al. (2005) – All cause	200 (100 – 290)	690 (330 – 1,100)
Ito et al. (2005) – Non-accidental	270 (170 – 370)	980 (580 – 1,400)
Levy et al. (2005) – All cause	280 (200 – 360)	980 (670 – 1,300)
Hospital admissions- respiratory causes (adult, 65 and older)[c]	470 (46 – 830)	2,000 (97 – 3,600)
Hospital admissions -respiratory causes (children, under 2)	380 (180 – 590)	1,200 (500 – 2,000)
Emergency room visit for asthma (all ages)	210 (0 – 550)	740 (0 – 1,900)
Minor restricted activity days (adults, age 18-65)	360,000 (160,000 – 570,000)	1,200,000 (440,000 – 1,900,000)
School absence days	130,000 (51,000 – 190,000)	450,000 (150,000 – 680,000)

Notes:

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell et al. (2004); Huang et al. (2005); Schwartz (2005) ; Bell et al. (2005); Ito et al. (2005); Levy et al. (2005). The estimates of ozone-related premature mortality should therefore not be summed.

[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 6-5 Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with a Coordinated U.S. Strategy to Control Ship Emissions

Source of Mortality Estimate	2020 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	2,100	5,300	8,500
Laden et al. (2006)	7,400	14,000	20,000
Expert A	2,600	14,000	26,000
Expert B	1,400	11,000	23,000
Expert C	2,000	11,000	23,000
Expert D	1,600	7,600	12,000
Expert E	9,000	18,000	27,000
Expert F	6,800	9,800	14,000
Expert G	0	6,300	12,000
Expert H	30	8,100	18,000
Expert I	1,700	11,000	19,000
Expert J	2,600	8,700	19,000
Expert K	0	1,900	8,800
Expert L	1,100	7,500	15,000

Table 6-6 Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with a Coordinated U.S. Strategy to Control Ship Emissions

Source of Mortality Estimate	2030 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	5,000	13,000	20,000
Laden et al. (2006)	18,000	32,000	47,000
Expert A	6,300	34,000	61,000
Expert B	3,400	26,000	55,000
Expert C	4,700	26,000	55,000
Expert D	3,800	18,000	30,000
Expert E	22,000	42,000	64,000
Expert F	17,000	24,000	34,000
Expert G	0	15,000	28,000
Expert H	71	19,000	44,000
Expert I	4,100	26,000	45,000
Expert J	6,200	21,000	46,000
Expert K	0	4,500	21,000
Expert L	2,600	18,000	35,000

6.3 Monetized Benefits

Monetized values for each quantified health endpoint are presented in Table 6-7. For each endpoint presented in Table 6-7, we provide both the mean estimate and the 90% confidence interval. Total aggregate monetized benefits are presented in Tables 6-8 and 6-9 using either a 3 percent or 7 percent discount rate, respectively. All of the monetary benefits are in constant-year 2006 dollars.

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 coordinated strategy 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.

Our estimate of total monetized benefits in 2020 for the coordinated strategy, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between $47 billion and $110 billion, assuming a 3 percent discount rate, or between $42 billion and $100 billion, assuming a 7 percent discount rate. In 2030, we estimate the monetized benefits to be between $110 billion and $280 billion, assuming a 3 percent discount rate, or between $100 billion and $260 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 of benefits categories (see Table 6-2). 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 here.

Table 6-7 Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2006$) [a,b]

		2020	2030
$PM_{2.5}$-Related Health Effect		Estimated Mean Value of Reductions (5^{th} and 95^{th} %ile)	
Premature Mortality – Derived from Epidemiology Studies[c,d,]	Adult, age 30+ - ACS study (Pope et al., 2002)		
	3% discount rate	$43,000 ($5,000 - $110,000)	$100,000 ($12,000 - $270,000)
	7% discount rate	$38,000 ($4,500 - $100,000)	$94,000 ($11,000 - $250,000)
	Adult, age 25+ - Six-cities study (Laden et al., 2006)		
	3% discount rate	$110,000 ($14,000 - $270,000)	$270,000 ($35,000 - $670,000)
	7% discount rate	$98,000 ($13,000 - $250,000)	$240,000 ($32,000 - $610,000)
	Infant Mortality, <1 year – (Woodruff et al. 1997)	$180 ($0 - $670)	$330 ($0 - $1,300)
Chronic bronchitis (adults, 26 and over)		$1,900 ($140 - $6,500)	$4,300 ($340 - $15,000)
Non-fatal acute myocardial infarctions			
3% discount rate		$960 ($170 - $2,300)	$2,300 ($390 - $5,600)
7% discount rate		$930 ($160 - $2,300)	$2,200 ($360 - $5,500)
Hospital admissions for respiratory causes		$17 ($8.4 - $25)	$41 ($21 - $61)
Hospital admissions for cardiovascular causes		$76 ($48 - $110)	$190 ($120 - $270)
Emergency room visits for asthma		$1.3 ($0.70 - $1.9)	$3.0 ($1.6 - $4.5)
Acute bronchitis (children, age 8–12)		$0.63 ($0 - $1.6)	$1.4 ($0 - $3.4)
Lower respiratory symptoms (children, 7–14)		$2.0 ($0.75 - $3.7)	$4.4 ($1.7 - $8.1)
Upper respiratory symptoms (asthma, 9–11)		$2.4 ($0.65 - $5.3)	$5.3 ($1.5 - $12)
Asthma exacerbations		$5.1 ($0.51 - $15)	$11 ($1.1 - $34)
Work loss days		$110 ($94 - $120)	$230 ($200 - $260)
Minor restricted-activity days (MRADs)		$270 ($150 – $390)	$570 ($330 - $830)
Ozone-related Health Effect			
Premature Mortality, All ages – Derived from Multi-city analyses	Bell et al., 2004	$540 ($63 - $1,400)	$2,000 ($230 - $5,300)
	Huang et al., 2005	$910 ($110 - $2,300)	$3,400 ($390 - $8,900)
	Schwartz, 2005	$830 ($94 - $2,200)	$3,000 ($320 - $8,200)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	$1,700 ($220 - $4,400)	$6,300 ($810 - $16,000)

	Ito et al., 2005	$2,400 ($330 - $5,900)	$8,900 ($1,200 - $22,000)
	Levy et al., 2005	$2,400 ($340 - $5,900)	$8,900 ($1,200 - $22,000)
Hospital admissions- respiratory causes (adult, 65 and older)		$11 ($1.1 - $20)	$47 ($2.3 - $85)
Hospital admissions- respiratory causes (children, under 2)		$3.8 ($1.8 – $5.9)	$12 ($5.0 - $20)
Emergency room visit for asthma (all ages)		$0.08 ($0.03 - $0.20)	$0.27 ($0 - $0.68)
Minor restricted activity days (adults, age 18-65)		$23 ($9.8 - $41)	$73 ($26 - $130)
School absence days		$12 ($4.6 - $17)	$40 ($13 - $61)

Notes:

[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 from the epidemiology literature is not additive. Rather, the valuations represent a range of possible mortality benefits.

Table 6-8 Total Monetized Benefits Associated with a Coordinated U.S. Strategy to Control Ship Emissions – 3% Discount Rate

Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from the ACS and Six Cities Studies					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$47 - $110	Multi-city	Bell et al., 2004	$110 - $280
	Huang et al., 2005	$47 - $110		Huang et al., 2005	$120 - $280
	Schwartz, 2005	$47 - $110		Schwartz, 2005	$120 - $280
Meta-analysis	Bell et al., 2005	$48 - $110	Meta-analysis	Bell et al., 2005	$120 - $280
	Ito et al., 2005	$48 - $110		Ito et al., 2005	$120 - $280
	Levy et al., 2005	$48 - $110		Levy et al., 2005	$120 - $280
Total Ozone and PM Benefits (billions, 2006$) – 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
Multi-city	Bell et al., 2004	$19 - $150	Multi-city	Bell et al., 2004	$48 - $360
	Huang et al., 2005	$19 - $150		Huang et al., 2005	$49 - $360
	Schwartz, 2005	$19 - $150		Schwartz, 2005	$49 - $360
Meta-analysis	Bell et al., 2005	$20 - $150	Meta-analysis	Bell et al., 2005	$52 - $370
	Ito et al., 2005	$21 - $150		Ito et al., 2005	$54 - $370
	Levy et al., 2005	$21 - $150		Levy et al., 2005	$54 - $370

Table 6-9 Total Monetized Benefits Associated with a Coordinated U.S. Strategy to Control Ship Emissions – 7% Discount Rate

Total Ozone and PM Benefits (billions, 2006$) – PM Mortality Derived from the ACS and Six Cities Studies					
2020			**2030**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$42 - $100	Multi-city	Bell et al., 2004	$100 - $250
	Huang et al., 2005	$43 - $100		Huang et al., 2005	$110 - $250
	Schwartz, 2005	$43 - $100		Schwartz, 2005	$110 - $250
Meta-analysis	Bell et al., 2005	$44 - $100	Meta-analysis	Bell et al., 2005	$110 - $250
	Ito et al., 2005	$44 - $100		Ito et al., 2005	$110 - $260
	Levy et al., 2005	$44 - $100		Levy et al., 2005	$110 - $260
Total Ozone and PM Benefits (billions, 2006$) – 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
Multi-city	Bell et al., 2004	$18 - $130	Multi-city	Bell et al., 2004	$44 - $330
	Huang et al., 2005	$18 - $130		Huang et al., 2005	$45 - $330
	Schwartz, 2005	$18 - $130		Schwartz, 2005	$45 - $330
Meta-analysis	Bell et al., 2005	$19 - $130	Meta-analysis	Bell et al., 2005	$48 - $330
	Ito et al., 2005	$19 - $140		Ito et al., 2005	$51 - $330
	Levy et al., 2005	$19 - $140		Levy et al., 2005	$51 - $330

6.4 Methodology

6.4.1 Human 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), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. The following subsections describe the sources for each of the first three elements: size of the potentially affected populations; $PM_{2.5}$ and ozone effect estimates; and baseline incidence rates. Section 4.2.2 describes the ozone and PM air quality inputs to the health impact functions.

6.4.1.1 Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[26] 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.[27]

6.4.1.2 Effect Estimate Sources

The most significant quantifiable benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents[28,29] and the World Health Organization's 2003 and 2004[30,31] reports outline numerous human health effects known or suspected to be linked to exposure to ambient ozone and PM. EPA recently evaluated the ozone and PM literature for use in the benefits analysis for the final 2008 Ozone NAAQS and final 2006 PM NAAQS analyses. We use the same literature in this analysis; for more information on the studies that underlie the health impacts quantified in this RIA, please refer to those documents.

It is important to note that we are unable to separately quantify all of the possible PM and ozone health effects that have been reported in the literature for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases versus hospital admissions for all or a sub-set of respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; or (3) the lack of an established concentration-response (CR) relationship. Table 6-10 lists the health endpoints included in this analysis.

Table 6-10 Ozone- and PM-Related Health Endpoints

ENDPOINT	*POLLUTANT*	*STUDY*	*STUDY POPULATION*
Premature Mortality			
Premature mortality – daily time series	O_3	Multi-city Bell et al (2004) (NMMAPS study)[32] – Non-accidental Huang et al (2005)[33] - Cardiopulmonary Schwartz (2005)[34] – Non-accidental Meta-analyses: Bell et al (2005)[35] – All cause Ito et al (2005)[36] – Non-accidental Levy et al (2005)[37] – All cause	All ages
Premature mortality —cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[38] Laden et al. (2006)[39]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[40]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[41]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[42]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[43]	Adults (>18 years)
Hospital Admissions			
Respiratory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[44] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[45,46] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[47] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[48]	<2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[49] Ito (2003)—ICD 490-496 (COPD)[50]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[51]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[52]	<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

Asthma-related ER visits	O_3	Pooled estimate: Jaffe et al (2003)[53] Peel et al (2005)[54] Wilson et al (2005)[55]	 5–34 years All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[56]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[57]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[58]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[59]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[60] (cough, wheeze and shortness of breath) Vedal et al. (1998)[61] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[62]	18–65 years
School absence days	O_3	Pooled estimate: Gilliland et al. (2001)[63] Chen et al. (2000)[64]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[65]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

Notes:

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 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.[66,67]

6.4.1.3 Treatment of Potential Thresholds in PM2.5-Related Health Impact Functions

In recent analyses, OTAQ has estimated $PM_{2.5}$-related benefits assuming that a threshold exists in the PM-related concentration-response functions (at 10 $\mu g/m^3$) below which there are no associations between exposure to $PM_{2.5}$ and health impacts. For the benefits analysis of the coordinated strategy, however, we have revised this assumption. As explained in the recently published Portland Cement MACT RIA, EPA's preferred benefits estimation approach assumes

a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. Based on our review of the body of scientific literature, EPA applied the no-threshold model in this analysis, which is consistent with the approach taken in the recently published Portland Cement MACT RIA.[K] EPA's draft Integrated Science Assessment (ISA),[68] which was recently reviewed by EPA's Clean Air Scientific Advisory Committee (CASAC),[69,70] concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. However, during this review, CASAC did not comment on thresholds, and an absence of comments on the ISA regarding thresholds generally implies that CASAC accepted the ISA conclusion. Although this document does not represent final agency policy that has undergone the full agency scientific review process, it provides a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs. It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis. Because the Portland Cement RIA was completed while CASAC was reviewing the PM ISA, we solicited comment on the use of the no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP has been extended until September 4, 2009.[L] As explained in the recently published Portland Cement MACT RIA,[M] EPA's preferred benefits estimation approach assumes a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels. This approach reflects EPA's most current interpretation of the scientific literature on $PM_{2.5}$ and mortality. Please refer to the Portland Cement MACT RIA for a description of the history of the treatment of thresholds in our analyses.[71]

As can be seen in Table 6-11, we conducted a sensitivity analysis for premature mortality, with alternative thresholds at 3 $\mu g/m^3$ (the "background," or no-threshold, assumption), 7.5 $\mu g/m^3$, 10 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$. By replacing the no-threshold assumption in the ACS premature mortality function with a 10 $\mu g/m^3$ threshold model, the number of avoided incidences of premature mortality would decrease by approximately 40 percent.

[K] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

[L] Readers interested in commenting on the use of the no-threshold model for benefits analysis should direct their comments to Docket ID No. EPA–HQ–OAR–2002–0051 (available at http://www.regulations.gov) before the comment period closes.

[M] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

Table 6-11 PM-Related Mortality Benefits Associated with a Coordinated U.S. Strategy to Control Ship Emissions: Threshold Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Level of Assumed Threshold	PM Mortality Incidence	
	2020	2030
14 µg/m3 [b]	1,800	4,600
12 µg/m3	2,100	5,100
10 µg/m3 [c]	3,400	7,800
7.5 µg/m3 [d]	4,500	11,000
3 µg/m3 [e]	5,300	13,000

Notes:
[a] Note that this table only presents the effects of a threshold on PM-related mortality incidence based on the ACS study.
[b] Alternative annual PM NAAQS.
[c] Previous threshold assumption
[d] SAB-HES (2004)[86]
[e] NAS (2002)[87]

6.4.2 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 6-12. All values are in constant year 2006 dollars, adjusted for growth in real income out to 2020 and 2030 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. For details on valuation estimates for PM-related endpoints, see the 2006 PM NAAQS RIA. For details on valuation estimates for ozone-related endpoints, see the 2008 Ozone NAAQS RIA.

Table 6-12 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	$6,320,000	$7,590,000	$7,800,000	EPA currently recommends a default central VSL of $6.3 million based on a Weibull distribution fitted to twenty-six published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses. The guidelines can be accessed at: http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf
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][72]) 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)				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).[73]
3% discount rate				
Age 0–24	$66,902	$66,902	$66,902	Direct medical costs are based on simple average of estimates from
Age 25–44	$74,676	$74,676	$74,676	Russell et al. (1998)[74] and Wittels et al. (1990).[75]
Age 45–54	$78,834	$78,834	$78,834	Lost earnings:
Age 55–65	$140,649	$140,649	$140,649	Cropper and Krupnick (1990). Present discounted value of 5 years
Age 66 and over	$66,902	$66,902	$66,902	of lost earnings:
				age of onset: at 3% at 7%
7% discount rate				25-44 $8,774 $7,855
Age 0–24	$65,293	$65,293	$65,293	45-54 $12,932 $11,578
Age 25–44	$73,149	$73,149	$73,149	55-65 $74,746 $66,920
Age 45–54	$76,871	$76,871	$76,871	Direct medical expenses: An average of:
Age 55–65	$132,214	$132,214	$132,214	1. Wittels et al. (1990) ($102,658—no discounting)
Age 66 and over	$65,293	$65,293	$65,293	2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)

Table 6-12 Unit Values Used for Economic Valuation of Health Endpoints (2006$)[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)[76] (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)[77] and (2) $260.67, from Stanford et al. (1999).[78]

Table 6-12 Unit Values Used for Economic Valuation of Health Endpoints (2006$)[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)[79] 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).[80] 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).[81]

Table 6-12 Unit Values Used for Economic Valuation of Health Endpoints (2006$)[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).[82]

[a] All monetized annual benefit estimates associated with the coordinated strategy 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.[83] 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.

6.4.3 Manipulating Air Quality Modeling Data for Health Impacts Analysis

In Chapter 2, we summarized the methods for and results of estimating air quality for the coordinated strategy presented in this proposal. These air quality results are in turn associated with human populations to estimate changes in health effects. For the purposes of this 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 proposed ECA. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). This section describes how we converted the CMAQ modeling output into full-season profiles suitable for the health impacts analysis.

6.4.3.1 General Methodology

First, we 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.[N,O] 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., BenMAP).

To estimate ozone-related health 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.[P,Q]

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 $PM_{2.5}$

[N] The ozone season for this analysis is defined as the 5-month period from May to September.
[O] Based on AIRS, there were 961 ozone monitors with sufficient data (i.e., 50 percent or more days reporting at least nine hourly observations per day [8 am to 8 pm] during the ozone season).
[P] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.
[Q] 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.

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 coordinated strategy to control ship emissions.

Table 6-13 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 6-13. Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Associated with a Coordinated U.S. Strategy to Control Ship Emissions

	2020		2030	
Statistic[a]	Baseline	Change[b]	Baseline	Change[b]
Ozone Metric: National Population-Weighted Average (ppb)[c]				
Daily Maximum 8-Hour Average Concentration	44.60	0.21	44.33	0.54
$PM_{2.5}$ Metric: National Population-Weighted Average (ug/m^3)				
Annual Average Concentration	10.24	0.35	10.40	0.68

Notes:
[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (i.e., May through September). .
[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.

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 coordinated strategy. The discrepancies impact the benefits analysis in three ways:

- As noted in Chapter 3, the air quality modeling used for the 2020 scenarios is based on inventory estimates that were modeled using incorrect ECA boundary information off of the western coast of the U.S. A calculation error placed the western 200nm ECA boundary approximately 50nm closer to shore. We believe the impact of this difference, while modest, likely leads to a small underestimate of the 2020 benefits presented in this chapter.
- The 2020 air quality modeling scenarios do not include emission reductions associated with the implementation of global controls (set through IMO) beyond the assumed ECA boundary of 200 nm. Again, while we expect the impact of this difference is modest, the omission of these additional emission reductions likely leads to a small underestimate of the 2020 benefits presented in this section.
- Also noted in Chapter 3, the air quality modeling for the 2030 scenario reflects air quality impacts associated with an assumed ECA distance of 100nm with global controls (set

through IMO) beyond the ECA boundary. To estimate the 2030 benefits associated with a 200 nm ECA boundary, we transferred the relationship between modeled impacts between 100 nm and 200 nm ECA boundaries observed in 2020. For each health endpoint and associated valuation, we calculated a ratio based on the national-level estimate for the 200 nm and 100 nm scenario and applied that to the related 2030 100 nm estimate. For the final RIA, we plan to model the 2030 coordinated strategy to control ship emissions with a 200 nm boundary and global controls beyond.

6.5 Methods for Describing Uncertainty

The National Research Council (NRC)[84] 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.[R] 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.

For premature mortality associated with exposure to PM, we follow the same approach that has been used in several recent RIAs.[85,86,87] 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 6-11.

Second, as a sensitivity analysis, we use the results of our expert elicitation of the concentration response function describing the relationship between premature mortality and

[R] 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.

ambient $PM_{2.5}$ concentration.[S, 88] 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.

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.

6.6 Comparison of Costs and Benefits

This section presents the cost-benefit comparison related to the expected impacts of our coordinated strategy for ocean-going vessels. In estimating the net benefits of the coordinated strategy, the appropriate cost measure is 'social costs.' Social costs represent the welfare costs of a rule to society and do not consider transfer payments (such as taxes) that are simply redistributions of wealth. For this analysis, we estimate that the social costs of the coordinated program are equivalent to the estimated compliance costs of the program. While vessel owners and operators will see their costs increase by the amount of those compliance costs, they are expected to pass them on in their entirety to consumers of marine transportation services in the form of increased freight rates. Ultimately, these costs will be borne by the final consumers of goods transported by ocean-going vessels in the form of higher prices for those goods. The social benefits of the coordinated strategy are represented by the monetized value of health and welfare improvements experienced by the U.S. population. Table 6-14 contains the estimated social costs and the estimated monetized benefits of the coordinated strategy.

The results in Table 6-14 suggest that the 2020 monetized benefits of the coordinated strategy are greater than the expected costs. Specifically, the annual benefits of the total program will range between $47 to $110 billion annually in 2020 using a three percent discount rate, or between $42 to $100 billion assuming a 7 percent discount rate, compared to estimated social costs of approximately $1.9 billion in that same year. These benefits are expected to increase to between $110 and $280 billion annually in 2030 using a three percent discount rate, or between

[S] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

$100 and $260 billion assuming a 7 percent discount rate, while the social costs are estimated to be approximately $3.1 billion. Though there are a number of health and environmental effects associated with the coordinated strategy that we are unable to quantify or monetize (see Table 6-2), the benefits of the coordinated strategy far outweigh the projected costs.

Using a conservative benefits estimate, the 2020 benefits outweigh the costs by a factor of 22. Using the upper end of the benefits range, the benefits could outweigh the costs by a factor of 58. Likewise, in 2030 benefits outweigh the costs by at least a factor of 32 and could be as much as a factor of 90. Thus, even taking the most conservative benefits assumptions, benefits of the coordinated strategy clearly outweigh the costs.

Table 6-14 Summary of Annual Benefits and Costs Associated with a Coordinated U.S. Strategy to Control Ship Emissions [a]
(Millions of 2006 dollars)

Description	2020	2030
Total Estimated Costs[b]	$1,900	$3,100
Total Estimated Health Benefits[c,d,e,f]		
3 percent discount rate	$47,000 to $110,000	$110,000 to $280,000
7 percent discount rate	$42,000 to $100,000	$100,000 to $260,000
Annual Net Benefits (Total Benefits – Total Costs)		
3 percent discount rate	$45,000 to $110,000	$110,000 to $280,000
7 percent discount rate	$40,000 to $98,000	$97,000 to $260,000

Notes:
[a] All estimates represent annual benefits and costs anticipated for the years 2020 and 2030. Totals are rounded to two significant digits and 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 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 Bell et al., 2005 ozone premature mortality function to $PM_{2.5}$-related premature mortality derived from the ACS (Pope et al., 2002) and Six-Cities (Laden et al., 2006) studies.
[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.
[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 6-2.

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CHAPTER 7: ECONOMIC IMPACT ANALYSIS

CHAPTER 7: Economic Impact Analysis

This chapter contains our analysis of the expected economic impacts of our coordinated strategy on the markets for Category 3 marine diesel engines, ocean-going vessels, and the marine transportation service sector. We examine the impacts of all components of the coordinated strategy on the markets for Category 3 marine diesel engines, ocean-going vessels, marine fuels, and international marine transportation services. This includes the cost of the Clean Air Act emission control program for Category 3 marine diesel engines for U.S. vessel owners and the costs of complying with the ECA emission and fuel sulfur controls for all ships operating in the area proposed by the U.S. Government to be designated as an Emission Control Area (ECA) under MARPOL Annex VI. We look at two aspects of the economic impacts: estimated social costs and how they are shared across stakeholders, and estimated market impacts in terms of changes in prices and quantities produced for directly affected markets.

This economic impact analysis uses a competitive model approach for all affected markets. The competitive market assumption is discussed in section 7.1.2, below.

The total estimated social costs of the coordinated strategy in 2030 are equivalent to the estimated compliance costs of the coordinated strategy, at approximately $3.1 billion.[A,B] These costs are expected to accrue initially to the owners and operators of affected vessels. These owners and operators are expected to pass their increased costs on to the entities that purchase international marine transportation services in the form of higher freight rates. Ultimately, these costs will be borne by the final consumers of goods transported by ocean-going vessels in the form of slightly higher prices for those goods.

With regard to market-level impacts, we estimate that compliance with the coordinated strategy would increase the price of a new vessel by 0.5 to 2 percent, depending on the vessel. The impact of the coordinated strategy, including the ECA controls, on the price of ocean marine transportation services would vary, depending on the route and the amount of time spent in the proposed U.S. ECA. For example, we estimate that the cost of operating a ship in liner service between Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in the proposed ECA, would increase by about 3 percent. For a container ship, this represents a price increase of about $18 per container, assuming the total increase in operating costs is passed on to the purchaser of marine transportation services. This would be about a 3 percent price increase. The per passenger price of a seven-day Alaska cruise operating entirely within the ECA is expected to increase about $7 per day. For ships that spend less time in the ECA, the expected increase in total operating costs and therefore the impact on freight prices, would be smaller.

[A] All estimates presented in this section are in 2006 dollars.

[B] The costs totals reported in this NPRM are slightly different than those reported in the ECA proposal. This is because the ECA proposal did not include costs associated with the Annex VI existing engine program, Tier II, or the costs associated with existing vessel modifications that may be required to accommodate the use of lower sulfur fuel. Further, the cost totals presented in the ECA package included Canadian cost estimates.

7.1 Overview and Results

7.1.1 What is an Economic Impact Analysis?

In general, the purpose of an Economic Impact Analysis (EIA) is to provide information about the potential economic consequences of a regulatory action, such as the proposed coordinated strategy to reduce emissions from ocean-going vessels. Such an analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders. The estimated social costs can then be compared with estimated social benefits as presented in Chapter 6.

In an economic impact analysis, 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. There are two parts to the analysis. In the market analysis, we estimate how prices and quantities of goods directly affected by the 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.[1]

7.1.2 What Methodology Did EPA Use in This Economic Impact Analysis?

Our analysis of the economic impacts of the coordinated strategy is based on the application of basic microeconomic theory. We use a competitive market model approach in which the interaction between supply and demand set equilibrium market prices and quantities. Specifically, we can use the relationships between supply and demand to simulate how markets can be expected to respond to increases in production costs that occur as a result of the new emission control program. Using that information, we can estimate the social costs of the program and identify how those costs will be shared across the markets and, thus, across stakeholders.

There are two key assumptions about the affected markets that affect our analysis: the structure of the Category 3 engine market and the nature of demand in the ocean marine transportation market.

With regard to the structure of the Category 3 engine market, we assume this market is competitive. This assumption is discussed in more detail in Section 7.2.1.3.3.

With regard to the nature of demand for marine transportation services, we assume that demand is nearly perfectly inelastic. As explained in Section 7.2.1.1, this assumption is appropriate because there are no reasonable alternatives to transportation by ship for most goods. The assumption of nearly perfectly inelastic demand has three consequences for the analysis. First, with respect to market impacts, it means that equilibrium quantity in the affected markets will not change relative to the baseline, no-control scenario, and that the equilibrium prices for marine engines, vessels, and transportation services will increase by the amount of the compliance costs. This is explained more fully in Section 7.2.2. Second, it means that virtually all of the compliance costs will be borne by the users of marine transportation services. These costs are expected to be passed on to consumers of goods transported by sea in the form of

higher prices. Third, it means that it is not necessary to estimate the price elasticity of supply for the affected markets. As long as the supply curves can be assumed to be upward-sloping, the degree of the slope will not affect the estimated market impacts or social welfare impacts described below.

It should be noted that this economic analysis holds all other aspects of the market constant except for elements of the coordinated strategy. It does not attempt to predict the future market equilibrium conditions, particularly with respect to how excess capacity in today's market due to the current economic downturn will be absorbed. This approach is appropriate because the goal of an economic impact analysis is to explore the impacts of a specific program; allowing changes in other market conditions would confuse the impacts due to the proposed regulatory program.

The economic impacts of the coordinated strategy presented below rely on the estimated engineering compliance costs described in Chapter 5. These costs include hardware costs for new U.S. vessels, to comply with the Tier 2 and Tier 3 engine standards, and for existing U.S. vessels, to comply with the MARPOL Annex VI requirements for existing engines. There are also hardware costs for fuel switching equipment on new and existing U.S. vessels to comply with the 1,000 ppm fuel sulfur limit; the cost analysis assumes that 32 percent of all vessels require fuel switching equipment to be added (new vessels) or retrofit (existing vessels). Also included are expected increases in operating costs for U.S. and foreign vessels operating in the ECA. These increased operating costs include changes in fuel consumption rates, increases in fuel costs, and the use of urea for engines equipped with SCR, as well as a small increase in operating costs for operation outside the ECA due to the fuel price impacts of the program.

7.1.3 What Economic Sectors are Included in This Economic Impact Analysis?

The coordinated strategy consists of two parts: Clean Air Act emission standards for Category 3 engines, and fuel sulfur requirements for vessels operating in the proposed U.S. ECA. Therefore, we examine the economic impacts on the following markets: the Category 3 engine market, the market for vessels that use these engines, and the marine transportation services market. The characteristics of the markets analyzed that are relevant to the EIA are summarized in Table 7-1, and described in more detail in Section 7.3.

With respect to the fuels market, the market impacts were estimated through the cost analysis described in Chapter 5, using the WORLD model.

Table 7-1 Summary of Markets in Economic Impact Model

Description of Markets: Supply	C3 Marine Diesel Engines : • slow-speed diesel (SSD) • medium-speed diesel (MSD) Ocean Marine Vessels: 9 types of vessel • Auto Carrier • Bulk Carrier • Container • General Cargo • Passenger • Reefer • RoRo • Tanker • Misc. Marine Transportation Services: U.S. and foreign entities that provide ocean marine transportation services that operate with the proposed U.S. ECA using affected engines and fuels All supply curves upward sloping (price increase leads to increase in amount produced)
Description of Markets: Demand	C3 Marine Engines: Vessel manufacturers Ocean Marine Vessels: Marine vessel users (owners of all types of ocean vessels) Marine Transportation Services: Entities that use marine transportation services (consumer goods, chemical, agricultural, oil companies; personal transportation; etc.) Demand for marine transportation services assumed to be nearly perfectly inelastic; demand for other markets derived from demand for marine transportation services
Geographic Scope	50 states Note: USA ECA would apply in 48 states plus portions of Alaska, Hawaii
Market Structure	Competitive Market

7.1.4 Summary of Results

7.1.4.1 Market Impacts: Engine and Vessel Markets

The estimated market impacts for engines and vessels are based on the variable costs associated with the engine and vessel compliance programs; fixed costs are not included in the market analysis. This is appropriate because 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.

The assumption of nearly perfectly inelastic demand for marine transportation services means that the quantity of these services purchased is not expected to change as a result of costs of complying with the ECA requirements. As a result, the demand for vessels and engines would

also not change compared to the no-control scenario, and the quantities produced would remain the same.

The assumption of nearly perfectly inelastic demand for marine transportation services also means the price impacts of the coordinated strategy on new engines and vessels would be equivalent to the variable engineering compliance costs. Estimated price impacts for a sample of engine-vessel combinations are set out in Table 7-2, for medium speed engines, and Table 7-3, for slow speed engines. These are the estimated price impact associated with the Tier 3 engine standards on a vessel that will switch fuels to comply with the fuel sulfur requirements in the ECA. Because the standards do not phase in, the estimated price impacts are the same for all years, beginning in 2016.

Table 7-2 Summary of Estimated Market Impacts –Medium Speed Tier 3 Engines and Vessels ($2006) [a]

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW TIER 3 ENGINE PRICE IMPACT)[b]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[c]	NEW VESSEL TOTAL PRICE IMPACT
Auto Carrier	9,600	$573,200	$42,300	$615,500
Bulk Carrier	6,400	$483,500	$36,900	$520,400
Container	13,900	$687,800	$49,200	$736,000
General Cargo	5,200	$450,300	$34,900	$475,200
Passenger	23,800	$952,500	$65,400	$1,107,900
Reefer	7,400	$511,000	$38,500	$549,500
RoRo	8,600	$543,800	$40,500	$584,300
Tanker	6,700	$492,800	$37,400	$530,200
Misc.	9,400	$566,800	$41,900	$608,700

Notes:

[a] The new vessel engine price impacts listed here do not include a per engine cost of $10,000 for engines installed on U.S. vessels to comply with the proposed production testing requirement (§1042.302)

[b] Medium speed engine price impacts are estimated from the cost information presented in Chapter 5 using the following formula: (10%*($/SHIP_MECH→CR))+(30%*($/SHIP_ELEC→CR))+(T3 ENGINE MODS)+(T3SCR))

[c] Assumes 32 percent of new vessels would require the fuel switching equipment.

Table 7-3 Summary of Estimated Market Impacts – Slow Speed Tier 3 Engines and Vessels ($2006) [a]

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW TIER 3 ENGINE PRICE IMPACT)[b]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[c]	NEW VESSEL TOTAL PRICE IMPACT
Auto Carrier	11,300	$825,000	$48,000	$873,000
Bulk Carrier	8,400	$672,600	$42,700	$715,300
Container	27,500	$1,533,100	$63,900	$1,597,000
General Cargo	7,700	$632,900	$41,000	$673,900
Passenger	23,600	$1,385,300	$61,200	$1,446,500
Reefer	10,400	$781,000	$46,500	$827,500
RoRo	15,700	$1,042,100	$53,900	$1,096,000
Tanker	9,800	$744,200	$45,300	$789,500
Misc.	4,700	$453,600	$32,000	$485,600

Notes:
[a] The new vessel engine price impacts listed here do not include a per engine cost of $10,000 for engines installed on U.S. vessels to comply with the proposed production testing requirement (§1042.302)
[b] Slow speed engine price impacts are estimated from the cost information presented in Chapter 5 using the following formula: (5%*($/SHIP_MECH→CR))+(15%*($/SHIP_ELEC→CR))+(T3 ENGINE MODS)+(T3 SCR))
[c] Assumes 32 percent of new vessels would require the fuel switching equipment.

The estimated price impacts for Tier 2 vessels would be substantially lower, given the technology that will be used to meet the Tier 2 standards is much less expensive. The cost of complying with the Tier 2 standards ranges from about $56,000 to $100,000 for a medium speed engine, and from about $130,000 to $250,000 for a slow speed engine. Again, because the standards do not phase in, the estimated price impacts are the same for all years the Tier 2 standards are required, 2011 through 2015.

These estimated price impacts for Tier 2 and Tier 3 vessels are small when compared to the price of a new vessel. A selection of new vessel prices is provided in Table 7-4; these range from about $40 million to $480 million. The program price increases range from about $600,000 to $1.5 million. A price increase of $600,000 to comply with the Tier 3 standards and fuel switching requirements would be an increase of approximately 2 percent for a $40 million vessel. The largest vessel price increase noted above, for a Tier 3 passenger vessel, is about $1.5 million; this is a price increase of less than 1 percent for a $478 million passenger vessel. Independent of the nearly perfectly inelasticity of demand, price increases of this magnitude would be expected to have little, if any, effect on the sales of new vessels, all other economic conditions held constant.

Table 7-4 Newbuild Vessel Price by Ship Type and Size, Selected Vessels (Millions, $2008)

Vessel Type	Vessel Size Category	Size Range (Mean) (DWT)	Newbuild
Bulk Carrier	Handy	10,095 – 39,990 (27,593)	$56.00
	Handymax	40,009 – 54,881 (47,616)	$79.00
	Panamax	55,000 – 78,932 (69,691)	$97.00
	Capesize	80,000 – 364,767 (157,804)	$175.00
Container	Feeder	1,000-13,966 (9,053)	$38.00
	Intermediate	14,003-36,937 (24,775)	$70.00
	Panamax	37,042-54,700 (45,104)	$130.00
	Post Panamax	55,238-84,900 (67,216)	$165.00
Gas carrier	Midsize	1,001-34,800 (7,048)	$79.70
	LGC	35,760-59,421 (50,796)	$37.50
	VLGC	62,510-122,079 (77,898)	$207.70
General cargo	Coastal Small	1,000-9,999 (3,789)	$33.00
	Coastal Large	10,000-24,912 (15,673)	$43.00
	Handy	25,082-37,865 (29,869)	$52.00
	Panamax	41,600-49,370 (44,511)	$58.00
Passenger	All	1,000–19,189 (6,010)	$478.40
Reefer	All	1,000–19,126 (6,561)	$17.30
Ro-Ro	All	1,000–19,126 (7,819)	$41.20
Tanker	Coastal	1,000-23,853 (7,118)	$20.80
	Handymax	25,000-39,999 (34,422)	$59.00
	Panamax	40,000-75,992 (52,300)	$63.00
	AFRAmax	76,000-117,153 (103,112)	$77.00
	Suezmax	121,109-167,294 (153,445)	$95.00
	VLCC	180,377-319,994 (294,475)	$154.00

Sources: Lloyd's Shipping Economist (2008), Informa (2008), Lloyd's Sea-Web (2008)

7.1.4.2 Market Impacts: Fuel Market

The market impacts for the fuel markets were estimated through the modeling performed to estimate the fuel compliance costs for the coordinated strategy. In the WORLD model, the total quantity of fuel used is held constant, which is consistent with the assumption that the demand for international shipping transportation would not be expected to change due to the lack of transportation alternatives.

The expected price impacts of the coordinated strategy are set out in Table 7-5. Note that on a mass basis, less distillate than residual fuel is needed to go the same distance (5 percent less). The prices in Table 7-5 are adjusted for this impact. Table 7-5 shows that the coordinated strategy is expected to result in a small increase in the price of marine distillate fuel, about 1.3 percent. The price of residual fuel is expected to decrease slightly, by less than one percent, due to a reduction in demand for that fuel.

Table 7-5 Summary of Estimated Market Impacts - Fuel Markets

FUEL	UNITS	BASELINE PRICE	CONTROL PRICE	ADJUSTED FOR ENERGY DENSITY	% CHANGE
Distillate	$/tonne	$462	$468	N/A	+1.3%
Residual	$/tonne	$322	$321	N/A	-0.3%
Fuel Switching	$/tonne	$322	$468	$444	+38.9%

Because of the need to shift from residual fuel to distillate fuel in the ECA, ship owners are expected to see an increase in their total cost of fuel. This increase is because distillate fuel is more expensive than residual fuel. Factoring in the higher energy content of distillate fuel relative to residual fuel, the fuel cost increase would be about 39 percent.

7.1.4.3 Market Impacts: Marine Transportation Services Market

We used the above estimates of engine, vessel, and fuel price impacts to estimate the impacts on the prices of marine transportation services. This analysis, presented in Section 7.3, below, is limited to the impacts of increases in operating costs due to the fuel and emission requirements of the coordinated strategy. Operating costs would increase due to the increase in the price of fuel, the need to switch to fuel with a sulfur content not to exceed 1,000 ppm while operating in the ECA, and due to the need to dose the aftertreatment system with urea to meet the Tier 3 standards. Table 7-6 summarizes these price impacts for selected transportation markets. Table 7-6 also lists the vessel and engine parameters that were used in the calculations.

Table 7-6 Summary of Impacts of Operational Fuel/Urea Cost Increases

VESSEL TYPE	VESSEL AND ENGINE PARAMETERS	OPERATIONAL PRICE INCREASES
Container North Pacific Circle Route	36,540 kW 50,814 DWT	$17.53/TEU
Bulk Carrier North Pacific Circle Route	3,825 kW 16,600 DWT	$0.56/tonne
Cruise Liner (Alaska)	31,500 kW 226,000 DWT 1,886 passengers	$6.60/per passenger per day

This information suggests that the increase in marine transportation service prices would be small, both absolutely and when compared to the price charged by the ship owner per unit transported. For example, Stopford notes that the price of transporting a 20 foot container between the UK and Canada is estimated to be about $1,500; of that, $700 is the cost of the ocean freight; the rest is for port, terminal, and other charges.[2] An increase of about $18 represents an increase of less than 3 percent of ocean freight cost, and about one percent of transportation cost. Similarly, the price of a 7-day Alaska cruise varies from $100 to $400 per night or more. In that case, this price increase would range from 1.5 percent to about 6 percent.

Our analysis also suggests that increases in operational costs of the magnitude expected to occur for vessels operating in the ECA are within the range of historic price variations for bunker fuel. This is illustrated in Figure 7-1. This figure is based on variation in fuel price among the ports of Singapore, Houston, Rotterdam, and Fujairah.

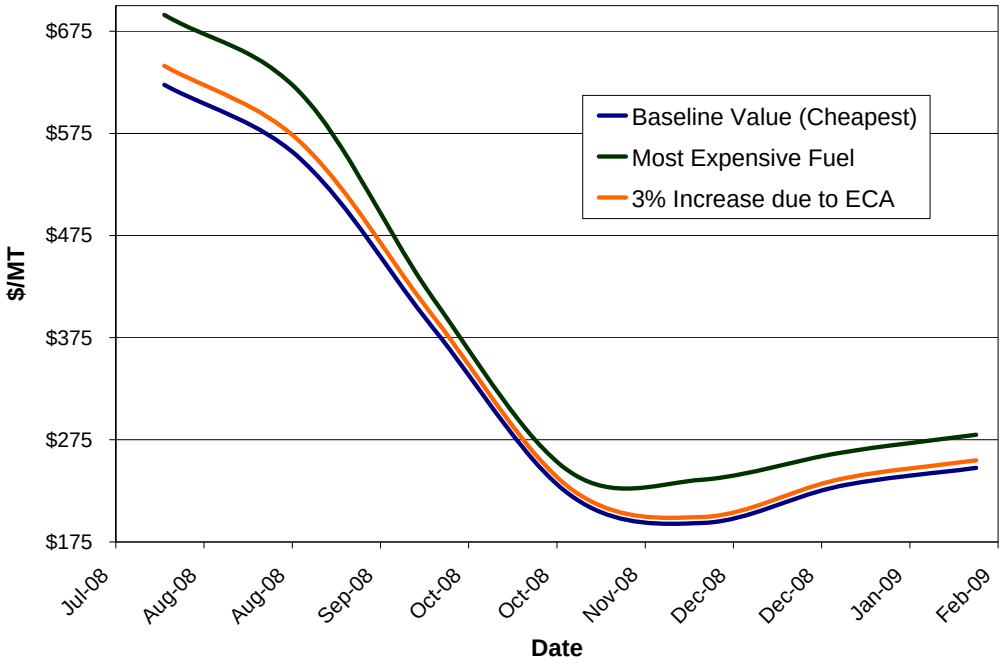

Figure 7-1 Range of Bunker Fuel Prices

This graph illustrates the price differential between these ports, comparing the estimated 3% ECA increase to the cheapest fuel for each month. We then plotted these calculated ECA increases (the 3% increases), the cheapest fuel (as a baseline) and the most expensive fuel for the same six month period. As can be observed from the previous calculations and the trends in Figure 7-1, there are both spatial and temporal price fluctuations in fuel prices. During this period (granted, a period of above-average fluctuations), the price of fuel varied both spatially and temporally. The variation over time is higher than the variation over ports; however, by either form of variation, the 3% increase in bunker fuel price due to the ECA is smaller than the normal price variation of the fuel.

7.1.4.4 Social Welfare Impacts and Their Distribution across Stakeholders

The total social costs of the coordinated strategy are based on both fixed and variable costs. This is because fixed costs are a cost to society: they displace other product development activities that may improve the quality or performance of engines and vessels. In this economic impact analysis, fixed costs are accounted for in the year in which they occur, with the fixed costs associated with the Tier 2 engine standards accounted for in 2010 and the fixed costs associated with the Tier 3 engine standards and the ECA controls accounted for in the five-year period beginning prior to their effective dates.

The social costs of the coordinated strategy are estimated to be the same as the total engineering compliance costs. These costs for all years are presented in Table 5-44, copied below for convenience. For 2030, the social costs are estimated to be about $3.1 billion. Due to the nearly perfectly inelastic demand for marine transportation services, these costs are expected to be borne fully by consumers of marine transportation services.

Table 7-7 Total Costs Associated with the Coordinated Strategy

Year	Fixed	Variable	Operational	Total
2010	$477,020	$0	$0	$477,020
2011	$1,018,766	$2,497,657	$1,306,556	$4,822,979
2012	$1,056,245	$2,580,365	$6,431,250	$10,067,860
2013	$1,095,347	$2,667,173	$244,951,550	$248,714,070
2014	$1,136,035	$2,757,514	$260,810,043	$264,703,592
2015	$972,037	$13,954,191	$1,369,402,786	$1,384,329,013
2016	$0	$28,052,583	$1,438,235,966	$1,466,288,549
2017	$0	$29,154,639	$1,525,633,990	$1,554,788,630
2018	$0	$30,302,933	$1,622,800,854	$1,653,103,787
2019	$0	$31,499,499	$1,721,756,141	$1,753,255,640
2020	$0	$32,746,463	$1,820,614,217	$1,853,360,680
2021	$0	$34,046,049	$1,925,263,118	$1,959,309,168
2022	$0	$35,400,583	$2,028,002,568	$2,063,403,150
2023	$0	$36,812,494	$2,147,543,473	$2,184,355,967
2024	$0	$38,284,325	$2,266,962,666	$2,305,246,991
2025	$0	$39,818,735	$2,387,551,773	$2,427,370,508
2026	$0	$41,418,504	$2,512,510,228	$2,553,928,732
2027	$0	$43,086,539	$2,638,815,284	$2,681,901,822
2028	$0	$44,825,880	$2,774,457,455	$2,819,283,335
2029	$0	$46,639,709	$2,913,118,509	$2,959,758,218
2030	$0	$48,531,352	$3,063,782,201	$3,112,313,554
2031	$0	$50,504,289	$3,205,898,377	$3,256,402,666
2032	$0	$52,562,159	$3,358,465,311	$3,411,027,470
2033	$0	$54,708,770	$3,519,017,395	$3,573,726,165
2034	$0	$56,948,104	$3,689,819,658	$3,746,767,762
2035	$0	$59,284,330	$3,867,580,840	$3,926,865,170
2036	$0	$61,721,806	$4,056,506,472	$4,118,228,278
2037	$0	$64,265,093	$4,258,730,159	$4,322,995,252
2038	$0	$66,918,964	$4,465,788,635	$4,532,707,599
2039	$0	$69,688,411	$4,680,205,640	$4,749,894,051
2040	$0	$72,578,659	$4,905,310,074	$4,977,888,733
NPV @ 3%	$5,311,963	$683,356,096	$42,179,757,713	$42,868,425,773
NPV @ 7%	$4,805,557	$358,019,816	$21,724,932,914	$22,087,758,287

These social costs are small when compared to the total value of U.S. waterborne foreign trade. In 2007, waterborne trade for government and non-government shipments by vessel into

and out of U.S. foreign trade zones, the 50 states, the District of Columbia, and Puerto Rico was about $1.4 trillion. Of that, about $1 trillion was for imports.[3]

If only U.S. vessels are considered, the social costs of the coordinated strategy in 2030 would be about $427.5 million. Again, these social costs are small when compared to the annual revenue for this sector. In 2002, the annual revenue for this sector was about $19.8.[4]

While users of marine transportation services are expected to bear the entire compliance costs of the program, these costs are expected to be passed on to consumers in the form of higher prices for the goods transported by sea. When these costs are spread across these goods, their impacts are expected to be very small. For example, an increase of $18 to transport a container from Singapore to Los Angeles would result in an increase of about one cent for a pair of shoes. In general, transportation costs are only a small portion of the costs of goods and materials. According to UNCTAD, freight costs in 2001 were only about 5.1 percent of import value in 2001, for developed countries.[5]

7.2 Economic Methodology

The methodology used in this Economic Impact Analysis (EIA) is rooted in applied microeconomic theory and was developed following U.S. EPA's recommendations.[6] This section describes the economic theory underlying the analysis and how it was applied to the problem of estimating the economic impacts of the proposed ECA on shipping engaged in international trade.

7.2.1 What Is the Economic Theory Used to Estimate Economic Impacts?

The approach used to estimate the economic impacts of the proposed ECA relies on the basic relationships between production and consumption in competitive markets.

7.2.1.1 Behavioral Model

This economic impact analysis uses a *behavioral* approach in that it builds on the engineering cost analysis by incorporating economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox[7] note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers. 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, which will generally affect the market environment in which they operate.

In this case, implementation of a control program results in an increase in production costs by the amount of the compliance costs. This generates a "shock" to existing 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, without changing the quantity produced. In response to the price increases, consumers will decrease the quantity they buy of the affected good (a change in the quantity demanded). This creates surplus production at the new price. Producers will react to the decrease in quantity demanded by reducing the quantity they produce, and they will be willing to sell the remaining

production at a lower price that does not cover the full amount of the compliance costs. Consumers will then react to this new price. These interactions continue until the surplus is removed and a new market equilibrium price and quantity combination is achieved.

The amount of the compliance costs that will be borne by stakeholders is ultimately limited by the price sensitivity of consumers and producers in the relevant markets, represented by the price elasticities of demand and supply for each market. 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 quantity). 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 quantity). A price elasticity of one is unit elastic, meaning there is a one-to-one correspondence between a percent change in price and percent change in quantity.

On the production side, price elasticity of supply depends on the time available to adjust production in response to a change in price, how easy it is to store goods, and the cost of increasing (or decreasing) output. In this analysis, we assume the supply for engines, vessels, and marine transportation services is elastic: an increase in the market price of an engine, vessel or freight rates will lead producers to want to produce more, while a decrease will lead them to produce less (this is the classic upward-sloping supply curve). It would be difficult to estimate the slope of the supply curve for each of these markets given the global nature of the sector. However, it is reasonable to assume that the supply elasticity for the ocean marine transportation services market is likely to be greater than one. This is because output can more easily be adjusted due to a change in price. For the same reason, the supply elasticity for the new Category 3 engine market is also likely to be greater than one, especially since these engines are often used in other land-based industries, notably in power plants. The supply elasticity for the vessel construction market, on the other hand, may be less than or equal to one depending on the vessel type, since it may be harder to adjust production and/or store output if the price drops, or rapidly increase production if the price increases. Because of the nature of this industry, it would not be possible to easily switch production to other goods, or to stop or start production of new vessels.

On the consumption side, we assume that the demand for engines is a function of the demand for vessels, which is a function of the demand for international shipping (demand for engines and vessels is derived from the demand for marine transportation services). This makes intuitive sense: Category 3 engine and ocean-going vessel manufacturers would not be expected to build an engine or vessel unless there is a purchaser, and purchasers will want a new vessel/engine only if there is a need for one to supply marine transportation services. Deriving the price elasticity of demand for the vessel and engine markets from the international shipping market is an important feature of this analysis because it provides a link between the product markets.

Finally, we assume that the price elasticity of demand for marine transportation services is nearly perfectly inelastic. This stems from the fact that, for most goods, there are no reasonable alternatives to shipping by vessel for the vast majority of products transported by sea to the United States and Canada. It is impossible to ship goods between these countries and Asia, Africa, or Europe by rail or highway. Transportation of goods between these countries and

Central and South America by rail or highway would be inefficient due to the time and costs involved. While aviation may be an alternative for some goods, it is impossible for goods shipped in bulk or goods shipped in large quantities. There are also capacity constraints associated with trans-continental aviation transportation, and the costs are higher on a per tonne basis. As a result, approximately 90 percent of world trade by tonnage is moved by ship, and ships provide the most efficient method to transport these goods on a tonne-mile basis.[8] Stopford notes that "shippers need the cargo and, until they have time to make alternative arrangements, must ship it regardless of cost … The fact that freight generally accounts for only a small portion of material costs reinforces this argument."[9] A nearly perfectly inelastic price elasticity of demand for marine transportation services means that virtually all of the compliance costs can be expected to be passed on to the consumers of marine transportation services, with no change in output for engine producers, ship builders, or owners and operators of ships engaged in international trade.

7.2.1.2 Multi-Market, Partial-Equilibrium Approach

This is also a *multi-market, partial equilibrium* approach. It is a multi-market approach in that more than one market is examined: the markets for marine engines, vessels, and international shipping transportation services. It is a partial-equilibrium approach in that rather than explicitly modeling all of the interactions in the global economy that are affected by international shipping, the individual markets that are directly affected by the ECA requirements are modeled in isolation. This technique has been referred to in the literature as "partial equilibrium analysis of multiple markets."[10]

This EIA does not examine the economic impact of the proposed ECA on finished goods that use ocean transportation services as inputs. This is because international shipping transportation services are only a small part of the total inputs of the final goods and services produced using the materials shipped. A change in the price of marine transportation services on the order anticipated by this program would not be expected to significantly affect the markets for the finished goods. So, for example, while we look at the impacts of the program on ocean transportation costs, we do not look at the impacts of the controls on gasoline produced using crude oil transported by ship, or on manufactured products that use petroleum products as inputs.

It should also be noted that this EIA estimates the aggregate economic impacts of the control program at the market level. This is not intended to be a firm-level analysis; therefore compliance costs facing any particular ship operator may be different from the market average, and the impacts of the program on particular firms can vary significantly. The difference can be important, particularly where the rule affects different firms' costs over different activity rates.

7.2.1.3 Competitive Market Structure

The methodology used in this EIA relies on the assumption that the relevant markets have a competitive market structure. This means that consumers and firms are price takers and do not have the ability to influence market prices. Competitive market structure is a widely accepted assumption for this type of analysis and only in rare cases are other approaches used.[11] Stopford's description of the shipping market and how prices are set in this market supports this assumption.[12]

In a competitive market at equilibrium with no externalities, 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 assumption of competitive market structure 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 a competitive market structure include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[C,13] 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).

7.2.1.3.1 Competition in the Marine Transportation Services Market

Ships that service the marine transportation services market are either tramp vessels or liner vessels. As explained below, both of these sectors can reasonably be modeled as competitive markets.

Tramp vessels "carry bulk and general cargoes not catered for by the liner industry."[14] These vessels have no fixed route or ports of call, or published freight rates. Instead, they arrange to carry loads on a per voyage basis and operate on the spot market. According to a survey performed for the World Trade Organization in 1998 (37 member countries, counting the EU as one, and representing nearly half of the tonnage of the world fleet), bulk traffic accounted for about 65 percent of the volume of trade in that sample.[15] That report notes that "contracts are allocated on an extremely competitive basis; business is won on the basis of freight rates a few cents per ton lower than the competition. Stopford notes that this sector has expanded greatly since the 1970s, benefiting from advances in communication that facilitated information flows. The result, he notes, is "the highly efficient transport system for bulk cargoes we have today."[16] Consequently, it is reasonable to assume a competitive market structure.

Liner vessels, in contrast, operate on fixed routes and schedules with published rates. The liner sector is specifically exempt from antitrust legislation, and so-called conference agreements set rates and conditions of service for the scheduled routes. However, this sector can also be assumed to operate competitively. This is because the Ocean Shipping Reform Act of 1998 allows the use of "service contracts," which are private contracts that do not have to comply with the conference rates. These open conferences exist only on the U.S. routes. The amount of freight shipped in liners using service contracts instead of published rates has grown tremendously since 1998; it has been estimated that 80% of cargo transported on routes between U.S. ports and other countries carried by conference members uses service contracts.[17] This availability of service contracts appears to have increased substantially the competitiveness of liner shipping in the U.S. In addition, the World Trade Organization survey suggests that "the share of traffic held by the conferences has been eroded as new state trading and South East

[C] The number of firms in a market is not a necessary condition for a competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Inc., p 333.

Asian operators have emerged and become powerful enough to offer on their own services equivalent to those of the conferences."[18]

It should be noted that contracts for liner shipping typically include a bunker fuel adjustment factor (BAF) in addition to the shipping rate. The BAF is used to adjust shipping costs in response to unexpected fuel cost variation after shipping rates are set.[19] The BAF is determined by individual line shipping company and allows ship owners to adjust their rates by these increases in operating costs, thereby passing increases in operating costs to the entities that purchase their transportation services.

In sum, tramp shipping appears to be a competitive market. Liner shipping, although exempt from antitrust laws, nevertheless is much less able than in the past to enforce its noncompetitively set published rates, and it faces some degree of competition from tramp shipping and from liners that are not members of the established conferences.

7.2.1.3.2 Competition in the Vessel Building Market

With regard to the vessel building market, there are short- and medium-term barriers to trade that could impede competition. Specifically, the shipping industry is characterized by high fixed costs (building a vessel). High entry costs can serve as a temporary barrier to entry in an industry: since existing shippers in the industry have already incurred those costs, they can operate at costs low enough to deter entry. However, this condition is offset by the excess capacity that appears to exist at many shipyards.[20] An industry with excess capacity faces strong competition, as shipyards are likely to compete with each other for any new business. As a result, shipyards are likely to operate with margins small enough that they must pass along any increases in costs. Any requirements that affect the costs of a new vessel are likely to be included in the cost of a new vessel. Finally, while vessel building is concentrated in a few countries (South Korea, China, Japan, Germany), the purchaser of a new vessel has many shipyards available since most countries maintain at least some vessel building capacity.

7.2.1.3.3 Competition in the Engine Manufacturing Market

In recent years, the Category 3 marine diesel engine industry has become more consolidated. In 1998, there were 19 Category 3 engine manufacturers, with four sharing 80 percent of the market.[21] Since that time, Wartsila purchased Sulzer, and Caterpillar purchased MaK. Currently, these companies along with MAN B&W and Mitsubishi account for the vast majority of the Category 3 engine market.

We modeled this market as competitive. This is because the Category 3 engine market is a mature industry, and pricing power in mature markets is typically limited. Vessel owners and builders can chose among many engine models and sizes for a particular vessel. In addition, Category 3 engine manufacturers also compete in the market for land-based power plants and and other industrial applications.

Because the market is dominated by a small number of engine manufacturers, however, an oligopolistic market structure may be more appropriate. In an oligopoly, it is not uncommon for manufacturers to exercise market power to set prices above their average cost, thereby

securing greater profits.[22] In such markets, the economic impacts of a regulatory program may exceed the compliance costs of the program.

However, an oligopoly market structure does not necessarily mean that the firms necessarily act non-competitively. According to the Bertrand competition model, price competition in an oligopoly achieves the similar results as a perfectly competitive market.[23] In this case, each firm chooses its price to compete with the other firms. Varian describes this as a model of competitive bidding: "Suppose that one firm 'bids' for the consumers' business by quoting a price above marginal cost. Then the other firm can always make a profit by undercutting this price by a lower price."[24] In the Bertrand model, price competition under constant returns to scale yields a price equal to the constant marginal cost. In other words, the price bidding prices leads to perfectly competitive results.

The theoretical conditions for Bertrand competition are: there are at least two firms producing homogeneous products; firms do not cooperate; firms have the same marginal cost (MC); marginal cost is constant; demand is linear; firms compete in price, and choose their respective prices simultaneously; there is strategic behavior by both firms; both firms compete solely on price and then supply the quantity demanded; and consumers buy everything from the cheaper firm or half at each, if the price is equal.[25] In an oligopoly market, price competition may be softened when the manufacturers face sharply rising marginal costs, when they compete repeatedly, or when their products are differentiated.

For the above reasons, we assume the Category 3 engine market is competitive, and firms in the market are involved in Bertrand competition in this analysis.

7.2.1.4 Intermediate-Run Impacts

This EIA explores economic impacts on affected markets in the intermediate run. In the intermediate run, some factors of production are fixed and some are variable. A short-run analysis, in contrast, imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate run means that some factors of production are fixed and some are variable, and illustrates how costs will be shared between producers and consumers as the markets adjust to the new compliance program. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

7.2.1.4.1 Short-Run 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. 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. Note that the BAF is a way to avoid this scenario. Additionally, the fact that liner price schedules are renegotiated at least annually, and that individual service contracts may be negotiated more frequently, suggests that a very short-run analysis would not be suitable.

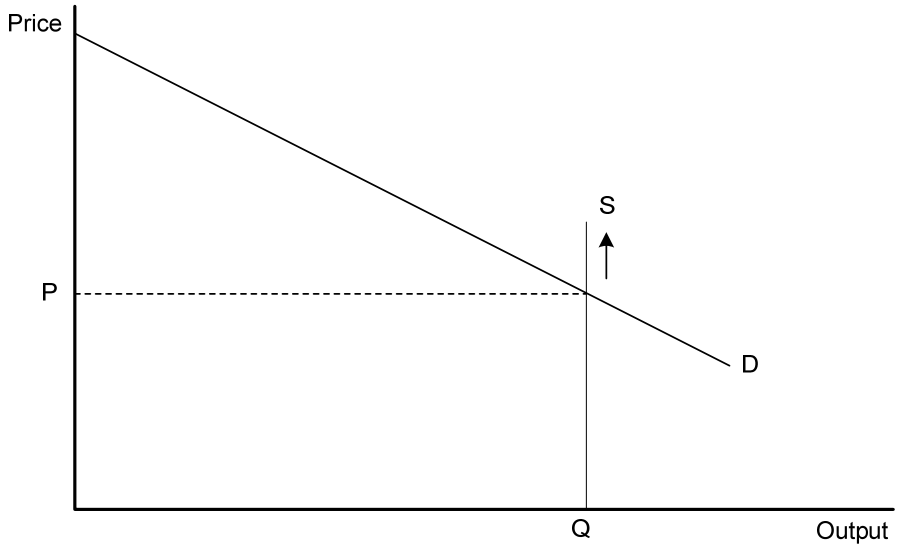

Figure 7-2 Short-Run: All Costs Borne by Producers

7.2.1.4.2 Long-Run Analysis

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. 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.

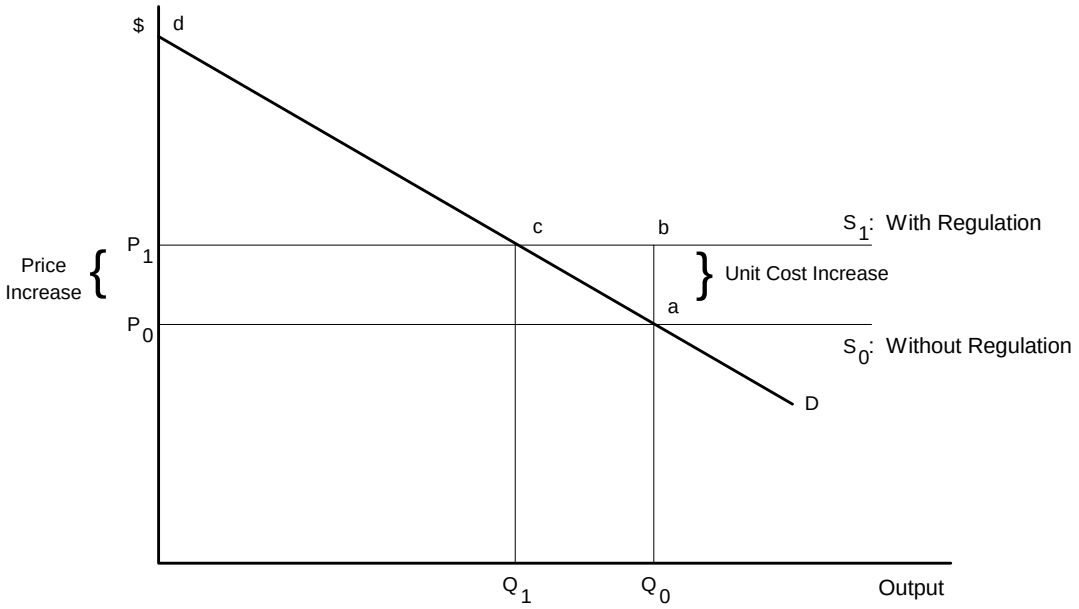

Figure 7-3 Long-Run: Full Cost Pass-Through

Market demand is represented by the standard downward-sloping curve. The market is assumed here to be 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 and is illustrated in Figure 7-3. 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."

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 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.

7.2.1.4.3 Intermediate Run Analysis

The intermediate run time frame allows examination of impacts of a regulatory program during the transition between the very 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.

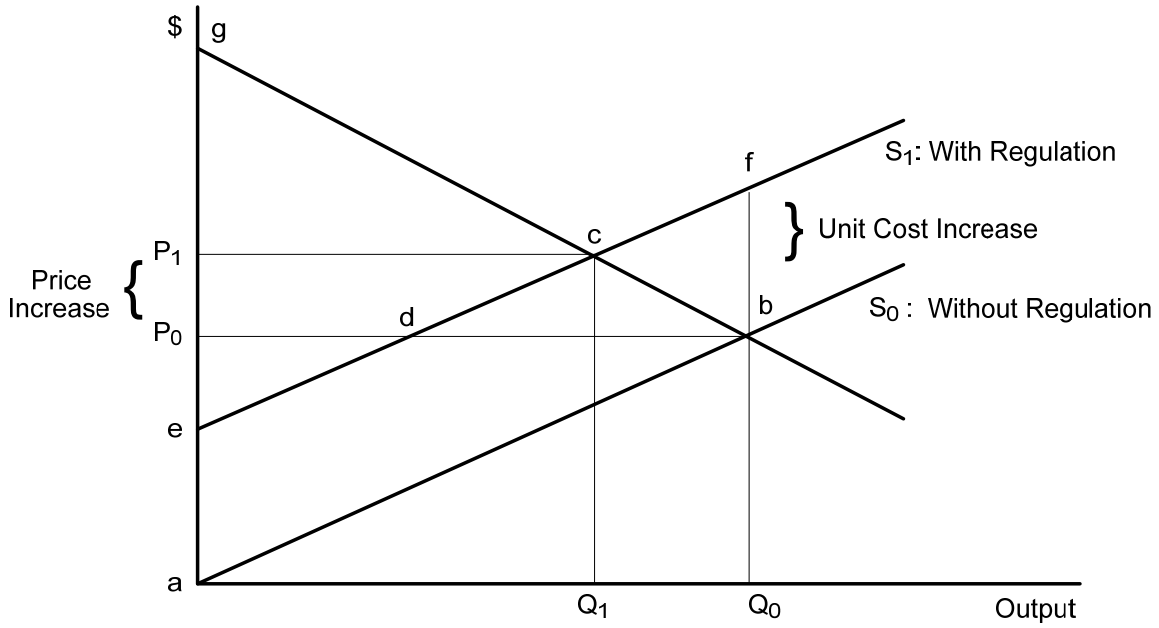

Figure 7-4 Intermediate-Run: Partial-Cost Pass-Through

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.

7.2.1.5 Economic Impacts of a Control Program – 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.

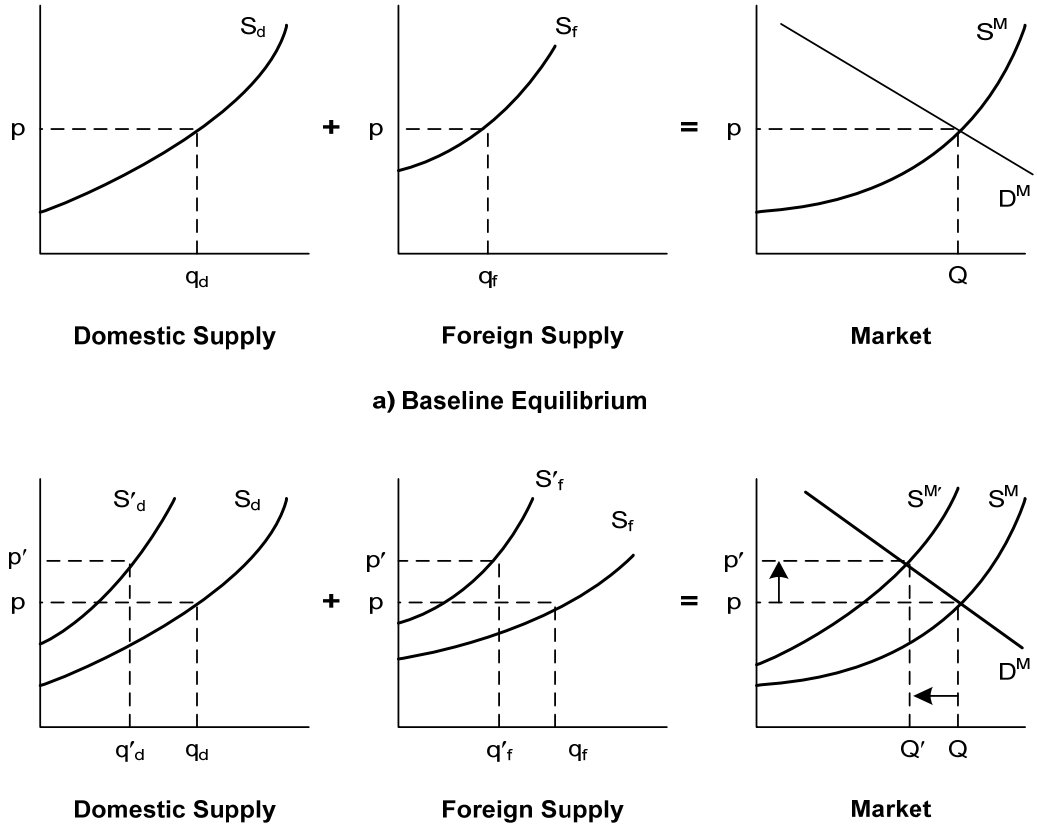

Figure 7-5 Market Equilibrium Without and With Regulation

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 consumer tastes, income, prices of related goods, or population would lead to change in demand and are illustrated as *shifts* in the position of the demand curve.[D,26] 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 or inward, depending on whether people choose to buy more or less of a good at a given price.

7.2.1.6 Economic Impacts of a Control Program – Multiple Markets

The above description is typical of the expected market effects for a single product market considered in isolation (for example, the ocean transportation service market). However, the markets considered in this EIA are more complicated because they are linked: the market for engines is affected by the market for vessels, which is affected by the market for international marine transportation services. In particular, 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. Similarly, the demand for vessels varies directly with the demand for marine transportation services. 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.

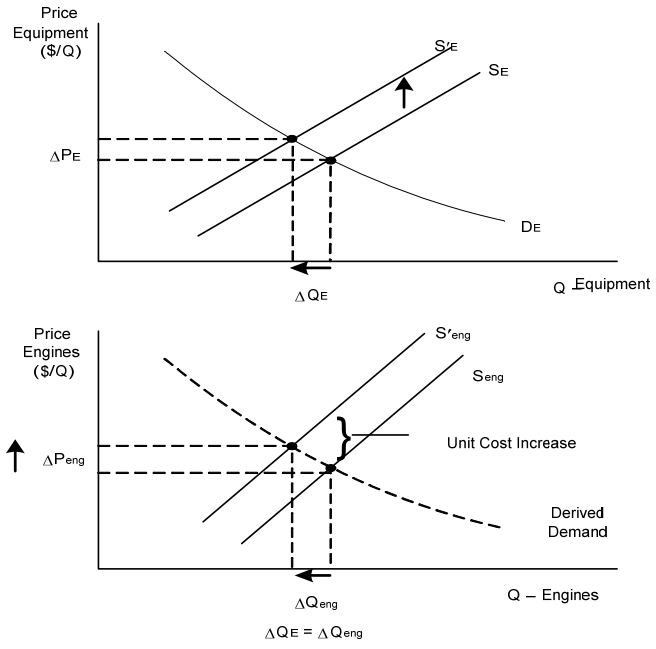

Figure 7-6 Derived-Demand Curve for Engines

[D] An accessible detailed discussion of these concepts can be found in Chapters 5-7 of Nicholson's (1998) intermediate microeconomics textbook.

Consider an event in the engine market, such as a new technology requirement, that causes the price of an engine to increase by ΔP_{eng}. This increase in the price of an engine will cause the supply curve in the engine market to shift up, leading to a decreased quantity (ΔQ_{eng}). The change in engine production leads to a decrease in the demand for equipment (ΔQ_E). The difference between the supply curves in the equipment market, $S'_E - S_E$, is the difference in price in the engine market, ΔP_{eng}, at each quantity. Note that the supply and demand curves in the equipment market are needed to identify the derived demand in the engine market.

In the market for vessels and engines, the derived demand curves are expected to be vertical. The full costs of the engines will be passed into the cost of vessels, and the cost of vessels will be passed into the cost of ocean transportation.

7.2.1.7 Using Economic Theory to Estimate the Social Costs of a Control Program

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).

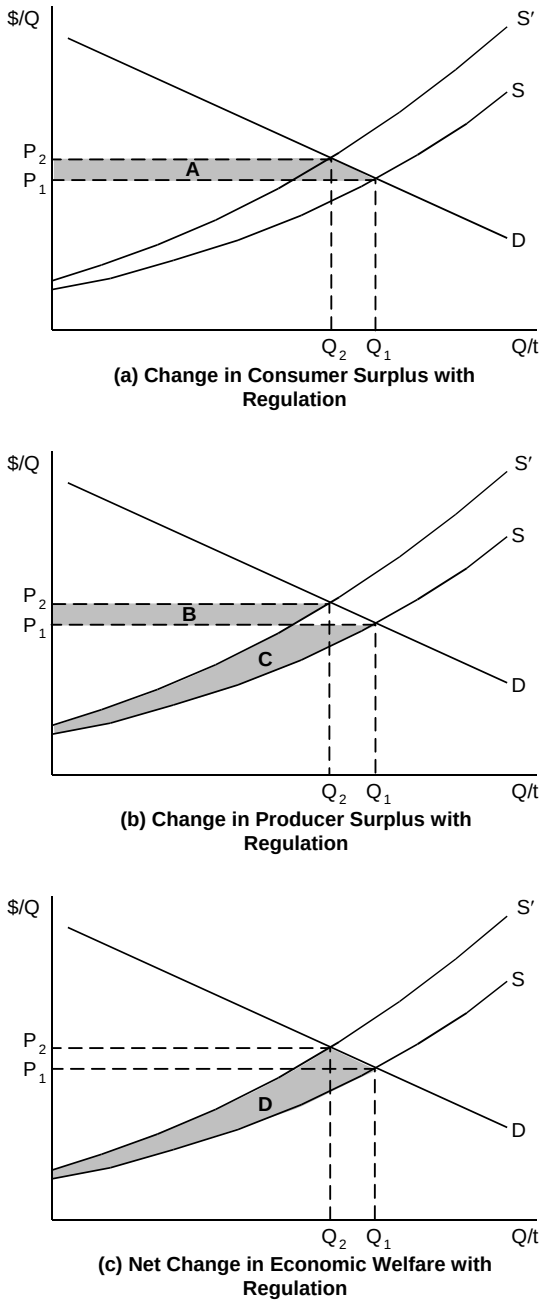

Figure 7-7 Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus

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 and 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_1 with quantity Q_1. 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 consumer 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, $Q_1 - Q_2$.

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.

7.2.1.8 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.

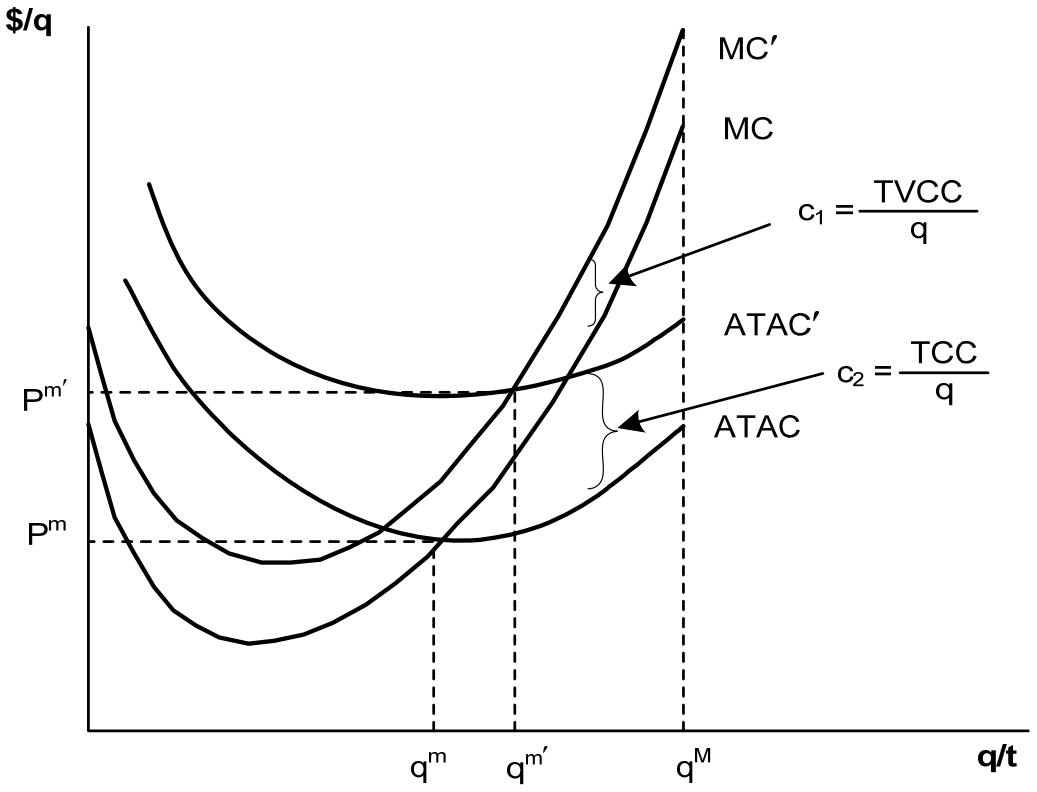

Figure 7-8 Modeling Fixed Regulatory Costs

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 included in the total social costs in the year in which they occur.

7.2.2 How Is This Economic Theory Applied In This EIA?

In the above explanation of how to estimate the market and social welfare impacts of a control action, the price elasticities of supply and demand were nonzero. This was reflected in the upward-slope of the supply curve and the downward slope of the demand curve. In the derived demand analysis, a nonzero price elasticity of demand in the vessel market yielded a nonzero price elasticity of demand in the engine market.

However, the price elasticity of demand in the international shipping market is expected to be nearly perfectly inelastic (demand curve with near-infinite slope – a vertical demand curve). This is not to say that an increase in price has no impact on quantity demanded; rather, it means that the price increase would have to be very large before there is a noticeable change in quantity demanded.

A nearly perfectly inelastic price elasticity of demand simplifies the analysis described above. Figure 7-9 reproduces the relationships in a multi-level market but this time with a nearly perfectly inelastic demand curve in the international shipping market. The relationships between this market and the markets for vessels and engines means that the derived demand curves for engines and vessels are also expected to be nearly perfectly inelastic. Specifically, if demand for transportation services is not expected to be affected by a change in price, then the demand for vessels will also remain constant, as will the demand for engines.

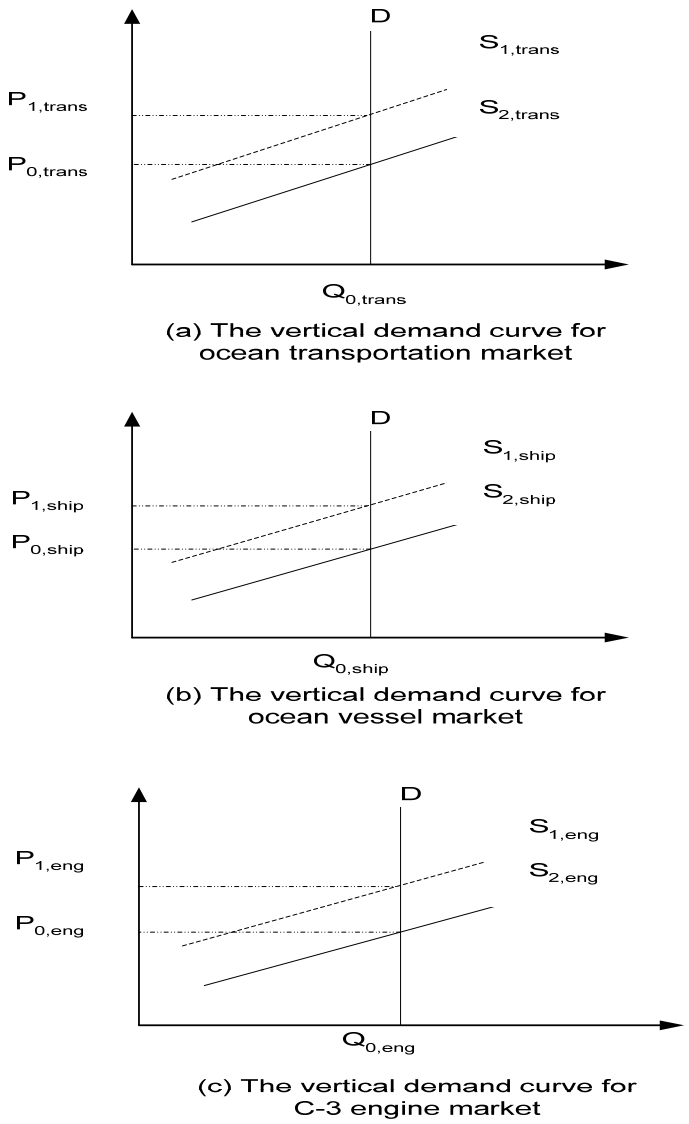

Figure 7-9 Market Impacts in Markets with Nearly Perfectly Inelastic Demand

As indicated in Figure 7-9, a change in unit production costs due to compliance with the engine emission and fuel sulfur requirements in the proposed ECA shifts the supply curves for engines, vessels, and ocean transportation services. The cost increase causes the market price to increase by the *full* amount of per unit control cost (i.e. from P_0 to P_1) while the quantity demanded for engines, vessels, and transportation services remains constant. Thus, engine manufacturers are expected to be able to pass on the full cost of producing Tier III compliant engines to the vessel builders, who are expected to be able to pass the full cost of installing the engines and fuel switching equipment on to the vessel owners. The vessel owners, in turn, are expected to be able to pass on these cost increases, as well as the additional operating costs they incur for the use of SCR reductant (urea) and low sulfur fuel while operating in the ECA.

Note that the fuel and urea costs affect the ocean transportation services market directly, but affect the vessel and engine markets only through the derived demand curves. That is, the

equilibrium prices and quantities for vessels and engines will change only if the quantity of ocean transportation services demanded changes due to fuel and urea costs. Because the changes in fuel and urea prices are expected to be too small to affect the quantity of ocean transportation services demanded, the markets for vessels and engines are not expected to be affected by fuel changes.

The sole exception for the assumption of nearly perfectly price elasticity of demand is the cruise market. Clearly, the consumers in that market, tourists and holiday-makers, have alternatives available for their recreational activities. If the cost of a cruise increases too much, they may decide to spend their vacation in other activities closer to home, or may elect to fly somewhere instead. As a result, the costs of compliance for the cruise industry are more likely to be shared among stakeholders. If the price elasticity of demand is larger (in absolute value) than the price elasticity of supply, ship owners will bear a larger share of the costs of the program; if the price elasticity of demand is smaller (in absolute value) than the price elasticity of supply, consumers will bear a larger share of the program. Similarly, the vessel builders and engine manufacturers will also bear a portion of the costs. If the quantity demanded for cruises decreases, the derived quantity demanded for vessels will decrease, as will the derived quantity demanded for engines. If the supply curves for these industries are not perfectly elastic (i.e., horizontal), then the downward-sloping derived demand curves will lead to shared impacts among the sectors.

As described in Section 7.3 of this chapter, the impacts on the cruise market are expected to be small, with total engine and vessel costs increasing about one percent and operating costs increasing between 1.5 and 6 percent. These increases are within the range of historic variations in bunker fuel prices. The impact on the cruise market, then, may be similar in effect to the market's response to those changes.

Finally, it may be possible for cruise ships to offset some of these costs by advertising the environmental benefits of using engines and fuels that comply with the ECA requirements. Many cruise passengers enjoy this form of recreational because it allows them a personal-level experience with the marine environment, and they may be willing to pay an increased fee to protect that nature. If people prefer more environmentally friendly cruises, then the demand curve for these cruises will shift up. Consumers will be willing to bear more of the costs of the changes. If the demand shift for environmentally friendly cruises is large enough, both the equilibrium price and quantity of cruises might increase.

7.3 Estimating Market Impacts on the Marine Transportation Market

To characterize the increase in vessel operating costs due to the coordinated strategy, calculations were performed for three types of ocean going vessels, container, bulk carrier, and cruise liner. Our estimates were developed using typical vessel characteristics, projected fuel and urea costs, and worst case sea-route data. This section presents the methodology used for these calculations.

7.3.1 Container Vessel

A typical container vessel was derived using data obtained from the Lloyd's of London Sea-Web Database[27]. This data base includes information on actual vessel size (Dead Weight Tonnes (DWT)) and engine power (kilowatt – hour (kW-hr)) for a wide range of vessel types.

Operating costs included those associated with switching from residual fuel to 0.1% sulfur distillate fuel and urea consumption for vessels equipped with selective catalytic reduction (SCR). The fuel and urea costs are based on projections that are presented in the ECA proposal. These fuel costs estimates are $322/tonne for residual fuel and $468/tonne for 0.1% sulfur distillate fuel. We use a urea consumption rate of 7.5% of fuel consumption, at $1.52/gallon.

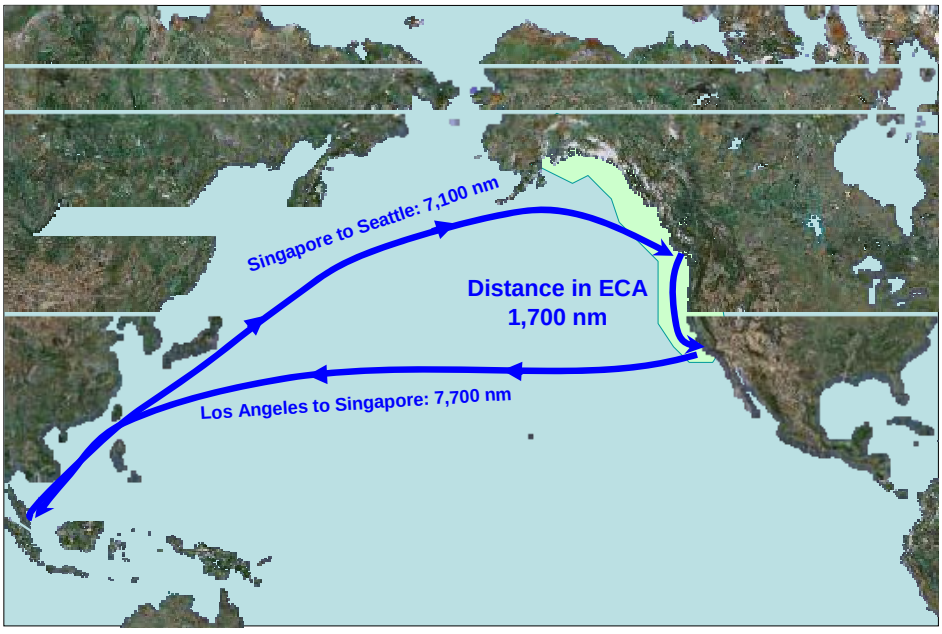

Figure 7-10 Example Sea Route

To develop a representative sea-route for our price estimations, we created a 'circle route' for a theoretical trip. Since the Port of Los Angeles[28], one of the largest ports in the U.S., lists the majority of its cargo as traveling from South Asia, our route had a vessel hypothetically travel from Singapore to the Port of Seattle, then down the West Coast of the United States (U.S.) to the Port of Los Angeles, then back to Singapore. To map this route, we divided it into three "legs." The first leg has the vessel traveling from Singapore to the Port of Seattle; the second part travels down the West Coast of the U.S. to the Port of Los Angeles/Long Beach

(POLA/LB); the third leg continues from Los Angeles to Singapore. This trip is illustrated in Figure 7-10. The total distance for this route was determined from http://nauticaldistance.com/, and is described below.

We understand that it will take some additional time and distance to switch vessel operations from one fuel to another. Additionally, we acknowledge that vessels may enter the ECA at an angle relative to the port in question, and would be operating in the ECA for a slightly longer distance than the 200 nautical miles of the ECA. Therefore, to make our fuel usage estimates as accurate as possible, we included some additional ECA traversing distances in our circle route calculations, adding 183 nm to the distance for reaching the Port of Seattle, and 35 nm to the distance from POLA/LB.

7.3.1.1 Baseline Operating Costs

In order to begin our estimated fuel cost increases, we needed to establish the fuel usage and prices for our baseline route (i.e., the price of the route operating on residual fuel). We determined average operational values for our hypothetical vessel by selecting the mid-point of the operational ranges used today by OGV. Therefore, our baseline estimations for the fuel usage for the first leg were determined by multiplying the engine power for the average sized containership (in kilowatts (kW)) by the average estimated engine efficiency (80 percent) as well as the average residual fuel consumption (195 grams fuel per kilowatt hour (g/kW-hr)). (Equation 7-1) This value was then multiplied by the nautical miles (nm) for the first leg of the trip (the distance from Singapore to Seattle (7,064 nm)), and divided by the average engine speed (16 knots). To obtain the correct units for the calculation, a unit conversion was also included. (Equation 7-2) As average values are represented here, it is possible that these values could fluctuate slightly depending on the vessel's speed, engine efficiency, and specific fuel consumption, but we believe that these estimates provide a reasonable forecast for the majority of container vessels in operation today.

Equation 7-1

$$36{,}540 kW \times 0.8 \times 195 \, {g_{resid}}/{kW - hr} = 5{,}700{,}240 \, {g_{resid}}/{hr}$$

Equation 7-2

$$\frac{5{,}700{,}240 \, {g_{resid}}/{hr} \times 7{,}064 nm}{16 \, {knots}/{hr}} \times \frac{tonne}{1{,}000{,}000 g} = 2{,}517 tonne_{resid}$$

The same determinations were conducted for the second leg of the trip (1,143 nm, Equation 7-3) and the third leg (7,669 nm, Equation 7-4).

Equation 7-3

$$\frac{5{,}700{,}240\, g_{resid}/hr \times 1{,}143 nm}{16\, knots/hr} \times \frac{tonne}{1{,}000{,}000 g} = 407 tonne_{resid}$$

Equation 7-4

$$\frac{5{,}700{,}240\, g_{resid}/hr \times 7{,}669 nm}{16\, knots/hr} \times \frac{tonne}{1{,}000{,}000 g} = 2{,}732 tonne_{resid}$$

Total fuel usage for each leg of the trip was multiplied by the price of the fuel (2006 U.S. dollars per tonne ($/tonne) which provided the baseline cost of fuel for each leg. These costs were then summed to produce an aggregate estimation of fuel cost for the entire circle trip (Equation 7-5). This calculation provides the baseline cost of about $1.8M for an average sized container ship to traverse the theoretical circle route.

Equation 7-5

$$(2{,}517 tonne_{resid} + 407 tonne_{resid} + 2{,}732 tonne_{resid}) \times \$322.48 / tonne_{resid} = \$1{,}823{,}947$$

7.3.1.2 Operating Costs with an ECA

Operating cost increases due to an ECA are due to increased fuel costs and urea consumption within the ECA. Operating costs are assumed to remain unchanged outside the ECA. In addition, the ECA is assumed to have no impact on the route travelled.

7.3.1.2.1 Increased Fuel Costs

To determine the fuel usage and price increase caused by the ECA on our vessel traveling our theoretical circle route, we conducted the same analysis as our baseline using the appropriate distillate fuel properties. Since the distillate fuel will most likely only be used in the ECA, the remainder of the trip will continue operating on residual fuel. Therefore, we adjusted our trip section distances accordingly, using residual fuel over the first leg for 6,679 nm and over 7,434 nm for the third leg, while the remainder of the trip was determined using a distillate fuel. Equation 7-6 provides the approximation for engine power and fuel consumption using distillate fuel and Equation 7-7, 8, and 9 calculate the corresponding trip segment fuel usages. Due to the chemical properties of the two marine fuels, there is approximately a five percent (5%) increase in energy, on a mass basis, when operating on the distillate fuel instead of the residual fuel, and this increase is accounted for in Equation 7-6.

Equation 7-6

$$36{,}540kW \times 0.8 \times \frac{195 \, g_{distil}/kW-hr}{1+0.05} = 5{,}428{,}800 \, g_{distil}/hr$$

Equation 7-7a Residual Fuel Estimation

$$\frac{5{,}700{,}240 \, g_{resid}/hr \times 6{,}679nm}{16 \, knots/hr} \times \frac{tonne}{1{,}000{,}000g} = 2{,}379tonne_{resid}$$

Equation 7-7b Distillate Fuel Estimation

$$\frac{5{,}428{,}800 \, g_{distil}/hr \times 385nm}{16 \, knots/hr} \times \frac{tonne}{1{,}000{,}000g} = 131tonne_{distil}$$

Equation 7-8

$$\frac{5{,}428{,}800 \, g_{distil}/hr \times 1{,}143nm}{16 \, knots/hr} \times \frac{tonne}{1{,}000{,}000g} = 388tonne_{distil}$$

Equation 7-9a Residual Fuel Estimation

$$\frac{5{,}700{,}240 \, g_{resid}/hr \times 7{,}434knots}{16 \, knots/hr} \times \frac{tonne}{1{,}000{,}000g} = 2{,}648tonne_{resid}$$

Equation 7-9b Distillate Fuel Estimation

$$\frac{5{,}428{,}800 \, g_{distil}/hr \times 235nm}{16 \, knots/hr} \times \frac{tonne}{1{,}000{,}000g} = 80tonne_{distil}$$

7.3.1.2.2 Urea Costs

Switching to a distillate marine fuel will achieve reductions only in sulfur and particulate emissions. In order to meet the required nitrogen oxides (NO_X) emission reductions, vessel owners/operators would need to install a Selective Catalytic Reduction (SCR) device, or similar technologies, on new vessels built in 2016 and later. Using an SCR requires dosing exhaust gases with urea to aid with the emission reductions, which adds some additional costs to the operation of the vessel. In an SCR on a marine engine, the average dosage of urea is seven and a half percent (7.5%) per gallon of distillate fuel used. Subsequently, to estimate the volume of urea required for our circle route, we multiplied the distillate quantity determined above by this urea percentage (Equation 7-10). As we expect these costs to be incurred several years in the future, we used the analysis preformed for the EPA by EnSys[29] which predicted that in 2020, 33.2% of the fuel used in ECAs will be on vessels equipped SCR. The urea costs below are adjusted to reflect this prediction.

Equation 7-10

$$599 tonnes_{distil} \times \frac{kg}{0.001 tonne} \times \frac{m^3}{836.6 kg_{distil}} \times \frac{264.17 gal}{m^3} \times 0.075 = 14{,}185 gal_{urea} \times 0.332 = 4{,}709 gal_{urea}$$

To determine the additional price of our vessel's operation through the ECA, we then multiplied the fuel and urea quantities by their corresponding prices ($322.48/tonne for residual, $467.92/tonne for distillate, and $1.52/gal for the urea). We then summed these values to determine the aggregate price for fuel and urea required for our container vessel to travel our circle route with the proposed ECA in place (Equation 7-11).

Equation 7-11

$$\begin{aligned}&[(2{,}379 tonne_{resid} + 2{,}648 tonne_{resid}) \times \$322.48 / tonne_{resid}] + \\ &[(131 tonne_{distil} + 388 tonne_{distil} + 80 tonne_{distil}) \times \$467.92 / tonne_{distil}] + \\ &(4{,}709 gal_{urea} \times \$1.52 / gal_{urea}) = \$1{,}908{,}549_{ECA}\end{aligned}$$

The total estimated price for an average sized containership traversing the circle with the ECA in place is just over $1.9M. The cost increase of this trip caused by the fuel and urea prices used in the ECA came from subtracting the baseline (residual fuel) trip price from the ECA price (Equation 7-12). The price differential between the baseline trip and the ECA trip is demonstrated in Equation 7-13 and takes into consideration the fuel cost portion of the operational cost for a vessel, which is typically around 60 percent of the total. As can be seen, by operating in the ECA for our theoretical circle route it is estimated that the operational costs due to the distillate fuel is approximately three percent (3%).

Equation 7-12

$$\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline} = \$84{,}602$$

Equation 7-13

$$0.60 \times \frac{\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline}}{\$1{,}823{,}947_{baseline}} \times 100 = 2.8\%$$

To put this price increase in some perspective, we assumed our average sized containership was hauling goods, such Twenty-foot Equivalent Units (TEU), and estimated the increase per each TEU. Estimating these prices required the cargo weight of the vessel. Literature shows that approximately 93-97% of a container vessel's DWT is used for hauling cargo, with the remaining weight composing the crew, vessel engines and hull, and fuel.[30] Equation 7-14 shows the calculation used to convert the vessel's DWT to cargo weight using the middle value of 95%.

Equation 7-14

$$50{,}814 DWT \times 0.95 = 48{,}273 c\arg o\_tonnes$$

Dividing the difference between the baseline fuel price and the ECA fuel price we calculated previously by the cargo tonnes as established in Equation 7-14 provided the price increase per tonne of good shipped for the entire route (Equation 7-15).

Equation 7-15

$$\frac{(\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline})}{48{,}273 c\arg o\_tonnes} = \$1.75 / c\arg o\_tonne_{increase}$$

Using this value and the weight of a full TEU (10 metric tonnes)[31], we determined the cost increase for shipping a fully loaded TEU across our circle route (Equation 7-16).

Equation 7-16

$$\frac{\$1.75}{c\arg o\_tonne_{increase}} \times \frac{10 tonnes}{full\_TEU} = \$17.53 / full\_TEU_{increase}$$

7.3.2 Bulk Carrier

Since the majority of goods transported to the U.S. are brought by bulk carriers as well as container vessels, and bulk carriers are of a different construction than container vessels, we also conducted estimations as to what the price increase per tonne of bulk cargo would be due to the ECA. For a comparison, we calculated what the price increase would be for a tonne of bulk cargo carried on a vessel traversing the same theoretical circle route as the containership.

Equation 7-17 shows the same calculations as performed above for the containership using the average engine power for a bulk carrier (3,825 kW) and the total trip distance (15,876 nm)

Equation 7-17

$$\frac{3{,}825kW \times 0.8 \times 195 \, {g_{resid}}/{kW-hr} \times 15{,}876nm}{16 \, {knots}/{hr}} \times \frac{tonne}{1{,}000{,}000g} = 592tonne_{resid}$$

This determination was also conducted for the ECA, using the appropriate values for the distillate part of the circle route (1,763 nm) and the residual fuel part of the route (14,113 nm) (Equation 7-18 and 19 respectively). Equation 7-20 determines the urea required for use in the ECA (as was established in Equation 7-10), and Equation 7-21 estimates the overall price increase for the bulk carrier if it was to operate on the theoretical circle route through the ECA.

Equation 7-18

$$3{,}825kW \times 0.8 \times \frac{195 \, {g_{resid}}/{kW-hr}}{1+0.05} \times \frac{1{,}763nm}{16 \, {knots}/{hr}} \times \frac{tonne}{1{,}000{,}000g} = 62.6tonne_{distil}$$

Equation 7-19

$$\frac{3{,}825kW \times 0.8 \times 195 \, {g_{resid}}/{kW-hr} \times 14{,}113nm}{16 \, {knots}/{hr}} \times \frac{tonne}{1{,}000{,}000g} = 526tonne_{resid}$$

Equation 7-20

$$62.6tonnes_{distil} \times \frac{kg}{0.001tonne} \times \frac{m^3}{836.6kg_{distil}} \times \frac{264.17gal}{m^3} \times 0.075 = 1{,}483gal_{urea} \times 0.332 = 492gal_{urea}$$

Equation 7-21

$$[(62.6tonne_{distil} \times \$467.92/tonne_{distil}) + (526tonne_{resid} \times \$322.48/tonne_{resid}) + (492gal_{urea} \times \$1.52/gal_{urea})] - [592tonne_{resid} \times \$322.48/tonne_{resid}] = \$8{,}756_{increase}$$

To establish this price increase in terms of bulk cargo shipped, the value from Equation 7-21 was divided by the available cargo weight for the bulk carrier which was determined from the actual vessel weight (16,600 tonnes) as was performed in Equation 7-14 (Equation 7-22).

Equation 7-22

$$\frac{\$8{,}756_{increase}}{(16{,}600 bulk\_carrgo\_tonnes \times 0.95)} = \$0.56 / bulk\_carrgo\_tonne_{increase}$$

As can be seen, for an average bulk carrier that would travel from Singapore to Seattle, POLA/LB, and then back out to Singapore, the price increase caused by operation in the ECA would be around $0.56 per tonne of good shipped. As with the other vessels, this price would fluctuate depending on the distance traveled within the ECA, the vessel's speed, and the engine power used.

7.3.3 Cruise Ship

We also conducted an analysis on a typical Alaskan cruise liner. These vessels tend to operate close to shore and would be within the ECA for the majority of their routes. As such, this analysis presents worst case cost impacts for this type of vessel.

To conduct this analysis, a series of average vessel characteristics were chosen along with a typical 7 day (168 hours) Alaskan cruise route. The characteristics used below are the main engine power (31,500 kW), auxiliary engine power (18,680 kW), base specific residual fuel consumption (178 g_{fuel}/kW-hr for main engines, 188 g_{fuel}/kW-hr for auxiliary engines), distance between voyage destinations (5 destinations with a distance ranging between 230 to 700 nm (shown in Table 7-8)), maximum vessel speed (21.5 knots), and the average number of passengers on-board the vessel (1,886 people). Additionally, the arrival and departure times at the various ports of call along the cruise route were used to calculate the average speed travelled between each destination (shown in Table 7-8). The required power for a given journey segment was calculated using the relationship shown in Equation 7-23. This relationship was developed for the "2005-2006 BC Ocean-Going Vessel Emissions Inventory,"[32] which was conducted by the Chamber of Shipping of British Columbia, Canada.

Equation 7-23

$$\text{Required engine power} = 0.8199 \times (\text{avg speed}/\text{max speed})^3 - 0.0191 \times (\text{avg speed}/\text{max speed})^2 + 0.0297 \times (\text{avg speed}/\text{max speed}) + 0.1682$$

This relationship was developed to approximate effective power given cruise ships' diesel-electric operation. The auxiliary engines reported within the Lloyd's of London 'Seaweb' database[33], and are presumably operated independently of the vessels main diesel-electric power generation, as well as assumed to operate at an average of 50% power for the entire voyage.

To demonstrate the price increase for the cruise liner that would operate within the ECA, calculations for one leg of the Alaskan voyage are shown in Equation 7-24 to 27, the entire trip operational cost increase per person in Equation 7-28, and with Table 7-8 depicting the total increases over the entire trip broken out by destination.

Equation 7-24

$$31{,}500kW \times 0.5683 \times \frac{178g_{fuel}}{kW-hr} \times 704nm \times \frac{hr}{16.76knots} \times \frac{tonne}{1{,}000{,}000g} = 134tonne_{resid}$$

Equation 7-25

$$\frac{134tonne_{resid}}{1{,}886people} \times \frac{\$322.48}{tonne_{resid}} = \$22.89 / person_{resid}$$

Equation 7-26

$$31{,}500kW \times 0.5683 \times \frac{178g_{fuel}}{(1.05)kW-hr} \times 704nm \times \frac{hr}{16.76knots} \times \frac{tonne}{1{,}000{,}000g} = 127tonne_{distil}$$

Equation 7-27

$$\frac{127tonne_{distil}}{1{,}886people} \times \frac{\$467.92}{tonne_{distil}} = \$31.62 / person_{distil}$$

Equation 7-28

$$\$31.62 - \$22.89 = \$8.73 / person_{main\_increase}$$

Table 7-8 Alaskan Cruise Liner Destinations and the Corresponding Operational Price Increases

Destination Origin	Destination Conclusion	Distance Between Locations (nm)	Average Speed Traveled Between Ports (knots)	Calculated Engine Load (Equation 7-23)	Estimated Price Increase / Person ($)
Vancouver	Sitka	704	16.76	0.5683	$8.73
Sitka	Hubbard Glacier	253	16.32	0.5385	$3.06
Hubbard Glacier	Juneau	246	14.47	0.4295	$2.67
Juneau	Ketchilkan	237	13.17	0.3675	$2.42
Ketchilkan	Vancouver	534	15.48	0.4856	$6.13
Total					**23.02_{main_increase}$**

Additionally, the operational cost increases for the auxiliary engines were estimated. Equation 7-29 to 33), as well as the cost increases caused by dosing the engine exhaust with urea (Equation 7-34 & 35), and the total price increase for the cruise (Equation 7-36) divided by the length of the cruise (Equation 7-37).

Equation 7-29

$$18{,}680kW \times 0.50 \times \frac{188g_{fuel}}{kW-hr} \times 168hrs \times \frac{tonne}{1{,}000{,}000g} = 295tonne_{resid}$$

Equation 7-30

$$\frac{295tonne_{resid}}{1{,}886people} \times \frac{\$322.48}{tonne_{resid}} = \$50.44 / person_{resid}$$

Equation 7-31

$$18{,}680kW \times 0.50 \times \frac{188g_{fuel}}{(1.05)kW-hr} \times 168hrs \times \frac{tonne}{1{,}000{,}000g} = 281tonne_{distil}$$

Equation 7-32

$$\frac{281tonne_{distil}}{1{,}886people} \times \frac{\$467.92}{tonne_{distil}} = \$69.71 / person_{distil}$$

Equation 7 33

$$\$69.71 - \$50.44 = \$19.27 / person_{aux\_increase}$$

Equation 7-34

$$616.75tonnes_{distil} \times \frac{kg}{0.001tonne} \times \frac{m^3}{836.6kg_{distil}} \times \frac{264.17gal}{m^3} \times 0.075 = 14{,}606gal_{urea} \times 0.332 = 4{,}849gal_{urea}$$

Equation 7-35

$$\frac{4{,}849gal_{urea}}{1{,}886people} \times \$1.52 / gal_{urea} = \$3.91_{urea\_increase}$$

Equation 7-36

$$\$23.02_{main\_increase} + \$19.27_{aux\_increase} + \$3.91_{urea\_increase} = \$46.20 / person_{total\_increase}$$

Equation 7-37

$$\frac{\$46.20 / person_{total\_increase}}{7days_{cruise\_length}} = \$6.60 / person / day$$

To put this price increase in perspective of the additional cost for a typical seven-day Alaskan cruise, we also determined the % increase for the various stateroom types available on the vessel. These values were established as shown in Equation 7-38 and Table 7-9 lists the four main stateroom types used on a typical Alaskan cruise liner. It should be noted that these

estimates are provided for illustration only; cruise ship lines may choose some other method to allocate the increase in operating costs among passengers.

Equation 7-38

$$\frac{\$46.20}{Stateroom\_price(\$599)} \times 100 = 7.7\%$$

Table 7-9 Representative Alaskan Cruise Liner Stateroom Price Increases

Stateroom Type	Original Average Price Per Night ($)	Percentage Increase
Interior	$100	6.6%
Ocean View	$200	3.3%
Balcony	$300	2.2%
Suite	$400	1.7%

As can be seen from all the above price increase estimations, the additional costs of the distillate fuel and the urea required to operate in the proposed ECA will not be a significant monetary increase to the overall operation of the vessel, regardless of vessel type.

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CHAPTER 8: SMALL ENTITY IMPACT ANALYSIS

CHAPTER 8: Small Entity Impact Analysis

This chapter contains the results of our small entity screening analysis for the proposed rule regarding emissions from Category 3 marine diesel engines (i.e., those marine diesel engines with per cylinder displacement at or above 30 liters). This analysis is required under the provisions of the Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act (RFA/SBREFA). As described below, our analysis shows that there are no small entities that would be impacted by the proposed regulations. Therefore, consistent with EPA's RFA/SBREFA guidelines, we plan to certify that this rule will not, if promulgated, have a significant economic impact on a substantial number of small entities.

This chapter provides some background information on the proposed rule and describes the outcome of our screening analysis. Section 8.1 describes the engine and fuel standards we are considering. Sections 8.2 and 8.3 provide small business information for the diesel marine engine program. Section 8.4 provides small business information for the diesel fuel program.

8.1 Standards Under Consideration

In October 2008, negotiations were successfully concluded for amendments to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL Annex VI). These amendments, which are based on the proposal submitted to IMO by the United States Government in February 2007, set additional tiers of standards for marine diesel engine oxides of nitrogen (NO_X) emissions and the sulfur content of fuel.

Our Category 3 proposal would add the Annex VI NO_X limits to our Clean Air Act marine diesel engine requirements for Category 3 engines, and create an allowance for the production of diesel fuel specifically for these engines. Specifically, we are proposing to adopt two additional tiers of NO_X limits for Category 3 engines. The Tier 2 standards would result in a 20 percent reduction in NO_X in 2011 as compared to the existing Tier 1 standards, based largely on in-cylinder control technologies. The Tier 3 standards, taking effect in 2016, would rely upon high-efficiency exhaust aftertreatment technology such as selective catalytic reduction (SCR) and would result in an 80 percent reduction in NO_X. We are also proposing to modify our diesel fuel program to allow the manufacture and sale of marine diesel fuel with a sulfur content up to 1,000 parts per millions (ppm) for use in engines with a displacement of more than 30 liters per cylinder.

As explained below, this proposal is not expected to have a significant impact on a substantial number of small businesses.

8.2 Marine Diesel Engine Manufacturers

The responsibility for meeting the new engine standards would fall on the engine manufacturers. Such manufacturers are those primarily engaged in manufacture of large diesel marine engines as defined by North American Industry Classification System (NAICS) code 333618. There are no U.S. companies that manufacture Category 3 marine diesel engines in the U.S.

While there is one U.S. company that is a parent company to a foreign Category 3 engine manufacturing company, this company is not a small business (using the Small Business Administration definition of companies with less than or equal to 1,000 employees), and the engine manufacturing does not occur in the U.S. We are unaware of any foreign manufacturers of such engines with a U.S–based facility that qualify as a small business.

For these reasons, we conclude that the proposed engine regulations would not place a substantial burden on any small U.S. engine manufacturers.

8.3 Vessel Manufacturers

While the primary responsibility for meeting the new engine standards lies with the engine manufacturers, the vessel manufacturers are potentially affected as well in the case of the Tier 3 standards. Such manufacturers are those primarily engaged in the shipbuilding and repairing as defined by NAICS code 336611. Vessel manufacturers will have to accommodate the addition of exhaust aftertreatment hardware in their design and manufacturing processes.

We have identified 6 shipyards in the U.S. capable of producing Category 3 vessels. Of those, most build primarily military vessels. One of these shipyards is owned by a foreign company, and none of these shipyards is a small business that would meet the Small Business Administration definition of 1,000 or fewer employees.

For these reasons, we conclude that the proposed regulations would not place a substantial burden on any small U.S. vessel manufacturers.

8.4 Fuel Manufacturers and Distributors

We are proposing a revision to our diesel fuel program to allow the manufacture and sale of marine diesel fuel with a sulfur content up to 1,000 ppm for use in Category 3 engines. This would allow our regulations to be consistent with the new sulfur limits that will become applicable in 2015 under IMO regulations in Emission Control Areas. Our current diesel fuel program sets a sulfur limit of 15 ppm that is fully phased in by December 1, 2014 for the production of diesel fuel designated for use in Category 1 and Category 2 marine applications (DMX and DMA). Without this proposed change to our diesel fuel regulations, while fuel with a sulfur content of up to 1,000 ppm could be used on Category 3 applications, it would be unlawful to produce, distribute or sell it within the United States.

This revision to our diesel fuel program will not require any person to manufacture, distribute or sell 1,000 ppm sulfur fuel. It simply allows for its production and sale, which is precluded under our current diesel fuel regulations.

This allowance for 1,000 ppm sulfur fuel would be a benefit to those fuel producers, distributors or marketers who choose to produce or sell it, as it allows for higher sulfur content than diesel fuels allowed under current EPA regulations. Since we are not considering mandating production of this fuel, fuel manufacturers, distributors and marketers can opt out of producing, distributing or selling it. Thus, allowing this fuel would not require a mandatory change in any company's business situation. Those companies that would find it beneficial to

produce, distribute or sell this fuel would do so. Conversely, those companies that would not find it beneficial would simply continue to operate the way they otherwise would in the absence of this new allowance.

For the reasons just outlined, the allowance we are considering for 1,000 ppm sulfur marine diesel fuel would not place a substantial burden on any small U.S. refiners, pipeline operators, fuel terminal operators, or fuel marketers.