Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter

Technical Support Document

United States
Environmental Protection
Agency

Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter

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

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Table of Contents

Executive Summary

Introduction

On June 25, 2010, the United States submitted a proposal (MEPC 61/7/3) to the International Maritime Organization (IMO) to designate an Emission Control Area (ECA) for specific portions of the coastal waters around Puerto Rico and the U.S. Virgin Islands. This action would control emissions of nitrogen oxides (NO_X), sulfur oxides (SO_X), and particulate matter (PM) from ships. Designation of the proposed ECA would significantly reduce emissions from ships and deliver substantial benefits to the local population, as well as to marine and terrestrial ecosystems

Also submitted to the IMO is an Information Document (MEPC 61-INF.9), which provides a complete analysis of how the proposal addresses the IMO's approval criteria. This Technical Support Document provides additional detail on the technical analyses supporting those submissions.

Description of Population and Areas

Chapter 1 provides a description of The Commonwealth of Puerto Rico and the U.S. Virgin Islands. This includes information about geography, population and population densities, special ecological areas, and the economies of these islands, and supplements information contained in the Information Document prepared for the proposal package. The combination of people and sensitive ecosystems being located in close proximity to ports and areas of ship activity with the high levels of ship activity in this area mean that emissions from ships are contributing to ambient concentrations of air pollution and to adverse environmental impacts in Puerto Rico and the U.S. Virgin Islands.

Emission Inventory

Chapter 2 describes how U.S. emission inventories were developed to describe air emissions from ships operating in waters within the proposed ECA. These inventories provide the foundation upon which all the subsequent analyses were built, and address Criterion 6 of Section 3, Appendix III to MARPOL Annex VI. Beyond the level of detail provided in MEPC 61/7/3, Chapter 2 explains how the inputs were developed and what assumptions were made in assessing what the emissions are from ships currently (2002 base year), what the emissions would look like in 2020 without the proposed ECA, and what reductions can be expected from the proposed ECA.

Chapter 2 describes the "bottom-up" methodology that was used, based on the latest state of the art models and inputs. This chapter describes which port-related emissions were included and why, and how emissions were obtained for ships while underway in U.S. waters. This chapter explains in great detail each parameter that went into the modeling and analyses, including which ships are included, which fuels are used by those ships, which other (non-ECA) emission controls are in place for each scenario, and what growth rates are expected, incorporating forecasts of the demand for marine transportation services in 2020.

Impacts of Emissions on Human Health and the Environment

Chapter 3 describes the impact of ships' emissions on human health and ecosystems and supports Section 5.4 of the Information Document. Chapter 3 includes a description of the pollutants proposed for control in the U.S. Caribbean ECA. The proposed ECA would not only reduce direct emissions of NO_X, SO_X and PM, but also secondarily formed ambient PM and ground-level ozone. Section 3.1 describes the nature of these pollutants, formation processes, and relationship to ship emissions. Section 3.2 presents the health effects associated with exposure to NO_X, SO_X, PM and ground-level ozone, summarizing the key scientific literature. Section 3.3 describes the impacts of emissions from ships on terrestrial and aquatic ecosystems such as acidification, nutrient enrichment, ozone uptake and visibility degradation.

Cost Analyses

Chapter 4 describes our estimates of the costs associated with the reduction of NO_X, SO_X, and PM emissions from ships, not only to the shipping industry but also to marine fuel suppliers and companies who rely on the shipping industry. This chapter provides additional detail regarding the analyses conducted in support of Criteria 7 and 8 of Section 3, Appendix III to MARPOL Annex VI. This chapter describes the analyses used to evaluate the cost impact of Tier III NO_X requirements combined with low sulfur fuel use on vessels operating within the proposed ECA, including estimates of low sulfur fuel production costs and operating costs. This chapter also presents cost per ton estimates for ECA-based NO_X and fuel sulfur standards and compares these with the costs of established land-based control programs.

Economic Impact Analysis

Chapter 5 examines the economic impacts of the projected ECA costs on shipping engaged in international trade. This chapter provides additional detail in support of Criterion 8 of Section 3, Appendix III to MARPOL Annex VI. This chapter describes the econometric methodology that was used in estimating two aspects of the economic impacts: social costs and how they are shared across stakeholders, and market impacts for the new engine and new vessel markets.

CHAPTER 1: Description of Population and Environmental Areas at Risk

The proposed Emission Control Area (ECA) consists of the Commonwealth of Puerto Rico and the U.S. Virgin Islands. These islands are unincorporated territories of the United States. They are situated where the Western Atlantic Ocean meets the Caribbean Sea, among the chain of islands called the Antilles of the West Indies. This chapter describes the geography, population, and economy of each of these U.S. territories.

1.1 The Commonwealth of Puerto Rico

The Commonwealth of Puerto Rico is an archipelago of the easternmost islands of the Greater Antilles. Puerto Rico consists of the main island of Puerto Rico and several smaller islands including Vieques, Culebra, Mona and Monito, Desecheo, Caja de Muertos, and La Isleta de San Juan.

The main island of Puerto Rico extends a maximum of about 180 km east-west and 65 km north-south, with a total land area of 9,000 square km. Puerto Rico's mountainous interior rises to a peak altitude of 1,339 meters at Cerro de Punta, part of La Cordillera Central mountain range. Together with the Sierra de Luquillo and Sierra de Cayey ranges, mountainous terrain covers most of the interior and roughly two-thirds of the entire island. An area of rugged limestone or karst topography extends to the north of La Cordillera Central, occupying a large portion of north-central and northwest of the island. Over much of the remainder of the island, flat coastal plains separate the mountains from the sea.[1] Figure 1-1 identifies the location of these major landforms on Puerto Rico and the Virgin Islands.

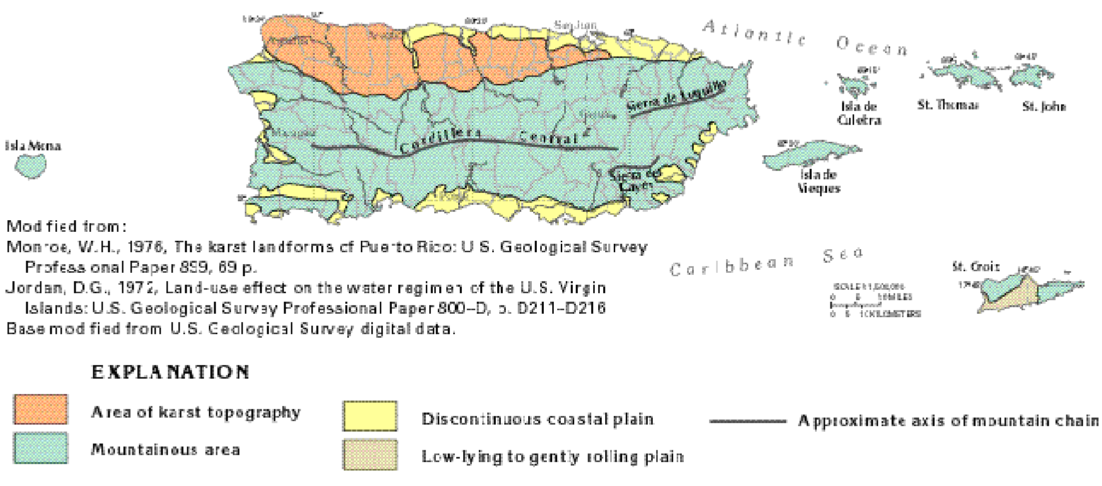

Figure 1-1: Topography of Puerto Rico and the Virgin Islands[1]

The topography of Puerto Rico influences weather patterns, particularly in the mountain ranges, in part by lifting the moist air masses and increasing rainfall. As a result, annual precipitation varies directly with altitude.[1] This phenomenon occurs especially on the eastern side on the main island, as the prevailing winds from the east carry the moist air towards the mountains. Puerto Rico's climate is marine tropical with seasonal variation in precipitation.[2]

Puerto Rico's climate and geography contribute to a great deal of natural diversity. Ecosystems range from bioluminescent bays and tropical mangrove swamps to coral reefs. Puerto Rico has two areas classified by UNESCO as World Biosphere Reserves: Luquillo and Guanica. The Luquillo Mountains in the northeast of Puerto Rico contain the only protected tropical rainforest in the United States forest system, El Yunque. The Guanica Reserve, located in the southwest of the island, consists of several mangrove cays and a subtropical dry forest.[3] Furthermore, Mona and Monito Island, 70 km off the west coast of the main island, has been denoted as the Galapagos of the Caribbean. It contains sensitive ecosystems and provides habitat for several endangered species, for example the Mona Island ground iguana and the hawksbill turtle.[4]

The human population of Puerto Rico is densely clustered near the coasts into highly urbanized communities. Approximately 70 percent of the population lives within 10 kilometers of the shore. Rural areas account for only a marginal percentage of the total population in Puerto Rico.[5] Figure 1-2 illustrates the high population density along the coast. This map also shows the co-location of commercial ports with the most densely populated regions. As a consequence of their proximity to ports and the coastline, inhabitants of the islands Vieques, Culebra, and the main island of Puerto Rico are clearly affected by ship emissions.

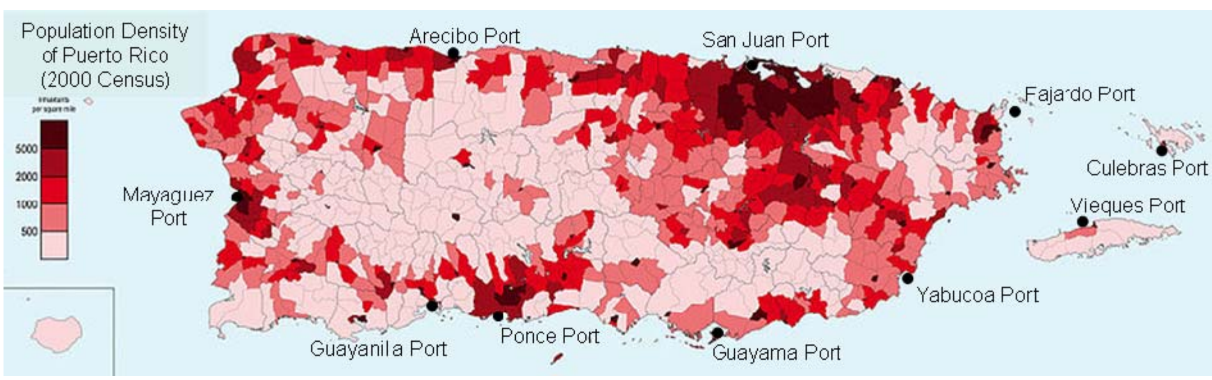

Figure 1-2 Port locations and population density of Puerto Rico[6]

The U.S. Census Bureau estimates the total population of Puerto Rico at approximately 4.0 million people for 2009.[7] If Puerto Rico were a U.S. state, it would rank 27th in population size, after Kentucky and before Oregon. Additionally, Puerto Rico ranks behind all 50 states except Delaware and Rhode Island in land area, at approximately 9,000 square kilometers. This gives Puerto Rico an average population density of about 440 people per square kilometer, second in the United States after New Jersey.[8] Only around 20 countries in the world have a higher population density.[9] Not only is Puerto Rico densely populated, but the population is heavily distributed among groups that are especially sensitive to air pollution, particularly children and the elderly. Over 1.5 million, or 38 percent of the population, is under 18 or over the age of 65.[10]

There are approximately 1.2 million households in Puerto Rico. The average household size is 3.2 people, with families making up 75 percent of the households. Just three percent of those living in Puerto Rico are foreign born. Of the native-born population, more than 90 percent was born in the municipio[A] where they currently reside.[10]

Of the population above 16 years old, 47 percent is classified as in the labor force, which is far lower than all US states. Major occupations include management/professional (29 percent of the employed population), sales/office (28 percent) and service occupations (19 percent). The leading industries by employment are education/health care/social assistance (22 percent of the employed population), retail trade (13 percent) and manufacturing (11 percent). In 2008, approximately 16 percent were unemployed.[10]

About 45 percent of the population was classified at or below the poverty threshold in 2008. This is far above the national average in the United States of 13 percent. The poverty rate for children in Puerto Rico is even higher: 56 percent.[10] Moreover, much of this population lacks adequate access to medical services. Approximately 32 percent of the population, or 1.27 million Puerto Ricans, are considered medically underserved.[11]

While the links between these socioeconomic conditions and risks from air pollution is complex, when combined with the high concentration of these population groups in close proximity to large sources of emission such as marine ports, there is little doubt the residents face an elevated risk.

San Juan, Puerto Rico's largest city, has a population of about 420,000 within the municipio boundaries and 2.6 million throughout the metropolitan area.[12] The area has a population density of about 950 people per square kilometer, making it 170th in population density among urban areas worldwide.[13] Located on the North shore of Puerto Rico, San Juan is built along one of the biggest natural harbors in the Caribbean Sea. The Port of San Juan is the center for goods movement on the island, moving approximately 11 million metric tons of products on nearly 3,800 vessel trips in 2008. Based on tonnage, San Juan ranks 49th out of the top 150 commercial ports in the United States that year.[14] However, the port is in the top 10 in the country when ranked by container traffic. In 2009 the Port of San Juan moved 1.7 million twenty-foot equivalent units[15] of containerized cargo. San Juan is also a major destination for cruise ship passengers. In 2008 an estimated 1.4 million passengers on over 500 port calls visited the Port of San Juan, making it one of the top cruise destinations in the Caribbean.[16] San Juan is the fifth busiest cruise ship departure port in the United States.[17]

The city of Ponce, located on the southwest side of the main island, is also the home to a major port. Ponce is Puerto Rico's second largest municipio with 180,000 inhabitants.[7] The port complex, which will be renamed Port of the Americas, is undergoing large-scale redevelopment in order to relieve the congestion in San Juan. The port ranked as the 83rd busiest port, by

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[A] A municipio is the primary legal subdivision of Puerto Rico.

tonnage, out of the top 150 commercial ports in the United States in 2008.[14] When completed, Port of the Americas will be capable of handling up to 1.5 million twenty-foot containers and 600,000 tons of general cargo each year. As of 2008, 3.8 million metric tons of goods moved through the port in Ponce.[18]

Mayaguez, an industrial and port city on the west coast of the island, is home to over 90,000 people.[7] The port in Mayaguez moved approximately 350,000 tons of cargo in 2008, much of which was fuel shipments.

Similarly, the port city of Arecibo, just downwind (west) of San Juan, is home to a port primarily used for importing fuel. In 2008 fuel shipments alone totaled 53,000 tons. Arecibo contains 100,000 residents.[7] The city's terrain consists of hills surrounding the city, forming a natural bowl.

The inland city of Caguas in eastern Puerto Rico is another major commercial center. It is situated in a valley surrounded by mountains, where air pollutants tend to accumulate rather than disperse. Although not port city, Caguas is subject to air pollution carried downwind from ship traffic along the east coast of Puerto Rico.

Other major port cities include Guayama, Yabucoa and Fajardo. Population and density figures for the main coastal and inland municipios are listed in Table 1-1.

Table 1-1 Annual Estimates of the Resident Population and Population Density for Municipios of Puerto Rico. Source data: Reference 7.

MUNICIPIO	POPULATION (2009)	POP. DENSITY (PEOPLE/KM^2)
Arecibo	102,770	315
San Juan	420,326	3,394
Fajardo	42,365	548
Yabucoa	48,615	339
Guayama	45,372	270
Ponce	178,346	600
Guayanilla	23,752	217
Mayaguez	92,156	458
Caguas	143,274	944
Culebras	2,156	72
Vieques	9,311	71

In the late 1940s and early 1950s, the government of Puerto Rico implemented a plan to encourage economic development by transforming the island's economy from an agriculture-based economy (primarily sugar production) to one based on industry. The plan involved importing raw materials, utilizing local labor to manufacture products, and then distributing the finished products throughout the U.S. market. Throughout the 1950s the plan proceeded, and by the end of the decade, the gross domestic product of Puerto Rico had almost doubled.[19]

As a result, the economy of the territory has moved from agricultural (sugar production) to industrial, with manufacturing currently accounting for about 45 per cent of GDP and agriculture only about 1 per cent. The sector has evolved to be more capital intensive over the past three decades, with pharmaceuticals production now comprising the largest share within the sector. Employment within the sector has likewise shifted. The high dependency on skilled labor has reduced the manufacturing sector workforce to just over 10% in 2007, down from 19% in 1991.[20]

Puerto Rico has very strong economic links with the continental United States. Because of its lack of natural resources, the territory obtains the raw materials as well as chemicals, machinery and equipment, clothing, food, fish, and petroleum from outside the island, mainly from the continental United States (55 per cent), Ireland (24 per cent) and Japan (5 per cent).[20] Finished goods include chemicals, electronics, apparel, canned tuna, rum, beverage concentrates, and medical equipment, and are mainly destined for the continental United States (90 per cent).[2]

Chemicals, in turn, are the largest export product, also accounting for two-thirds of the total value of export shipments.[20] In all, Puerto Rico reported approximately $80 billion in manufacturers' shipments in 2007, 65 percent of which is related to chemical manufacture.[21]

Aside from a small fraction of renewable energy production, Puerto Rico relies entirely on external shipments of petroleum, natural gas and coal to meet its energy needs. Petroleum imports totaled approximately 190,000 barrels per day, 20 percent of which are in the form of crude oil which is then refined on the island. In addition, nearly 30 billion cubic feet of natural gas and 1.7 million tons of coal are shipped to Puerto Rico each year.[22]

The customs district of Puerto Rico, including all of its major ports, rank in the top 25 ports in the United States in terms of foreign trade and value. In 2008 over 14 million metric tons of goods traveled through Puerto Rican ports at an estimated value of over $13 billion.[23]

In addition to ships entering Puerto Rican ports, there is a substantial amount of ship activity around the island from vessels on their way to or from the Panama Canal and other countries in the Americas. These ship operations are described in Section 7 of the Information Document accompanying MEPC 61/7/3.

Puerto Rico is not only frequented by ships transporting goods, but also people. Approximately 1.4 million visitors arrived by cruise ship in 2008. Puerto Rico has historically been a top destination for cruises. Cruises and other tourism constitute a vital component of Puerto Rico's economy. Tourist expenditures in Puerto Rico approached $3.5 billion in 2007. The industry also provides jobs for seven percent of the workforce.[20] According to the UN World Tourism Organization, Puerto Rico had about 4 million international tourist arrivals in 2007, ranking it 50th in the world.[24]

In sum, Puerto Rico's economy is highly dependent on marine transportation. This dependency along with the physical and human geography, place the population at an elevated risk from ship-related air pollution.

1.2 U.S. Virgin Islands

The U.S. Virgin Islands are the westernmost islands of the Lesser Antilles, located between Puerto Rico (about 90 miles west) and the British Virgin Islands, and near the Anegada passage, a deep (2,300 meter) channel that connects the Atlantic Ocean with the Caribbean Sea. The U.S. Virgin Islands are comprised of three main islands, Saint Thomas, Saint John, and Saint Croix, as well as several dozen smaller islands. The entire island chain measures about 45 km east-west by about 11 km north-south.

This area is geologically active, being near the boundary of the Caribbean and North American plates. The U.S. Virgin Islands are volcanic in origin and mostly hilly to rugged and mountainous with little level land, although jungle-like regions may be found on the elevated plateaus. These islands are known for their white sand beaches and coral reefs. More than half of the island of St. John has been managed by the U.S. National Park Service since the Virgin Islands National Park was expanded in 1962 to include over 5,000 acres of submerged lands to protect and preserve coral gardens and seascapes. Several other natural areas have been officially designated for preservation and conservation, including the Virgin Islands Coral Reef Monument, whose reefs are sheltered by mangrove forests and seagrass beds.[4] UNESCO has designated over two-thirds of the island of St. Johns as a Biosphere Reserve.[3]

Like Puerto Rico, geographic constraints result in the citizens of the U.S. Virgin Islands being located in densely populated coastal areas. Figure 1-3 illustrates the major cities of the three main U.S. Virgin Islands and their population densities. Also, like Puerto Rico, this map shows that all inhabitants of the U.S. Virgin Islands live in close proximity to commercial ports or the coasts and are clearly affected by ship emissions.

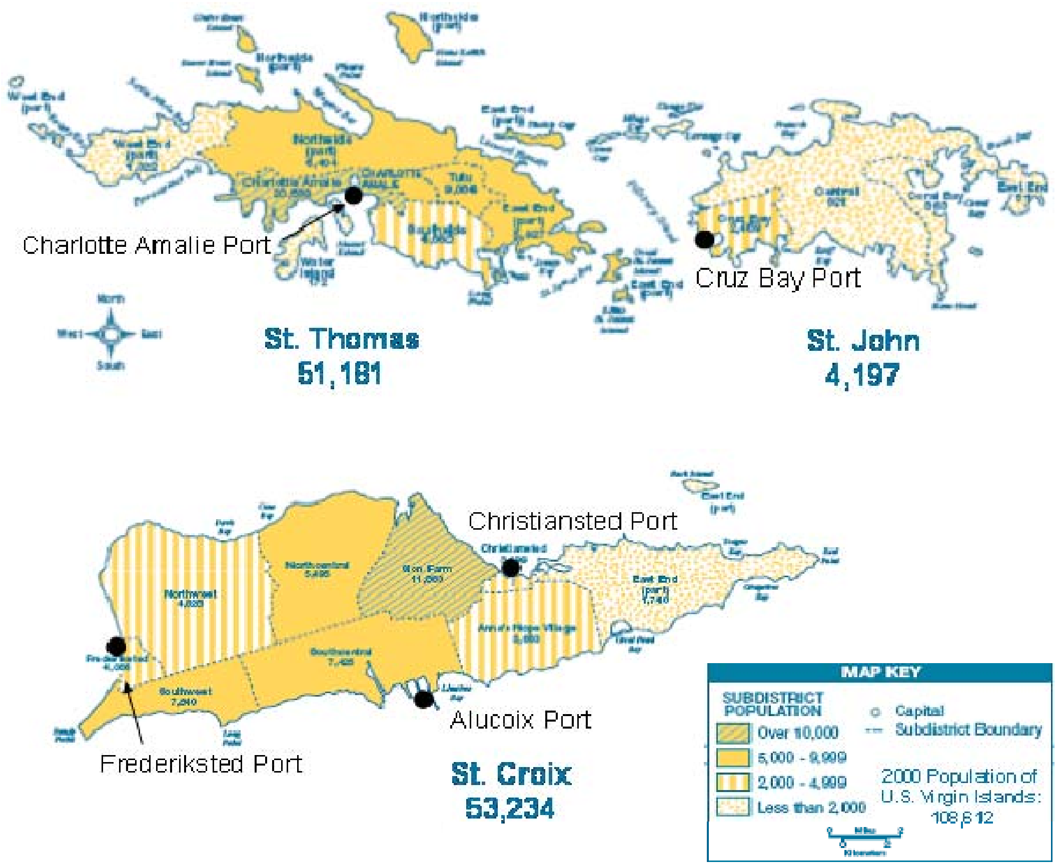

Figure 1-3 Port locations and population density of the U.S. Virgin Islands

The total population of the U.S. Virgin Islands is about 109,000. The population density of the islands is about 360 people per square kilometer, ranking it 34th in the world among nations[25]. This population is spread between St. Thomas (51,000 people; 630 people per square kilometer) and St. Croix (53,000 people; 280 people per square kilometer). An additional 4,000 people live in St. John; the rest of the islands have small or no populations.[5,26]

St. Thomas is the site of the U.S. Virgin Islands' capital and largest city, Charlotte Amalie. Approximately 19,000 people live in the capital. Charlotte Amalie, as is typical of St. Thomas and St. John islands, is characterized by steep topography that tends to contain air pollution.

Charlotte Amalie is also the location of the largest port in the U.S. Virgin Islands, St. Thomas Port. In 2005, St. Thomas alone saw over two million cruise passengers and over 800 cruise ship calls. In addition to cruise ships, smaller ferries and other passenger vessels frequent the port and the small islands across from Charlotte Amalie (Hassel Island and Water Island). St. Thomas is also a major transshipment port for cargo destined elsewhere in the Caribbean. In total, Virgin Island ports handled over one million tons of cargo in 2005.[27]

St. Croix is the largest and most populous of the U.S. Virgin Islands and contains the Ports of Frederiksted, Alucoix, and Christiansted. The most heavily populated areas of St. Croix are located downwind of Christiansted Port.

The main industry in the U.S. Virgin Islands is tourism, which accounts for about 80 percent of the territory's income.[25] Like Puerto Rico, the U.S. Virgin Islands are also engaged in manufacturing, importing raw materials and exporting finished goods including textiles, electronics, rum, and pharmaceuticals. Consequently, the U.S. Virgin Islands are dependent upon the shipping industry. The largest trade partners for the U.S. Virgin Islands are the United States and Puerto Rico.

Finally, St. Croix is the location of one of the world's largest petroleum refineries, Hovensa. A joint venture between Hess Corporation and Petroleos de Venezuela, this refinery supplies heating oil and gasoline to the U.S. Gulf and East coasts. In 2008, the U.S. Virgin Islands sent 320,000 barrels per day of refined products to the United States. With a capacity of about 500,000 barrels per day, Hovensa is one of the ten largest refineries in the world and the largest private employer in the U.S. Virgin Islands. This refinery is subject to U.S. domestic environmental regulations.[28]

In sum, the economy of the U.S. Virgin Islands is highly dependent on marine transportation. This dependency, in combination with the physical and human geography of the territory, place its population and environment at an elevated risk from ship-related pollution.

1.3 Conclusion

Both Puerto Rico and the U.S. Virgin Islands are densely populated islands that receive a large amount of ship traffic, both from trade vessels and tourist vessels. Due to the topographic and geographic makeup of these islands, most of the population is located around the coasts. The two territories are heavily fueled by the manufacturing industry, exemplified by the import of raw materials and export of finished goods. As a result, there is a significant portion of the population residing in and around the numerous port cities as workers in the manufacturing industry. In addition, as described in Section 7 of the Information Document, Puerto Rico and the U.S. Virgin Islands are located in high transit areas. Ships voyaging from Europe, Africa, and Asia operate in passages to the east and west of these islands. The emissions from the considerable ship traffic in this region have an impact on air quality, human health, and the environment, in Puerto Rico and the U.S. Virgin Islands.

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CHAPTER 2: Emission Inventory

2.1 Introduction

This chapter presents our estimated air emission inventories for ships that operate in the proposed ECA for the Commonwealth of Puerto Rico and the U.S. Virgin Islands (PR/USVI). This chapter is organized in four parts. First, we describe the domain of ships included in the analysis. Second, we describe the modeling methodology. Third, we present the results of this modeling, for the baseline inventory year of 2002 as well as the baseline and control scenarios for 2020. Finally, we present inventories for other sources of emissions for comparison.

Using the methodology described below, the estimated ship emissions inventories for the proposed U.S. Caribbean ECA for 2020 are as set out in Table 2-1. Inventories for both the reference (baseline) and the control scenarios are presented. ECA designation is expected to reduce emissions of NO_X, SO_X, and PM by 27 percent, 96 percent, and 86 percent, respectively, in 2020.

Table 2-1 C3 Emission Inventories for Proposed ECA in 2020

EMISSION TYPE	ANNUAL EMISSIONS (METRIC TONNES)[a,b]						
	NO_X	PM_{10}	$PM_{2.5}$[c]	HC	CO	SO_2	CO_2
Reference	36,950	3,793	3,488	1,509	3,609	29,568	1,797,909
Control	27,032	512	471	1,509	3,609	1,075	1,711,452
Delta Emissions	*-9,919*	*-3,342*	*-3,017*	*0*	*0*	*-28,493*	*-86,457*
Delta Emissions (%)	*-27%*	*-86%*	*-86%*	*0%*	*0%*	*-96%*	*-5%*

2.2 Description of Ships Included in the Analysis

The ship inventories reported in this chapter are for vessels with Category 3 propulsion engines (defined as engines with per cylinder displacement at or above 30 liters). These are the ships that are most likely to be affected by the MARPOL Annex VI fuel sulfur limits since these vessels are most likely to be designed to use residual fuel. While smaller vessels will also be affected by the proposed ECA, it is also the case that many of these vessels (those flagged or registered in the United States) are already subject to comparable U.S. marine diesel engine and fuel requirements under the CAA. In either case, these smaller vessels are likely to be using distillate fuel and therefore switching to a lower sulfur diesel fuel is not expected to impose a significant burden on their owners.

The ship inventories include emissions from both propulsion and auxiliary engines installed on board the Category 3 vessels included in the analysis.

The ship emission inventories are based on the U.S. Army Corps of Engineers (USACE) foreign traffic entrances and clearances data set. This is derived from U.S. Customs Vessels Entrances and Clearances data. The following vessels are required to file a Vessel Entrance or Clearance Statement:

- Any vessel from a foreign port or place;
- Any foreign vessel from a domestic port;
- Any vessel of the United States arriving from another U.S. port and having merchandise on board being transported in bond (this does not include bonded ship's stores or supplies), or transporting unentered foreign merchandise; or
- Any vessel, either U.S. or foreign, which has visited a hovering vessel (19 USC 1401(k)), or has delivered or received merchandise or passengers outside of U.S. waters.

The Entrances and Clearances data sets cover only foreign cargo movements. However, many ships tend to travel in circular routes (e.g., from Miami to Puerto Rico to Mexico to Brazil and then back to Miami). Cargo moved from Miami to Brazil would be foreign cargo, but the trip between Miami (origin) and the first port in Puerto Rico would be captured in the clearances data since it shows the first port of call.

Not included in this data set are US/domestic ships operating solely between the continental United States and Puerto Rico or the U.S. Virgin Islands. Most of that traffic is thought to be on ships with Category 2 propulsion engines or tug/barge combination vessels, and these smaller ships are already subject to U.S. marine diesel engine requirements, and the sulfur content of fuel available in the U.S. ports in which they operate is also subject to federal controls.

2.3 Inventory Methodology

The methodology used to estimate the inventories for the proposed ECA is consistent with the methodology used for the North American ECA. This methodology is summarized below; more details about the methodology as well as the additional calculations and minor changes required for the current application are presented in later sections of this chapter.

The inventory methodology consists of several parts.

First, we developed an inventory for 2002 for a broader modeling domain (called the inventory domain) consisting of the entire area around Puerto Rico and the U.S. Virgin Islands that is subject to the sovereign authority of the United States and consists of the exclusive economic zone surrounding these islands. The year 2002 was chosen to be consistent with the analysis performed for the North American ECA and allows us to take advantage of much of the work performed for that analysis, including inter-port emissions and estimated growth rates.

The 2002 inventory consists of two parts that were estimated using two different methods: port emissions and interport emissions.

> <u>Port inventories</u> consist of emissions that occur in a port, defined as up to 25 miles from the entrance of the port. Port inventories were developed for seven ports in Puerto Rico and five ports in the U.S. Virgin Islands. Port-specific emissions were estimated using a "bottom-up" approach based on port-specific vessel calls, emission factors, and activity for each port. For all other ports, estimates from the STEEM model are used (see below).

Interport emissions consist of emissions that occur outside of ports but within the inventory domain. These inventories were obtained using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM). STEEM also uses a "bottom-up" approach, estimating emissions from C3 vessels using historical 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 the proposed ECA.

The regional emission inventories produced by the current STEEM interport model are most accurate for vessels while cruising in ocean shipping lanes; the near port inventories use more detailed local port information and 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 2) the remaining interport portion of the STEEM inventory, which extends from the endpoint of the near port inventories to the outer boundary of the Caribbean inventory domain.

Merging these inventories requires spatially allocating the in-port emissions, removing the data for the 12 ports from the STEEM inventory, and replacing it with the detailed port inventories. The STEEM port data was retained for all other Puerto Rican and Virgin Island ports. The result of this process was a complete, spatially allocated inventory for 2002 covering the entire inventory domain. 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.

Next, baseline and control inventories were developed for the entire inventory domain for 2020. The baseline inventories for 2020 were estimated by applying a growth rate and emission adjustment factors to the 2002 inventories. The emission adjustment factors account for emission controls that will be in effect in 2020, including the MARPOL Annex VI Tier I and Tier II NO_X standards for new engines and the Regulation 13 NO_X retrofit program. The control inventories for 2020 were estimated by applying the same growth rate as the 2020 baseline case but a different set of emission adjustment factors that also account for the ECA engine and fuel sulfur controls. The result of this process was a complete, spatially allocated inventory for 2020 covering the entire inventory domain, for both the baseline and control scenarios.

Finally, the inventories for the proposed ECA for the 2020 baseline and control scenarios were developed by totaling the emissions within the proposed ECA boundaries.

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.

2.4 Development of 2002 Inventories

The inventories for the proposed ECA are derived from inventories estimated for the inventory domain consisting of the U.S. Exclusive Economic Zone around the islands of Puerto Rico and the U.S. Virgin Islands. The year 2002 was chosen to be consistent with the analysis performed for the North American ECA and allows us to take advantage of much of the work performed for that analysis, including inter-port emissions and estimated growth rates. The total inventories for 2002 are the total of port and interport inventories described in this section. The result is a spatially allocated inventory for the inventory domain.

2.4.1 Near Port Emissions

The outer boundaries of the ports are defined as 25 nautical miles (nm) from the terminus of the reduced speed zone. Port emissions are estimated for different modes of operation and then summed. Emissions for each mode are estimated 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 methodology and port inventory development was conducted under contract; details of the methodology as applied to the U.S. ports is described in the contractor report.[1]

2.4.1.1 Ports Modeled

The 12 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 within a 20 kilometer radius of each 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.

Near port emissions were estimated for the ports listed in Table 2-2. The 12 ports were chosen because of the availability of call data from the USACE entrance and clearance data.[2] The port coordinates are provided in Appendix 2A.

Table 2-2 Modeled Ports

PUERTO RICO PORTS	U.S. VIRGIN ISLANDS PORTS
San Juan Fajardo Ponce Jobos Guayanilla Mayaguez Yabucao	St. Thomas Christiansted Frederiksted Port Harvey (alumina bauxite refinery) Port Hess (oil terminal)

These ports were chosen because they are the largest ports in Puerto Rico and the U.S. Virgin Islands. For all other ports in these territories, emissions inventories estimated by the STEEM model are used.

2.4.1.2 Near Port Inventory Methodology

Near port emissions for each port are estimated using a bottom-up approach based on the number of vessel calls and vessel characteristics. Emissions are estimated for four modes of operation:

> Hotelling: 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: Maneuvering occurs within a very short distance of the docks.
> Reduced speed zone (RSZ): 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.
> Cruise: The cruise mode emissions in the near ports analysis extend 25 nautical miles beyond the end of the RSZ lanes.

Emissions are calculated separately for propulsion and auxiliary engines.

The basic equation used to estimate emissions for each engine at each mode is as follows:

Equation 2-1

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

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

2.4.1.3 Data Inputs for Near Port Emission Inventories

The following inputs are required to estimate emissions inventories for each vessel at four modes of operation (cruise, RSZ, maneuvering, and hotelling); these inputs are described in more detail below.

Number of calls and ship characteristics (main engine power, cruise speed, and load factors)
Cruise distance
RSZ distances and speeds for each port
Auxiliary engine power and load factors
Main emission factors
Auxiliary emission factors
Low load adjustment factors for main engines
Maneuvering time-in-mode (hours/call)
Hotelling time-in-mode (hours/call)

Number of Calls and Ship Characteristics (main engine power, cruise speed, and load factors)

For this analysis, USACE entrance and clearance data for 2002,[3] together with Lloyd's data for ship characteristics,[4] were used to identify 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.

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. This was accomplished by matching all ship calls with information from Lloyd's Data, which is produced by Lloyd's Register-Fairplay Ltd. 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[5] and displacement per cylinder was calculated. Ships with main propulsion engines with per cylinder displacement less than 30 liters eliminated from the data set. Passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes and were retained in the data set as they are subject to the ECA requirements.

The dataset for vessels with Category 3 propulsion engines 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). Propulsion power and vessel cruise speed are also averaged for each bin.

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. Appendix 2B provides the specific equations used to calculate propulsion and auxiliary emissions for each activity mode.

Note that load factors for main engines are not listed explicitly, since they are calculated as a function of mode and/or cruise speed.

Cruise Distance

Cruise mode emissions are calculated assuming a 25 nautical mile distance into and out of the port outside of the reduced speed and maneuvering zones.

RSZ Distances and Speeds by Port

The reduced speed zone (RSZ) distance and speed were 10 nautical miles and 10 knots, respectively, for all PR/USVI ports.

Auxiliary Engine Power and Load Factors

Hotelling emissions are a significant part of port inventories, and it is important to distinguish propulsion engine emissions from auxiliary engine emissions when estimating these emissions. This is because hotelling emissions are generally generated by auxiliary engines.

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.[6] Average auxiliary engine power to propulsion power ratios were estimated by ship type and are presented in Table 2-3. These ratios by ship type were applied to the propulsion power data to derive auxiliary power for the ship types at each port.

Table 2-3 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

[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.

Auxiliary engine to propulsion engine power ratios vary by ship type and operating mode roughly from 0.19 to 0.40. Auxiliary load, shown in Table 2-4, is used together with the total auxiliary engine power to calculate auxiliary engine emissions. Starcrest's Vessel Boarding Program[7] showed that auxiliary engines are on all of the time, except when using shoreside power during hotelling.

Table 2-4 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

Main Engine Emission Factors

An analysis of emission data was prepared and published in 2002 by Entec.[8] 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, residual marine (RM) and marine distillate oil (MDO). Table 2-5 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. Since PM and SO_2 emission factors are dependent on the fuel sulfur level, the fuel types and fuel sulfur levels used in this analysis are described at the end of this section.

Table 2-5 Emission Factors for OGV Main Engines using RM, g/kWh

ENGINE	ALL PORTS						
	NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2
SSD	18.1	1.40	0.60	620.62	1.4	1.3	10.29
MSD	14.0	1.10	0.50	668.36	1.4	1.3	11.09
ST	2.1	0.20	0.10	970.71	1.5	1.4	16.10
GT	6.1	0.20	0.10	970.71	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 U.S. Government review.[9]

PM_{10}[A] values were determined based on existing engine test data in consultation with ARB.[10] GT PM_{10} emission factors were not part of the U.S. Government 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).[11] The equation used to generate emission factors based on sulfur content is shown below. $PM_{2.5}$ is assumed to be 92 percent of PM_{10}. While the US Government 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.

Equation 2-2 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

[A] PM_{10} is particulate matter of aerodynamic diameter 10 micrometers or less.

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

SO_2 emission factors were based upon a fuel sulfur to SO_2 conversion formula which was supplied by ENVIRON.[12] 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.[13] The brake specific fuel consumption (BSFC)[B] 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.[14]

Equation 2-3 Calculation of SO_2 Emission Factors, g/kWh

$$SO_2 \text{ EF} = \text{BSFC} \times 64/32 \times 0.97753 \times \text{Fuel Sulfur Fraction}$$

CO_2 emission factors were calculated from the BSFC assuming a fuel carbon content of 86.7 percent by weight[14] and a ratio of molecular weights of CO_2 and C at 3.667.

Equation 2-4 Calculation of CO_2 Emission Factors, g/kWh

$$CO_2 \text{ EF} = \text{BSFC} \times 3.667 \times 0.867$$

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

SO_2 emission factors were calculated using Equation 2-3 while PM emissions were determined using Equation 2-2.

Note on 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.[15] 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.

Based on an ARB survey,[16] average fuel sulfur level for residual marine was set to 2.7 percent, which is what was assumed in the North American ECA application for the eastern and

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

gulf coast portions of the U.S. A sulfur content of 1.5 percent was used for MDO.[17] 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 2-6, based on the ARB survey, provides the assumed mix of fuel types used for propulsion and auxiliary engines by ship type.

Table 2-6 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

Auxiliary Engine Emission Factors

The most current set of auxiliary engine emission factors also comes from Entec except as noted below for PM and SO_2. Table 2-7 provides these auxiliary engine emission factors.

Table 2-7 Auxiliary Engine Emission Factors by Fuel Type, g/kWh

ENGINE	FUEL	ALL PORTS						
		NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2
MSD	RM	14.70	1.10	0.40	668.36	1.4	1.3	11.09
	MDO	13.90	1.10	0.40	668.36	0.6	0.55	6.16

Auxiliary engine power was estimated from average propulsion power using the ratio of auxiliary power to propulsion power ratios described below.

Using the ratios of RM versus MDO use as given in Table 2-6 together with the emission factors shown in Table 2-7, the auxiliary engine emission factor averages by ship type are listed in Table 2-8. As discussed above, this fuel sulfur level may be too high for the PR/USVI. However, we do not believe this emission factor has a significant effect on the total emission inventory estimates.

Table 2-8 Auxiliary Engine Emission Factors by Ship Type, g/kWh

SHIP TYPE	ALL PORTS						
	NO_X	CO	HC	CO_2	PM_{10}	$PM_{2.5}$	SO_2
Passenger	14.64	1.10	0.40	668.36	1.4	1.3	10.70
Others	14.47	1.10	0.40	668.36	1.2	1.1	9.66

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 brake specific fuel consumption (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 the U.S. Government in 2000.[18] In the EEA report, equations have been developed for the various emissions. The low-load adjustment factors were developed based upon the concept that the BSFC increases as load decreases below about 20 percent load.

Using these algorithms, fuel consumption and emission factors versus load were calculated. By normalizing emission factors to 20% load, low-load multiplicative adjustment factors were calculated for propulsion engines and presented in Table 2-9. Due to how they are operated, there is no need for a low load adjustment factor for auxiliary engines.

Table 2-9 Calculated Low Load Multiplicative Adjustment Factors

LOAD (%) N	O_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

Maneuvering and Hotelling Time-in-Mode

Specific information about the amount of time spent in maneuvering and hotelling modes was not available for the 12 ports included in the ports inventory. Instead, we used the approach that was used for the U.S. mainland ports, in which all commercial ports were mapped to one of a smaller set of "typical ports" and the operating characteristics of the relevant typical port was applied to the specific matched ports. For this analysis, Tampa was selected as the typical port thought to be most representative of the PR/USVI ports, due to its location and mix of ship types that call on the port. Time-in-mode data by ship type for the Tampa port were used directly.

2.4.1.4 2002 Near Port Inventories

The resulting 2002 emission inventory for each of the 12 ports is provided in Table 2-10.

Table 2-10 2002 Emissions Summary for Twelve Puerto Rico and U.S. Virgin Island Ports

PORT NAME	ANNUAL EMISSIONS (METRIC TONNES)						
	NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
San Juan, PR	3,909	350	324	122	303	2,980	177,477
Fajardo, PR	29	3	2	1	2	20	1,297
St. Thomas, VI	2,305	231	215	74	178	2,030	112,970
Ponce, PR	420	35	32	14	34	263	17,272
Christiansted, VI	31	3	3	1	2	24	1,392
Jobos, PR	42	3	3	1	3	26	1,694
Guayanilla, PR	95	9	8	3	7	71	4,595
Mayaguez, PR	1,271	107	99	38	98	940	58,241
Yabucao, PR	53	4	4	2	4	33	2,170
Frederiksted, VI	73	8	7	2	5	69	3,967
Port Harvey, VI	230	21	19	8	18	169	10,678
Port Hess, VI	797	65	60	26	63	501	32,515
Total Port Emissions	*9,255*	*839*	*775*	*292*	*719*	*7,127*	*424,271*

2.4.2 Interport Emissions

The second part of the emissions inventory is emissions from ships traveling outside of the 25-mile port areas and for ports other than the 12 ports described above. These emissions are estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[19,20] This 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.

This modeling was performed to estimate interport emissions from main propulsion and auxiliary engines used by Category 3 ocean-going vessels operating in the modeling domain. The modeling domain consists of the entire area around Puerto Rico and the U.S. Virgin Islands that is subject to the sovereign authority of the United States.

2.4.2.1 Interport Inventory Methodology

The interport emissions were estimated using the Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM).[21,22] 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 ocean-going vessels. The model estimates emissions from main propulsion and auxiliary marine engines used on Category 3 vessels that engage in foreign commerce using historical shipping activity, ship attributes (i.e., characteristics), and activity-based emission factor information. These inputs are assembled using a 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. 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.[23] 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.[24] 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). This is illustrated in Figure 1-1.

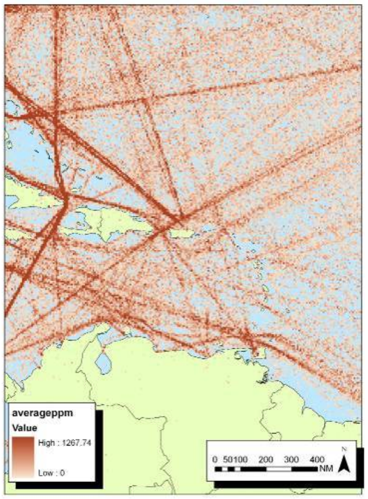


Figure 2-1 AMVER and ICOADS data

Every port is also spatially located in the waterway network using ArcGIS software.

As illustrated in Figure **2-2**, 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.

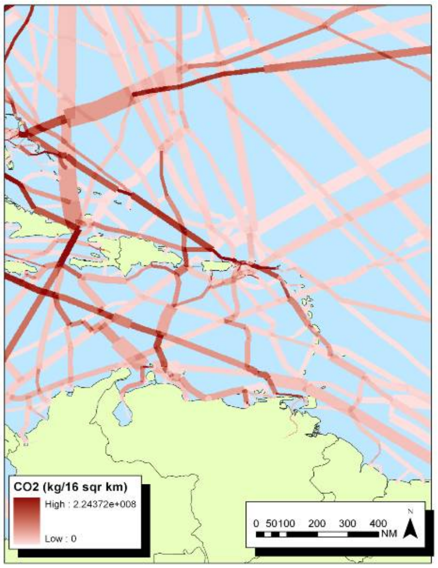


Figure 2-2 Illustration of STEEM Modeling Domain and Spatial Distribution of Shipping Lanes

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.

To allocate ships to the statistical lanes, 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:

Equation 2-5

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 within a 20 kilometers radius of each port 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.

2.4.2.2 Data Inputs for Interport Emission Inventories

The STEEM model includes detailed information about ship routes and destinations in order to provide spatially allocated emissions of ships in transit. The shipping lanes and directions were empirically derived from ship positioning data in several datasets. The International Comprehensive Ocean-Atmosphere Data Set (ICOADS) contains reports on marine surface and atmospheric conditions from the Voluntary Observing Ships (VOS) fleet.[25] STEEM also uses a dataset derived from the Automated Mutual-Assistance Vessel Rescue (AMVER) system,[26] which is based on a ship search and rescue reporting network sponsored by the U.S. Coast Guard. Traffic along each of these lanes is derived from USACE entrance and clearance data for 2002,[27] together with Lloyd's Register-Fairplay Ltd's data for ship characteristics. Information for number of calls, ship characteristics, propulsion engine power, and cruise speed were obtained from these data.

The emission factors and load factors used as inputs to STEEM are very similar to those used for the ports analysis. Additional adjustments were made to interport emission results for PM_{10} and SO_2 in order to reflect recent U.S. Government review of available engine test data and fuel sulfur levels. Details of the STEEM emission inputs and adjustments are located in Appendix 2C.

2.4.3 Total Ship Inventory for 2002

The national and regional inventories in this study are a combination of the results from the near ports analysis and the STEEM interport modeling. These two inventories are quite different in form. The STEEM characterizes emissions from vessels while traveling between ports. That includes when a vessel is maneuvering to enter or exit a port, cruising near a port as it traverses the area, or moving in a shipping lane across the open sea. 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, on the other hand, reflect emissions that occur inside of or within 25 miles of twelve specific ports and are not reported in a gridded format.

Therefore, to obtain the total inventory for 2002 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 U.S. Government contract with ICF.

2.4.3.1 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. 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.

Hotelling and Maneuvering emissions

Each port, and thus the designated location for hotelling and maneuvering emissions, is modeled as a single latitude/longitude coordinate point using the estimated port center. 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 the 12 ports used in this work are shown in Appendix 2A.

RSZ emissions

The RSZ routes associated with each of the 12 ports were modeled as lines. Each RSZ was assumed to be 10 nautical miles in length.

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.

Cruise emissions

The cruise mode links that extend 25 nautical miles 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.

2.4.3.2 2002 Inventory – Port and Nearport

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.

The percentage of STEEM emissions that are attributable to a port, and should be removed and replaced, was 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.

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.

For the San Juan port, the outer edges of the port inventories fell outside the Caribbean inventory domain; that portion outside the domain was removed. As a result, the port totals presented in the next section are slightly less than those reported in Section 2.4.1. The removed portion represents less than 4 percent of the total port emissions.

The total inventory was created by summing emission estimates for ships while at port and while underway (interport). The total 2002 inventory for the Caribbean inventory domain, along with the relative contributions of the port and interport emissions are presented in Table 2-11.

Table 2-11 2002 Total C3 Inventory for Caribbean Inventory Domain

EMISSION TYPE	ANNUAL EMISSIONS (METRIC TONNES)[a]						
	NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Port	8,955	807	742	282	697	6,869	408,456
Interport	19,358	1,512	1,391	642	1,511	11,219	691,419
Total Emissions	*28,313*	*2,319*	*2,134*	*923*	*2,208*	*18,088*	*1,099,875*

[a] The port emission totals in this table are slightly less than those in Table 2-10 due to the gridding process and trimming to include only port emissions that fall within the inventory boundaries.

The interport and port inventories are about 70 percent and 30 percent of the total, respectively.

2.5 Development of 2020 Inventories

To obtain the 2020 baseline and control inventories for the inventory domain, it is necessary to adjust the 2002 inventories to account for activity level growth and the emission reductions that would occur in 2020 absent the ECA controls (baseline case) and with the ECA controls (control case). This section describes how the adjustment factors were obtained and presents the inventories for the inventory domain for 2020. The inventories for the proposed U.S. Caribbean ECA are described in Section 2.6, below.

2.5.1 Adjustment Methodology

We used a multi-step approach to adjust the 2002 inventories to estimate the 2020 baseline and control scenarios for the inventory domain. Specifically, we apply a growth factor adjustment and an emission factor adjustment.

The growth factor adjustment is derived from the growth factors that were estimated for the North American ECA.

The emission factor adjustments are derived by developing a new set of emission factors based on the emission programs that will be in place in the baseline and control scenarios; the adjustment factor is the ratio of the 2002 emission factors to the 2020 emission factors.

2.5.1.1 Growth Factors for 2020

The starting point for developing the 2020 inventories is to determine the average annual growth rates from 2002 through 2020. The average annual growth rate for the inventory domain is derived from the average annual growth rates estimated for the North American ECA. These were estimated for seven regions within the U.S. EEZ. The seven regions are Alaska, East Coast, Gulf Coast, Hawaii, North Pacific, South Pacific, and Great Lakes. The definition of these regions and the methodology used to derive these growth rates are described in Appendix 2D.

From an examination of the shipping routes within the Caribbean EEZ, it appears that ships enter from all of the regions except the Great Lakes. As a result, the growth rate for the Caribbean EEZ was derived as a power-weighted average of the six regional growth rates. The growth rate is then compounded over the inventory projection time period for 2020 (i.e., 18 years). The growth rates and resulting multiplicative growth factors for each of the regions and the Caribbean EEZ are provided in Table 2-12.

Table 2-12 Emission Inventory Growth Factors for 2020

REGION	TOTAL PROPULSION POWER (MW)	2002-2020 AVERAGE ANNUALIZED GROWTH RATE (%)	MULTIPLICATIVE GROWTH FACTOR RELATIVE TO 2002
Alaska	14,931	3.3%	1.79
East Coast	865,085	4.5%	2.21
Gulf Coast	319,976	2.9%	1.67
Hawaii	38,353	5.0%	2.41
North Pacific	94,796	3.3%	1.79
South Pacific	571,433	5.0%	2.41
Caribbean domain (wgt avg)		4.3%	2.16

The multiplicative growth factor for the Caribbean inventory domain is applied to each of the pollutant totals for 2002 to project emissions to 2020. Additional adjustments are required to account for emission controls, which are described in the following sections.

2.5.1.2 Emission Requirements Included in the Adjustment: Baseline and Control

The emission adjustment factor is developed to reflect the control programs that will be in place in 2020 in both the baseline and control scenarios, compared to the 2002 scenario.

By 2020, ships will be required to comply with the MARPOL Annex VI Tier I NO_X standard for marine diesel engines that became effective in 2000, as well as the Tier II standard that will become effective in 2011. Also included in the 2020 baseline inventories is the NO_X retrofit program for pre-controlled engines in regulation 13 of MARPOL Annex VI.

The ECA requirements will add two other requirements. First, ships will be required to use fuel with a sulfur content not to exceed 0.10%. Although the 0.10% fuel sulfur requirement goes into place for all vessels operating in ECAs beginning in 2015, the use of 2020 as the analytic year will still provide a representative scenario for the impact of the 0.10% fuel sulfur requirement on human health and the environment. This is because the fuel requirements of the ECA go into effect all at once; there is no phase-in. So the impacts of the fuel requirement in 2020 are expected to be the same as in 2015, with a small increase due to growth.

The ECA program also requires ships constructed on or after January 1, 2016 to be equipped with engines that meet the Tier III NO_X limits. While 2020 will include five years of turnover to the Tier III standards, the long service lives of engines on ocean-going vessels mean that these impacts will be small and affect less than 25% of the total fleet, assuming an average 20-year service life. These NO_X reductions would not increase the benefits of the program by very much, if any.

The modelling presented here estimates the expected effect of shipping emissions in 2020. The year 2020 was chosen because it allows the use of detailed emission inventories that were created for other emission sources (e.g., land-based stationary and mobile sources) as part of wider scale air pollution modelling efforts. This allows us to compare the ship emission inventories to total anthropogenic emission inventories for Puerto Rico and the Virgin Islands. The choice of 2020 is also consistent with the fuel cost analysis.

The use of 2020 has two implications for the inventory analysis. First, with regard to the impacts of the ECA fuel sulphur requirements, the choice of 2020 slightly over-estimates the immediate benefits of the program in 2015. However, since the fuel controls apply to all vessels beginning in 2015 (there is no phase-in), the estimated impacts of the fuel requirement in 2020 are expected to be similar to the impacts in 2015, with the difference due to growth in the marine transportation sector. Therefore, the use of 2020 as the analytic year will still provide a representative scenario for the impact of the 0.1 percent fuel sulphur requirement on human health and the environment. Second, with regard to the NO_X impacts, the use of 2020 includes only five years of turnover to the Tier III standards. Because of the long service lives of engines on ocean-going vessels, this mean that the fleet will not be fully turned over for some time and therefore the full benefits of the ECA NO_X controls are not reflected in the analysis. In conclusion, the choice of 2020 as the analytic year provides a balance between modelling too early of a year where the Tier III NO_X standards may not yet apply and modelling too late of a year where there may be more uncertainty associated with projecting emissions into the future. It should be noted that, although the 0.5% global fuel sulphur standard goes into effect in 2020, we did not include the global standard in the 2020 analysis. This approach provides an estimate of benefits in the early (pre-2020) years of the program.

The effects of these controls are reflected in the 2020 emission inventories by applying appropriate adjustment factors that reflect the percentage of the vessel fleet in those years that are estimated to comply with the controls. Adjustment factors are ratios of 2020 to 2002 calendar year (CY) emission factors (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.

2.5.1.3 Emission Factors for 2020 Inventory Adjustments

The emission factors for the 2020 inventory adjustments reflect the application of the controls described above. 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.

For the NO_X limits, the current Tier I controls, which are modeled as achieving an 11 percent reduction from Tier 0, apply to the 2000 through 2010 model year (MY) engines. In 2011 thru 2015, Tier II controls are applied. Tier II controls are modeled as a 2.5 g/kW-hr reduction from Tier I. In the ECA area only, for 2016 MY engines and beyond, Tier III controls are applied. Tier III controls are modeled as achieving an 80 percent reduction from Tier I levels. The NO_X retrofit program for Tier 0 (pre-control) engines was modeled as 11 percent control from Tier 0 for 80 percent of 1990 thru 1999 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. Finally, control of fuel sulfur content within the ECA area to 0.10% affects both SO_2 and PM emissions.

The NO_X emission factors (EFs) by engine/ship type and tier are provided in Table 2-13. Tier 0 refers to pre-control. There are separate entries for Tier 0/1/2 base and Tier 0/1/2 control, since the control engines would be using distillate fuel, and there are small NO_X emission reductions assumed when switching from residual to distillate fuel.[28] The NO_X control EFs by tier were derived using the assumptions described above.

Table 2-13 Modeled NO_X Emission Factors by Tier

ENGINE/ SHIP TYPE	NO_X EF (g/kW-hr)								
	BASELINE CONTROL				AREAS				
	TIER 0	TIER 0 RETROFIT	TIER I	TIER II	TIER 0	TIER 0 RETROFIT	TIER I	TIER II	TIER III
Main									
SSD	18.1	16.1	16.1	13.6	17	15.1	15.1	12.6	3
MSD	14	12.5	12.5	10.0	13.2	11.7	11.7	9.2	2.3
ST	2.1	n/a	n/a	n/a	2	n/a	n/a	n/a	n/a
GT	6.1	n/a	n/a	n/a	5.7	n/a	n/a	n/a	n/a
Aux									
Pass	14.6	n/a[a]	13.0	10.5	14.6	n/a[a]	13.0	10.5	2.6
Other	14.5	n/a[a]	12.9	10.4	14.5	n/a[a]	12.9	10.4	2.6

[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.

Because this program phases in over time, it is necessary to estimate the adjustment factor for each year to obtain the appropriate adjustment factor for 2020. This is done by using vessel age distributions (Table 2-14) to generate calendar year NO_X EFs by engine/ship type for the base and control areas included in the scenarios. The adjustment factors for 2020 for the baseline and control scenarios are presented in Table 2-15.

Table 2-14 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

[a] MSD is medium speed diesel, SSD is slow speed diesel, GT is gas turbine, ST is steam turbine.

Table 2-15 Modeled NO_X Emission Factors by Calendar Year and Control Type

ENGINE/ SHIP TYPE	CY NO_X EF (g/kW-hr)		
	2002 2	020 BASE	2020 ECA CONTROL
Main			
SSD	18.1	14.7	10.8
MSD	14	10.9	7.7
ST	2.1	2.1	2.0
GT	6.1	6.1	5.7
Aux			
Pass	14.6	11.7	8.6
Other	14.5	11.5	8.6

The PM and SO_2 EFs are a function of fuel sulfur level. For the baseline portions of the inventory, the residual fuel sulfur level modeled is 27,000 ppm. The baseline distillate fuel sulfur level assumed for all areas is 15,000 ppm. As discussed previously, for the baseline, main engines use residual fuel and auxiliary engines use a mix of residual and distillate fuel. For the control areas, there is one level of distillate fuel sulfur assumed to be used by all engines: 1,000 ppm for the ECA control areas.

Table 2-16 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 Equation 2-2.

Table 2-16 Modeled PM_{10} Emission Factors

ENGINE/ SHIP TYPE	PM_{10} EF (g/kW-hr)	
	BASELINE	CONTROL AREAS
	27,000 ppm S	ECA 1,000 ppm S
Main		
SSD	1.40	0.19
MSD	1.40	0.19
ST	1.50	0.17
GT	1.50	0.17
Aux		
Pass	1.40	0.19
Other	1.20	0.19

Table 2-17 provides the modeled SO_2 EFs. SO_2 emission reductions are directly proportional to reductions in fuel sulfur content.

Table 2-17 Modeled SO_2 Emission Factors*

ENGINE/ SHIP TYPE	SO_2 EF (g/kW-hr)	
	BASELINE	CONTROL AREAS
	27,000 ppm S	ECA 1,000 ppm S
Main		
SSD	10.29	0.36
MSD	11.09	0.39
ST	16.10	0.57
GT	16.10	0.57
Aux		
Pass	10.70	0.39
Other	9.66	0.39

For the CO2 emission factors, CO2 is directly proportional to fuel consumed. Table 2-18 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.[29]

Table 2-18 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	185	589
MSD	210	668	200	637
ST	305	970	290	923
GT	305	970	290	923
Aux				
Pass	210	668	200	636
Other	210	668	200	636

The HC and CO emission factors are assumed to remain unchanged from the 2002 scenario, since there are no emission standards or requirements for those pollutants. The ECA NO_X and fuel sulfur requirements are anticipated to reduce the NO_X, SO_2 and PM emission factors. The switch to lower sulfur distillate fuel use is also expected to lower CO_2 emissions slightly.

2.5.1.4 Port Emission Adjustment Factors

The EF adjustment factors are a ratio of the control EF to the 2002 EF. Table 2-19 through Table 2-23 provide the EF adjustment factors for each pollutant for the 2020 baseline and control scenarios.

Table 2-19 NO_X EF Adjustment Factors by Engine/Ship Type and Control Type[a]

ENGINE/ SHIP TYPE	2020 BASE	2020 ECA CONTROL
Main		
SSD	0.8130	0.5967
MSD	0.7804	0.5515
ST	1.0000	0.9524
GT	1.0000	0.9344
Aux		
Pass	0.7985	0.5869
Other	0.7972	0.5940

[a] NO_X adjustment factors are a ratio of future base or control EFs to 2002 EFs

Table 2-20 PM_{10} EF Adjustment Factors by Engine/Ship Type and Control Type[a]

ENGINE/ SHIP TYPE	2020 BASE	2020 ECA CONTROL
Main		
SSD	1.0000	0.1352
MSD	1.0000	0.1328
ST	1.0000	0.1108
GT	1.0000	0.1108
Aux		
Pass	1.0000	0.1328
Other	1.0000	0.1550

[a] PM_{10} adjustment factors are a ratio of the control EFs to the 2002 EFs. PM is not adjusted for the future baseline because fuel sulfur levels are only assumed to change within the ECA.

Table 2-21 $PM_{2.5}$ EF Adjustment Factors by Engine/Ship Type and Control Type[a]

ENGINE/ SHIP TYPE	2020 BASE	2020 ECA CONTROL
Main		
SSD	1.0000	0.1339
MSD	1.0000	0.1316
ST	1.0000	0.1092
GT	1.0000	0.1092
Aux		
Pass	1.0000	0.1316
Other	1.0000	0.1555

[a] $PM_{2.5}$ adjustment factors are a ratio of the control EFs to the 2002 EFs. PM is not adjusted for the future baseline because fuel sulfur levels are only assumed to change within the ECA. The $PM_{2.5}$ adjustment factors are slightly different from those for PM_{10} due to rounding.

Table 2-22 SO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

ENGINE/ SHIP TYPE	2020 BASE	2020 ECA CONTROL
Main		
SSD	1.0000	0.0351
MSD	1.0000	0.0353
ST	1.0000	0.0352
GT	1.0000	0.0352
Aux		
Pass	1.0000	0.0365
Other	1.0000	0.0405

[a] SO_2 adjustment factors are a ratio of the control EFs to the 2002 EFs. SO_2 is not adjusted for the future baseline because fuel sulfur levels are only assumed to change within the ECA.

Table 2-23 CO_2 EF Adjustment Factors by Engine/Ship Type and Control Type[a]

ENGINE/ SHIP TYPE	2020 BASE	2020 ECA CONTROL
Main		
SSD	1.0000	0.9488
MSD	1.0000	0.9531
ST	1.0000	0.9509
GT	1.0000	0.9509
Aux		
Pass	1.0000	0.9525
Other	1.0000	0.9525

[a] CO_2 adjustment factors are a ratio of the control EFs to the 2002 EFs. CO_2 is not adjusted for the future baseline because fuel consumption (BSFC) is only assumed to change within the ECA.

2.5.1.5 Interport Emission Adjustment Factors

Since the interport portion of the inventory is not segregated by engine or ship type, it was necessary to develop a different set of emission adjustment factors for those emissions. This was done using the port-specific cruise emissions for the propulsion engines as a surrogate for interport emissions. This is appropriate because the majority of emissions while underway are from propulsion, not auxiliary, engines. Also, the cruise mode best represents ship operation while underway at sea.

The port-specific cruise emissions for the 2020 baseline and control scenarios were summed and ratios of these scenario totals to the 2002 totals were developed for each pollutant. This analysis was performed separately for each of the Puerto Rico and Virgin Island ports. These ratios were then adjusted to remove growth by dividing each by the growth factor (2.16). Composite EF adjustment factors were then developed for all PR/USVI ports combined by weighting each port's adjustment factors by the fraction of total propulsion installed power for that port.

The resulting EF adjustment factors applied to the 2002 interport portion of the inventory are provided in Table 2-24 below.

Table 2-24 EF Adjustment Factors for 2020 Scenarios[a]

POLLUTANT	2002	2020	
		BASE	ECA CONTROL
NO_X	1.0000	0.7986	0.5820
PM_{10}	1.0000	1.0000	0.1320
$PM_{2.5}$	1.0000	1.0000	0.1308
SO_2	1.0000	1.0000	0.0355
CO_2	1.0000	1.0000	0.9517

[a] Adjustment factors are ratios of future base or control EFs to 2002 EFs. These adjustment factors are used to adjust the interport portion of the 2002 inventory.

2.5.1.6 2020 Near Port and Interport Inventories

The 2020 near port and interport inventories were developed by applying the growth factors and emission factor adjustments to the 2002 inventories. These inventories were then combined to obtain the 2020 total inventories, for the baseline and control cases.

The interport inventories were scaled by a growth factor to 2020, as previously described, and the emission adjustment factors were applied.

The near port inventories were created by applying the growth and emission adjustment factors to the 2002 near port inventories. The near port inventories were then converted into a gridded format using the same approach as for the 2002 inventory. 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. The resulting baseline and control inventories for 2020 are presented in Table 2-25. The inventories include all emissions within the Caribbean inventory domain.

Table 2-25 Category 3 Vessel Inventories in the Inventory Domain for 2020 Scenarios[a]

SCENARIO	ANNUAL EMISSIONS (METRIC TONNES)						
	NO_X	PM_{10}	$PM_{2.5}$	HC	CO	SO_2	CO_2
Baseline	48,782	5,006	4,605	1,993	4,764	39,036	2,373,593
ECA Control	35,685	676	618	1,992	4,765	1,419	2,259,323

[a] These inventories include all emissions within the Caribbean inventory domain.

The fuel consumption by fuel type in the baseline and ECA cases is presented in Table 2-26.

Table 2-26 Fuel Consumption by Category 3 Vessels for 2020 Scenarios[a]

SCENARIO	METRIC TONNES FUEL		
	DISTILLATE	RESIDUAL	TOTAL
Baseline	40,446	705,263	745,709
ECA Control	709,809	0	709,809

[a] These inventories include all emissions within the Caribbean inventory domain.

2.6 Inventories for Proposed ECA

The size and shape of the proposed ECA differs from that of the Caribbean inventory domain. The inventory domain used in the above consists of the entire area around Puerto Rico and the U.S. Virgin Islands that is subject to the sovereign authority of the United States, which is the exclusive economic zone surrounding these islands. The proposed ECA is a subset of this area, and includes waters adjacent to coasts of the Commonwealth of Puerto Rico and the U.S. Virgin Islands. The northern and southern boundaries of the proposed area would extend roughly 50 nm and 40 nm, respectively, from the territorial sea baseline of the main island of Puerto Rico. The western edge of the proposed area would generally run north-south, about half way between the Puerto Rican island of Mona, and the west coast of the main island. The eastern edge of the proposed area would generally run north-south, but extend eastward through the area between the U.S. Virgin Islands and the British Virgin Islands and also eastward through the area between Saint Croix and Anguilla and Saint Kitts.

Because the port and interport inventories described above are spatially allocated, with every location assigned an appropriate quantity of emission and with the total inventory equivalent to the sum of all locations, it is a straightforward matter to estimate the inventories for the proposed ECA.

Specifically, to estimate the inventories for the proposed ECA, the boundaries of the proposed ECA, as described in Section 5 of the Information Paper, were overlaid upon the spatially explicit inventory (Figure 2-3). All gridded emissions cells within this ECA boundary were summed, with the totalled grid cells being equivalent to the inventory of the Caribbean ECA.

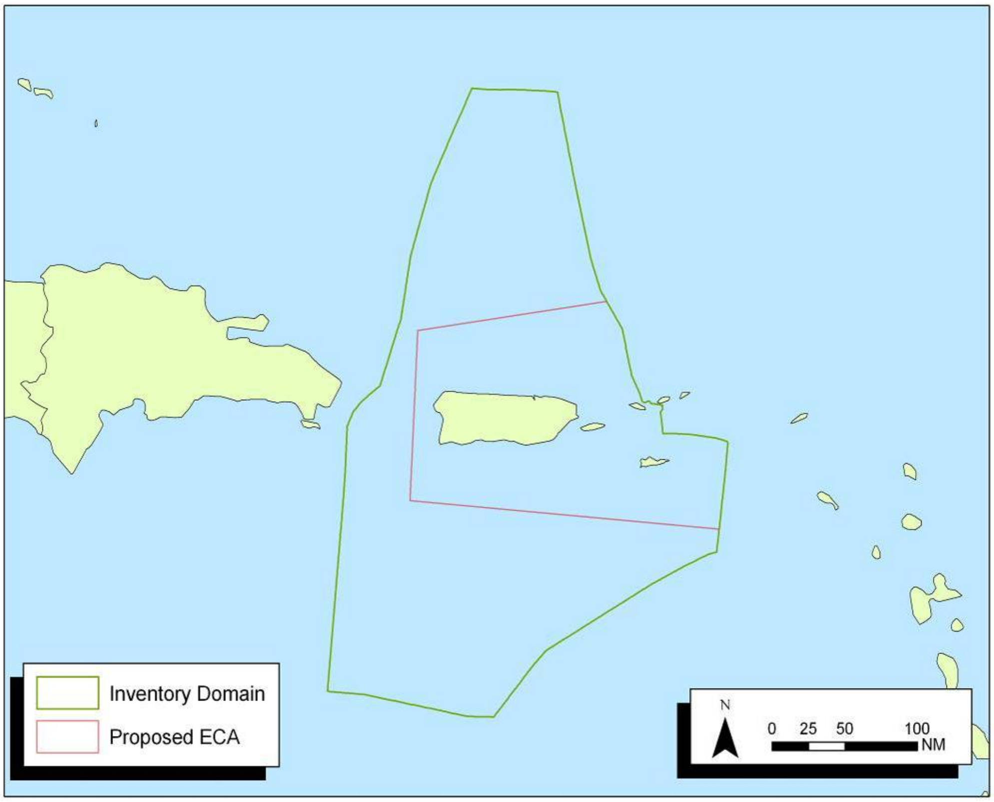


Figure 2-3: Boundary of the Inventory Domain and Proposed ECA

The 2020 inventories for the proposed ECA, for the baseline and control scenarios, are presented in Table 2-27. Also presented are the tones reduced and the percent reductions for each pollutant. This information shows that the proposed ECA includes about 75 percent of the total emissions in the inventory domain. More importantly, as shown in Chapter 3, these emissions are most likely to reach shore.

Table 2-27 C3 Emission Inventories for Proposed ECA in 2020

EMISSION TYPE	ANNUAL EMISSIONS (METRIC TONNES)[a,b]						
	NO_X	PM_{10}	$PM_{2.5}$[c]	HC	CO	SO_2	CO_2
Reference	36,950	3,793	3,488	1,509	3,609	29,568	1,797,909
Control	27,032	512	471	1,509	3,609	1,075	1,711,452
Delta Emissions	*-9,919*	*-3,342*	*-3,017*	*0*	*0*	*-28,493*	*-86,457*
Delta Emissions (%)	*-27%*	*-86%*	*-86%*	*0%*	*0%*	*-96%*	*-5%*

[a] The ship inventories include emissions within the proposed ECA.
[b] For this analysis, the commercial marine vessel emissions inventory does not include ships powered by "Category 1" or "Category 2" (i.e., <30 L/cyl) engines. These smaller engines installed on U.S.-flag vessels are already subject to strict national standards affecting NO_X, PM, and fuel sulphur content. Engines above 130 kW but less than 30 L/cyl on foreign-flag vessels are covered by Annex VI; however, the Annex VI reductions for these vessels have not been included in the analysis.
[c] The $PM_{2.5}$ inventories include directly-emitted $PM_{2.5}$ only.

2.7 Other Inventories

Inventories were developed for other types of air emissions sources, to calculate the percent that C3 marine vessels would contribute to the sum of emissions affecting populations and the environment in Puerto Rico and the U.S. Virgin Islands in 2020. The categories of sources considered in this analysis include land-based mobile and stationary sources, including aircraft.

The U.S. EPA periodically updates its national emission inventory (NEI) forecasts, and much of the data were taken from these nationally prepared inventories.[30] However, for some sources, additional calculations were made, as described below.

2.7.1 Overview of 2020 Non-C3 Emission Inventories

The emissions from mobile non-road and on-road sources were taken directly from the NEI projections for 2020. These account for expected growth as well as current domestic regulations that will apply in 2020. The emissions from non-point and small stationary sources were also taken directly from NEI projections for 2020.

The total emissions projected to be emitted from non-C3 sources in 2020 are presented in Table 2-28. The methods for estimating the major stationary source and aircraft emissions are described in the next section.

Table 2-28: Projected 2020 Emissions from Non-C3 Sources in Puerto Rico and the U.S. Virgin Islands

SOURCE CATEGORY	2020 ANNUAL EMISSIONS		
	NO_X	$PM_{2.5}$	SO_2
Stationary Sources	44,000	8,700	51,000
Highway and Nonroad Gasoline and Diesel Vehicles	15,000	1,000	200
Aircraft	2,200	80	60
Total Non-C3 Metric Tonnes	*62,000*	*9,800*	*52,000*

2.7.1.1 Major stationary sources

Emissions from major stationary sources (industries, utilities), were gathered from annual reports submitted by the facilities to local authorities for the reporting year 2008.[31] It is general practice in air quality planning to assume no net growth in stationary source air emission inventories. Overall, growth from these sources is assumed to be balanced by improved emission controls that must be applied when facilities are expanded. Thus, the 2020 emissions projections presented above are equal to the 2008 emissions calculated based on reported data from these sources.

For these sources, PM emissions are typically expressed in terms of primary filterable PM_{10} plus an estimate of the mass of particles that are formed by condensation after the exhaust gases exit the stack. This expression of PM differs from the standard expression of $PM_{2.5}$. Furthermore, the ratio of $PM_{2.5}$ to PM_{10} varies by source and fuel type. For this inventory analysis, the PM emissions estimates collected from the major stationary sources were assumed equal to $PM_{2.5}$. With most major stationary sources well controlled for PM emissions with either some form of aftertreatment or the use of clean fuels, this is a fair assumption. With the uncertainty in these PM_{10} to $PM_{2.5}$ conversions, it is possible the resulting inventory may slightly underestimate or overestimate the contribution of C3 marine vessels to total man-made $PM_{2.5}$ emissions. For the 2020 case without the ECA, the confidence interval for the marine percent of all man-made sources is plus or minus ten percent. For the 2020 case with the ECA, the confidence interval is plus or minus two percent.

2.7.1.2 Aircraft

Estimates of PM, SO_2, and some NO_X emissions in 2020 from aircraft in Puerto Rico and the U.S. Virgin Islands were taken directly from the NEI. While it is expected that these values may be underestimated, no better data are available. It is noted that the resulting inventory may slightly overestimate the contribution of C3 marine vessels to total man-made SO_2 and PM emissions.

Estimates of NO_X emissions from itinerant commercial air carrier operations were calculated by applying an emission factor (in grams of NO_X per landing and take off, g/LTO) to reported aircraft operation statistics. For the U.S. Virgin Islands, the NEI estimate was taken to represent local aircraft operations, as no significant long range commercial aircraft operate on these small islands. For Puerto Rico, non-military aircraft operations data for 2002 were taken from the U.S. Federal Aviation Association.[32] The itinerant air carrier operations data were multiplied by an emission factor of 10,968 g/LTO, a 2009 fleet average,[33] while the NEI estimate was taken to represent local operations. To project 2020 emissions for Puerto Rico, the 2002 aircraft operations data was multiplied by the aircraft NO_X growth rate from the NEI, 1.3.

2.8 Conclusion

An emission inventory for ships in PR/USVI was developed based on the latest state of the art models and inputs, using a “bottom-up” methodology. The inventory includes emissions for 12 ports, as well as emissions for ships while underway within the area of the proposed ECA. In addition, an emission inventory for other man-made pollution sources in Puerto Rico and the U.S. Virgin Islands was developed for purposes of comparison. The analysis shows that a comprehensive review was made of air emissions sources, and that ships are contributing significantly to air pollution in Puerto Rico and the U.S. Virgin Islands.

[1] ICF International (October 2007). Commercial Marine Port Inventory Development, prepared for the U.S. Environmental Protection Agency, EPA Report Number EPA-420-R-07-012c, Docket ID EPA-HQ-OAR-2007-0121-0063.1.

[2] U.S. Army Corps of Engineers Navigation Data Center, *Vessel Entrances and Clearances*, 2002, available at http://www.iwr.usace.army.mil/ndc/db/entclrn/data/entrclrn02/

[3] U.S. Army Corps of Engineers Navigation Data Center, *Vessel Entrances and Clearances*, 2002, available at http://www.iwr.usace.army.mil/ndc/db/entclrn/data/entrclrn02/

[4] ICF International (October 2007). Commercial Marine Port Inventory Development, prepared for the U.S. Environmental Protection Agency, EPA Report Number EPA-420-R-07-012c, Docket ID EPA-HQ-OAR-2007-0121-0063.1.

[5] Nexus Media Communications, *The Motor Ship's Guide to Marine Diesel Engines 2005,* available at http://www.motorship.com/

[6] California Air Resources Board (September 2005). 2005 Oceangoing Ship Survey, Summary of Results.

[7] Starcrest Consulting Group (June 2004). Port-Wide Baseline Air Emissions Inventory, prepared for the Port of Los Angeles

[8] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[9] U.S. Environmental Protection Agency (January 2009). Main Engine CO and HC Emission Factors in C3 Model and Current Literature, Memorandum from Ari Kahan to Docket EPA-HQ-OAR-2007-0121.

[10] U.S. Environmental Protection Agency (September 2007). Estimation of Particulate Matter Emission Factors for Diesel Engines on Ocean-Going Vessels, Memorandum from Mike Samulski to Docket EPA-HQ-OAR-2007-0121, Docket ID EPA-HQ-OAR-2007-0121-0060.

[11] U.S. Environmental Protection Agency (September 2007). Estimation of Particulate Matter Emission Factors for Diesel Engines on Ocean-Going Vessels, Memorandum from Mike Samulski to Docket EPA-HQ-OAR-2007-0121, Docket ID EPA-HQ-OAR-2007-0121-0060.

[12] Memo from Chris Lindhjem of ENVIRON, *PM Emission Factors*, December 5, 2005.

[13] U.S. Environmental Protection Agency, Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression Ignition (April 2004). Appendix C, EPA- 420-P-04-009, available online at http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2004/420p04009.pdf, Docket ID EPA-HQ-OAR-2003-0190-0411.

[14] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[15] RTI International (December 2006). Global Trade and Fuels Assessment – Future Trends and Effects of Designation Requiring Clean Fuels in the Marine Sector: Task Order No. 1, Draft Report, prepared for the U.S. Environmental Protection Agency, EPA Report Number EPA420-D-07-006, Docket ID EPA-HQ-OAR-2007-0121-0063.3.

[16] California Air Resources Board (September 2005). 2005 Oceangoing Ship Survey, Summary of Results.

[17] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[18] Energy and Environmental Analysis Inc. (February 2000). Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data, EPA420-R-00-002, available online at http://www.epa.gov/otaq/models/nonrdmdl/c-marine/r00002.pdf.

[19] Corbett, J. et al. (April 2007). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, Docket ID EPA-HQ-OAR-2007-0121-0063.2.

[20] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[21] Corbett, J. et al. (April 2007). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, Docket ID EPA-HQ-OAR-2007-0121-0063.2.

[22] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[23] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[24] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[25] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[26] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[27] U.S. Army Corps of Engineers Navigation Data Center (2002), Vessel Entrances and Clearances available at http://www.iwr.usace.army.mil/ndc/db/entclrn/data/entrclrn02/

[28] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[29] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[30] U.S. Environmental Protection Agency (2007) National Emission Inventory Data, Version 3 of 2002 NEI, State Tier 2 Sector Summary. Available at http://www.epa.gov/ttn/chief/net/2002inventory.html#inventorydata. Filename "pf02v3\projections\2020cc-2002cc_20070925.xls."

[31] Email dated June 10, 2009 from Luis R. Sierra Torres, Chief Inspection and Compliance Division, Air Quality Area, Puerto Rico Environmental Quality Board, with attached file "E.xls;" and email dated September 3, 2009 from Verline Marcellin of the USVI Department of Planning and Natural Resources, submitting the stationary source emission inventory for 2004 to 2008 via attached file "emissions-revised.xls."

[32] Federal Aviation Administration, APO Terminal Area Forecast Detail 2002 Report, http://aspm.faa.gov/main/taf.asp, accessed September 2009.

[33] "Aircraft NOx Emissions Limitation", submitted by the United States to the ICAO Committee on Aviation Environmental Protection, Working Group 3: Emissions Technical (CAEP/8-WG3-WP/6-14, October 2009).

Appendices

Appendix 2A: Port Coordinates

Table 2A-1 Port Coordinates[a]

Port Name	US ACE CODE	PORT COORDINATES	
		Longitude	Latitude
Ponce, PR	C2151	--66.716670	18.001260
San Juan, PR	C2136	-66.166670	18.666670
Fajardo, PR	C2139	-65.648401	18.324173
Jobos, PR	n/a[b]	-66.1876488	17.95325968
Guayanilla, PR	n/a	-66.7530155	17.98942757
Mayaguez, PR	n/a	-67.1564198	18.20260974
Yabucao, PR	n/a	-65.834481	18.0534
Christiansted, St. Croix, VI	C2157	-64.732420	17.752710
St. Thomas, VI	C2143	-64.899990	18.350010
Frederiksted, St. Croix, VI	n/a	-64.8857045	17.7142481
Port Harvey, St. Croix, VI	n/a	-64.7709	17.70753889
Port Hess, St. Croix, VI	n/a	-64.7473556	17.69643056

[a] US Army Corps of Engineers (USACE) data from http://www.iwr.usace.army.mil/ndc/db/pport/dbf/
Other locations from http://maps.google.com and online information searches.
Harvey is an alumina bauxite refinery and Hess is an oil terminal.
[b] n/a = not applicable

Appendix 2B: Port Methodology and Equations

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 the PR/USVI deep water ports.

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

Equation 2B-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.

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 2B-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 2B-3

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

Where:
Cruise distance = one way distance (25 nautical miles)
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 2B-4

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

Since cruise speed is estimated at 94 percent of maximum speed[34], the load factor for main engines at cruise is 0.83.

Substituting Equation 2B-3 for time in cruise into Equation 2B-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 2B-5 Cruise Mode Emissions for Main Engines

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

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)
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 2B-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)
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, these inputs were developed by port for bins that varied by ship type, engine type, and dead weight tonnage (DWT) range.

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 2B-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 2B-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 2B-9

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

In addition:

Equation 2B-10

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

Where:
0.94 = Fraction of cruise speed to maximum speed

Substituting Equation 2B-10 into Equation 2B-9, the equation to calculate load factor becomes:

Equation 2B-11

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

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 2B-8 for time in mode and Equation 2B-11 for load factor into Equation 2B-7 , the expression used to calculate RSZ mode emissions for the main engines becomes:

Equation 2B-12 RSZ Mode Emissions for Main Engines

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

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 (10 nm for all PR/USVI ports)
RSZ speed = speed, in knots (10 knts for all PR/USVI ports)
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 2B-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 (10 nm for all PR/USVI ports)
RSZ speed = speed, in knots (10 knts for all PR/USVI ports)
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 are assumed to be 10 nm for all PR/USVI ports. RSZ speed is assumed constant at 10 knots for all ships entering the harbor area.

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 2B-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 2B-15

$$LoadFactor_{man[main]} = (Man\,Speed[knots] / Maximum\,Speed[knots])^3$$

In addition:

Equation 2B-16

$$Maximum\,Speed = Cruise\,Speed[knots] / 0.94$$

Where:
0.94 = Fraction of cruise speed to maximum speed

Also, the maneuvering speed is 5.8 knots. Substituting Equation 2B-16 into Equation 2B-15, and using a maneuvering speed of 5.8 knots, the equation to calculate load factor becomes:

Equation 2B-17

$$LoadFactor_{man[main]} = (5.45 / Cruise\,Speed)^3$$

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

Substituting Equation 2B-17 for load factor into Equation 2B-14, the expression used to calculate maneuvering mode emissions for the main engines becomes:

Equation 2B-18 Maneuvering Mode Emissions for Main Engines

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

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 12 ports. For this analysis, maneuvering times and load factors available for Tampa were used to calculate maneuvering emissions for the PR/USVI ports.

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

Equation 2B-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.

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 2B-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 the 12 ports. For this analysis, hotelling times available for Tampa were used to calculate hotelling emissions for the PR/USVI ports.

[34] Starcrest Consulting Group (June 2004). Port-Wide Baseline Air Emissions Inventory, prepared for the Port of Los Angeles

Appendix 2C: Emission Inputs to STEEM

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.

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.[35] 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.

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.

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.[36,37] The resulting vessel cruise speeds for ships with missing data are shown in Table 2C-1.

Table 2C-1 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

[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 earlier 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.[38] (The ICF report attributed these power values to a study for the Port of Los Angeles by Starcrest Consulting.[34]) 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 2C-2.

Table 2C-2 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

[a] The ICF reference reported a value of 11,000 for auxiliary engines used on passenger vessels.[38]

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

[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.[39] 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.[39,40] 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. The main engine load factors at cruise speed by ship type are shown in Table 2C-3.

Auxiliary engine load factors, except for passenger ships, were obtained from the ICF International study referenced above. These values are also shown in Table 2C-3. 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 2C-3 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

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 2C-4. 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.[41,42,43,44] 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.[45] 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.[46]

Table 2C-4 Main Engine Emission Factors by Ship and Fuel Type

ENGINE TYPE	FUEL TYPE	MAIN ENGINE EMISSION FACTORS (g/kW-hr)					
		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

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

The emission factors for auxiliary engines are shown in Table 2C-5. 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.[34] For SO_2, the fuel specific emission factors were obtained from Entec and Corbett and Koehler.[,39] The composite emission factors displayed in the table are discussed below.

Table 2C-5 Auxiliary Engine Emission Factors by Ship and Fuel Type

ENGINE TYPE	FUEL TYPE	AUXILIARY ENGINE EMISSION FACTORS (g/kW-hr)					
		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	**

[a] Estimated from PM_{10} using a multiplicative adjustment factor of 0.92.
[b] See Table 2C-6 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.[47]

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 2C-5 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 2C-6.

Table 2C-6 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

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 the U.S. Government's recent review of available engine test data and fuel sulfur levels 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. 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, the interport PM inventories were adjusted 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.

[35] Corbett, J. et al. (May 2006). Estimation, Validation and Forecasts of Regional Commercial Marine Vessel Inventories, Tasks 1 and 2: Baseline Inventory and Ports Comparison, Final Report, prepared by University of Delaware for the California Air Resource Board, Contract Number 04-346, and the Commission for Environmental Cooperation in North America, Contract Number 113.111, May 2006, Docket ID EPA-HQ-OAR-2007-0121-0013.

[36] Lloyd's Register and International Maritime Organization, Marine Exhaust Emission Quantification Study – Baltic Sea, in MEPC 45/INF.7. 1998.

[37] Entec UK Limited (2002). Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, prepared for the European Commission, Docket ID EPA-HQ-OAR-2007-0121-0059.

[38] ICF International (January 5, 2006). Current Methodologies and Best Practices in Preparing Port Emission Inventories, Final Report, prepared for the U.S. Environmental Protection Agency, available online at http://www.epa.gov/sectors/ports/bp_portemissionsfinal.pdf.

[39] Corbett, J.J. and H.W. Koehler (2003). Updated Emissions from Ocean Shipping, *Journal of Geophysical Research*, 108(D20); p. 4650.

[40] Corbett, J.J. and H.W. Koehler (2004). Considering Alternative Input Parameters in an Activity-Based Ship Fuel Consumption and Emissions Model: Reply to Comment by Oyvind Endresen et al. on "Updated Emissions from Ocean Shipping," *Journal of Geophysical Research*. 109(D23303).

[41] Levelton Consultants Ltd. (2006). Marine Emission Inventory Study Eastern Canada and Great Lakes – Interim Report 4: Gridding Results, prepared for Transportation Development Centre, Transport Canada.

[42] California Air Resources Board (October 2005). Emissions Estimation Methodology for Ocean-Going Vessels.

[43] ICF International (January 5, 2006). Current Methodologies and Best Practices in Preparing Port Emission Inventories, Final Report, prepared for the U.S. Environmental Protection Agency, available online at http://www.epa.gov/sectors/ports/bp-portemissionsfinal.pdf.

[44] Corbett, J.J. and H.W. Koehler (2003). Updated Emissions from Ocean Shipping, *Journal of Geophysical Research*, 108 (D20); p. 4650.

[45] ENVIRON International Corporation (2002). Commercial Marine Emission Inventory Development, prepared for the U.S. Environmental Protection Agency, EPA Report Number: EPA420-R-02-019.

[46] California Air Resources Board (September 2005). 2005 Oceangoing Ship Survey, Summary of Results.

[47] California Air Resources Board (September 2005). 2005 Oceangoing Ship Survey, Summary of Results.

Appendix 2D: Growth Factor Development

This appendix describes the development of growth factors for various U.S. Regions that were used as the basis for the PR/USVI growth rate. The derivation of the PR/USVI growth rate is described in section 2.5.1.

Geographic Regions

The geographic area reflects ship operations that occur within 200 nautical miles (nm) from the official U.S. baseline but excludes operations in Exclusive Economic Zones of other countries. The official U.S. baseline 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. The boundary was mapped using geographic information system (GIS) shapefiles obtained from the National Oceanic and Atmospheric Administration, Office of Coast Survey.[48] 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.[49]

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 year 2020.

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, shapefiles were created 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 Hawai’i, Maui, O’ahu, Moloka‘i, Ni’ihau, Kaua’i, 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 2D-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)

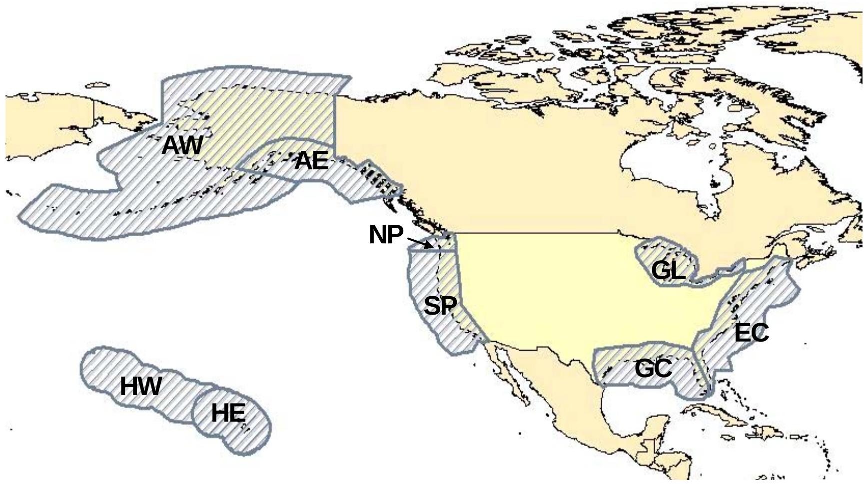


Figure 2D-1 Regional Modeling Domains

Growth Factors by Geographic Region

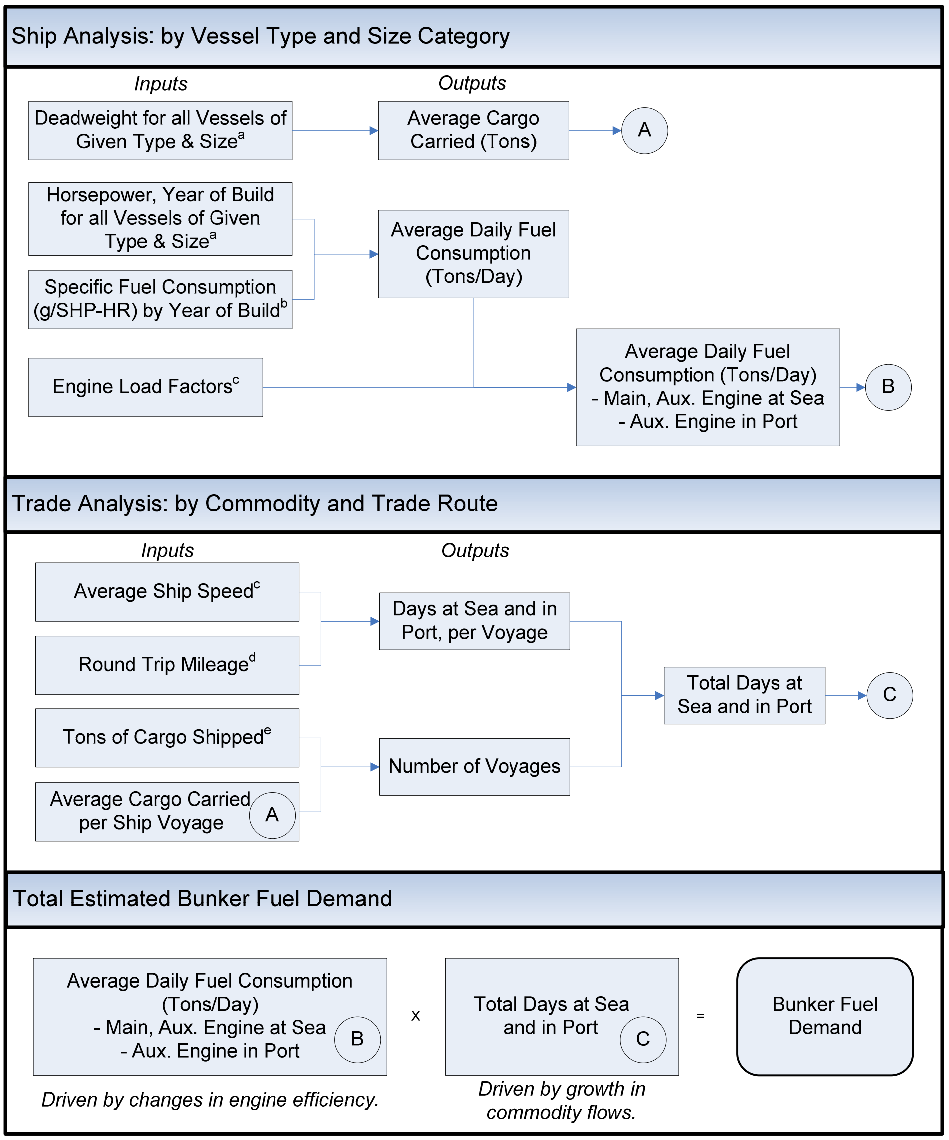
The growth factors that are used to estimate future year emission inventories are based on the expected demand for marine bunker fuels that is associated with shipping goods, i.e., commodities, into and out of the U.S. This section describes the growth factors that are used to project the emissions to 2020 for each of the nine geographic regions evaluated in this analysis. 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 the U.S. government.[50,51] This is followed by the derivation of the growth factors for the nine geographic regions of interest.

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 2D-2 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%.[52] 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 2D-2 Illustration of Method for Estimating Bunker Fuel Demand

Trade Analysis

The trade flows between geographic regions of the world, as illustrated by the middle portion of Figure 2D-2 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 2D-1 shows the countries associated with each region.

Table 2D-1 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

AGGREGATE REGIONS	BASE COUNTRIES / REGIONS
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

[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.[53]

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 2D-2 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 2D-2 Illustration of World Trade Estimates for Composite Commodities, 2005, 2012, and 2020

COMMODITY TYPE	CARGO (millions of tons)		
	2005 2	012 2	020
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

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. 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 Clarkson's Shipping Database.[54] These assignments are shown in Table 2D-3.

Table 2D-3 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 2D-4 summarizes the size categories that were used in the analysis and provides other information on the general attributes of the vessels from Clarkson's 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 2D-4 Fleet Characteristics

SHIP TYPE	SIZE BY DWT	MINIMUM SIZE (DWT)	MAXIMUM SIZE (DWT)	NUMBER OF SHIPS	TOTAL DWT (millions)	TOTAL HORSE-POWER (millions)	TOTAL KILO-WATTS (millions)
Container	Suezmax	83,000	140,000	101	9.83	8.56	6.38
	PostPanamax	56,500	83,000	465	30.96	29.3	21.85
	Panamax	42,100	56,500	375	18.04	15.04	11.21
	Intermediate	14,000	42,100	1,507	39.8	32.38	24.14
	Feeder	0	14,000	1,100	8.84	7.91	5.90
General Cargo	All	All		3,214	26.65	27.07	20.18
Dry Bulk	Capesize	79,000	0	715	114.22	13.81	10.30
	Panamax	54,000	79,000	1,287	90.17	16.71	12.46
	Handymax	40,000	54,000	991	46.5	10.69	7.97
	Handy	0	40,000	2,155	58.09	19.58	14.60
Crude Oil Tanker	VLCC	180,000	0	470	136.75	15.29	11.40
	Suezmax	120,000	180,000	268	40.63	5.82	4.34
	AFRAmax	75,000	120,000	511	51.83	8.58	6.40
	Panamax	43,000	75,000	164	10.32	2.17	1.62
	Handymax	27,000	43,000	100	3.45	1.13	0.84
	Coastal	0	27,000	377	3.85	1.98	1.48
Chemical Tanker	All	All		2,391	38.8	15.54	11.59
Petroleum Product Tanker	AFRAmax	68,000	0	226	19.94	3.6	2.68
	Panamax	40,000	68,000	352	16.92	4.19	3.12
	Handy	27,000	40,000	236	7.9	2.56	1.91
	Coastal	0	27,000	349	3.15	1.54	1.15
Natural Gas Carrier	VLGC	60,000	0	157	11.57	5.63	4.20
	LGC	35,000	60,000	140	6.88	2.55	1.90
	Midsize	0	35,000	863	4.79	3.74	2.79
Other	All	All		7,675	88.51	53.6	39.96
Total	--	--	--	26,189	888.4	308.96	230.36

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. Clarkson's 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, which is equivalent to 1.341 g/kW-hr).

The 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.[55]

Figure 2D-3 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. Post-2000 SFC values are constant at approximately 135 g/hp-hr (180 g/kW-hr).

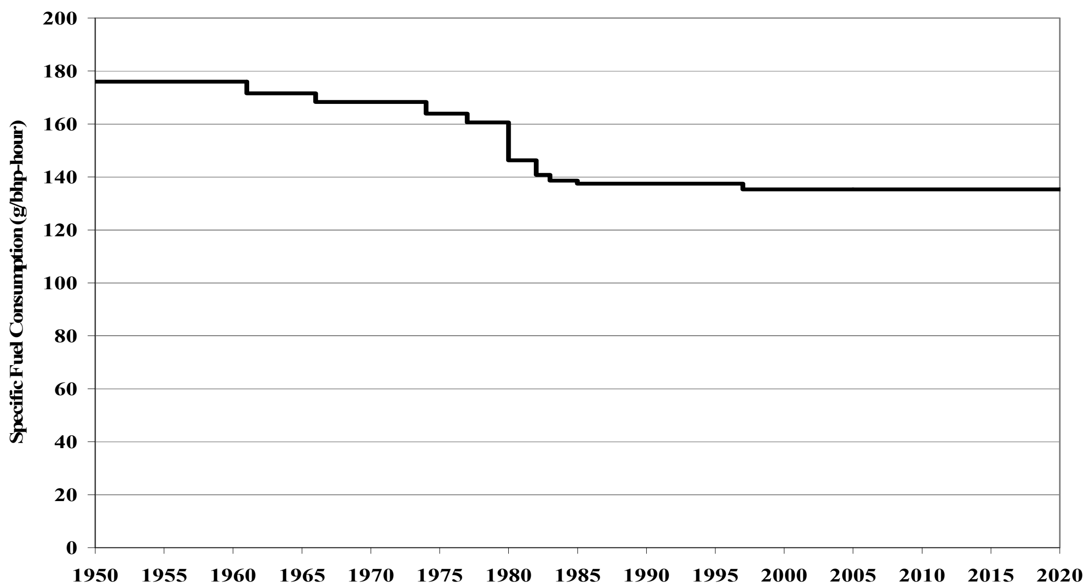


Figure 2D-3 Diesel Engine Specific Fuel Consumption

RTI assumed a fixed SFC of 220 g/HP-hr (295 g/kW-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 2D-1

$$\text{Fleet AFC}_{v,s} = \frac{1}{N}\sum\left[SFC_{v,s} \times HP_{v,s} \times 10^{-6} \, tonnes / g\right]$$

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 2D-5 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.[56]

Table 2D-5 Main and Auxiliary Engine Load Factors

VESSEL TYPE	MAIN ENGINE LOAD FACTOR (%)	AUXILIARY ENGINE AS % OF MAIN ENGINE	AUXILIARY ENGINE AS % 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.

Trade Analysis by Commodity Type and Trade Route

Determining the total number of days at sea and in port 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 Clarkson's 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 the next section.)

The days at sea were calculated by dividing the round trip distance by the average vessel speed:

Equation 2D-2

$$\text{Days at Sea Per Voyage}_{v,s,route} = \frac{\text{round trip distance route}}{\text{speed}_{v,s} \times 24\,\text{hrs}}$$

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 2D-6 presents the speeds by vessel type that were used in the analysis.[56] These values are the same for all size categories, and are assumed to remain constant over the forecast period.

Table 2D-6 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 2D-3

$$\text{Number of Voyages}_{v,s,trade} = \frac{\text{total metric tonnes of cargo moved}}{\text{fleet average DWT}_{v,s} \times \text{utilization rate}}$$

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.

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 2D-4

$$\begin{aligned} FC_y &= \sum_{trade} \sum_{route} FC_{trade,route,year} \\ &= \sum_{trade} \sum_{route} \left[AFC_{trade,route,y\,at\,sea} \text{ x Days at Sea}_{trade,route,y} + AFC_{trade,route,y\,at\,port} \text{ x Days at Port}_{trade,route,y} \right] \end{aligned}$$

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 2D-5

$$AFC_{trade,route,y\,at\,sea} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Fleet AFC}_{v,s} \text{ x} \left(\text{MELF} + \text{AE at sea LF}\right)\right]$$

$$AFC_{trade,route,y\,at\,port} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Fleet AFC}_{v,s} \text{ x AE import LF}\right]$$

$$\text{Days at Sea}_{trade,route,y} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Days at sea per voyage}_{v,s} \text{ x Number of voyages}_{v,s}\right]$$

$$\text{Days at Port}_{trade,route,y} = \sum_{v,s,t,r} (\text{Percent of trade along route})_{v,s} \left[\text{Days at port per voyage x Number of voyages}\right]$$

Where:

- AFC = Average daily fuel consumption in metric tones
- *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 and the trade analysis previously described.

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.

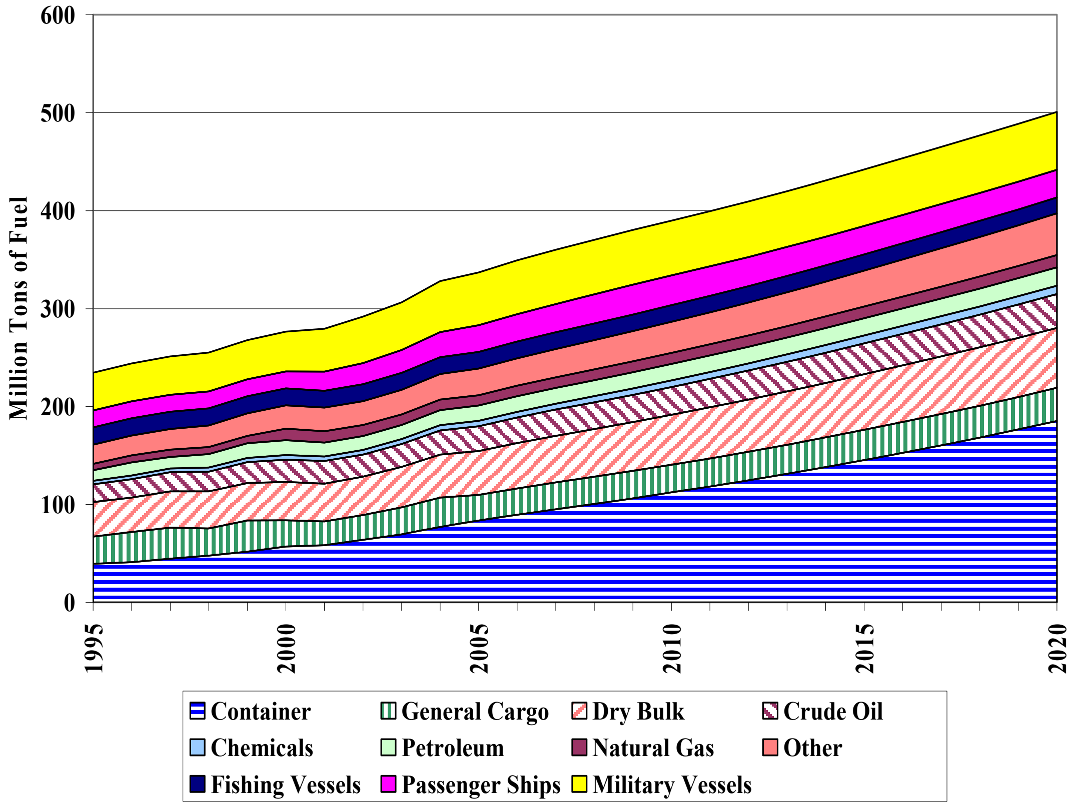


Figure 2D-4 Worldwide Bunker Fuel Consumption

Figure 2D-4 shows estimated world-wide bunker fuel consumption by vessel type. Figure 2D-5 shows the annual growth rates by vessel-type/cargo that are used in the projections shown in Figure 2D-4. 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.

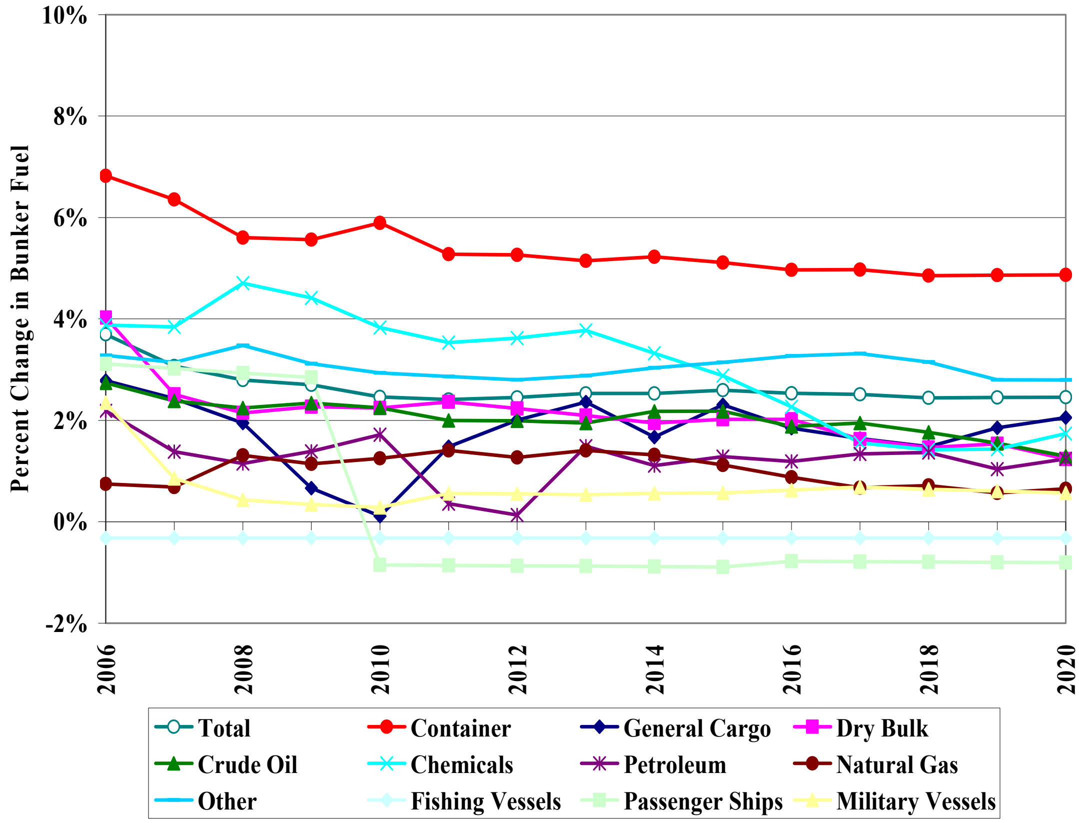


Figure 2D-5 Annual Growth Rate in World-Wide Bunker Fuel Use by Commodity Type

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.[57] 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)[58] 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 2D-6 to find the length of a voyage in days. Table 2D-7 presents the day lengths for non-containerized vessel types and Table 2D-8 shows the same information for container vessels.

Table 2D-7 Day Length for Voyages for Non-Container Cargo Ship (approximate average)

GLOBAL INSIGHTS TRADE REGIONS	DAYS PER VOYAGE				
	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 2D-8 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

ORIGIN – DESTINATION REGIONS	DAYS PER VOYAGE
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

Bunker Fuel Consumption for the United States

Figure 2D-6 and Figure 2D-7 present the estimates of fuel use for delivering trade goods to and from the U.S. The results in Figure 2D-6 show estimated historical bunker fuel use in year 2001 of around 47 million tonnes (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 tonnes by 2020 with the most growth occurring on trade routes from the East Coast and the "South Pacific" region of the West Coast.

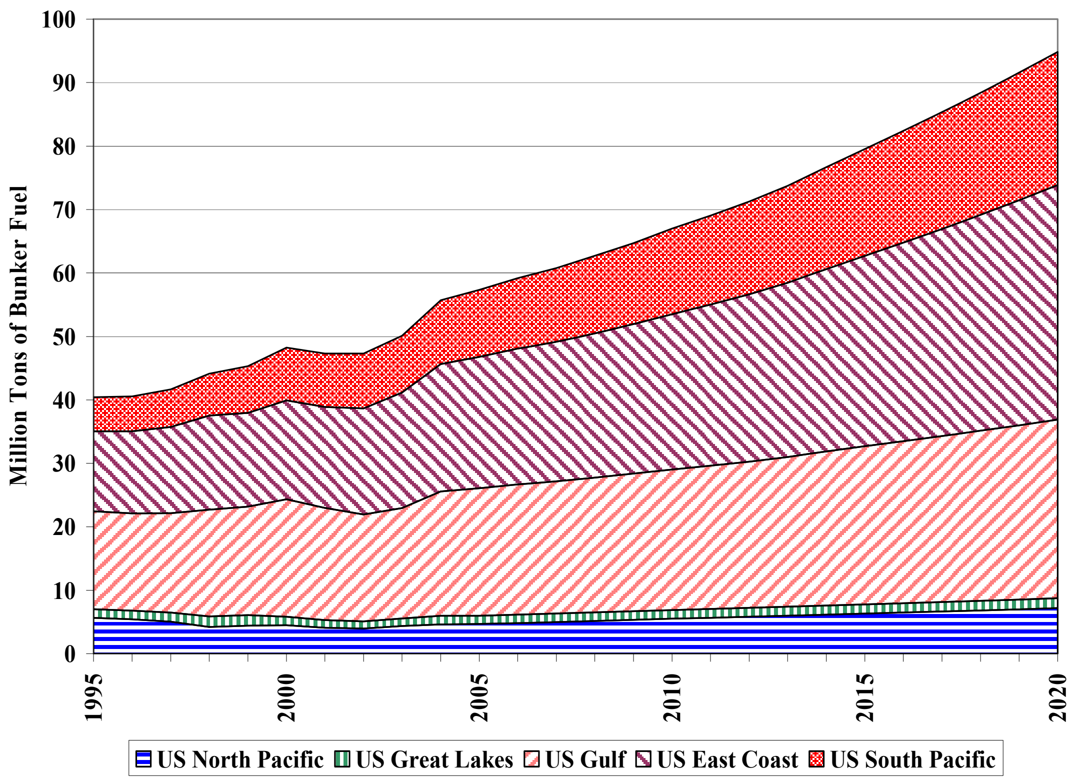


Figure 2D-6 Bunker Fuel Used to Import and Export Cargo by Region of the United States

Figure 2D-7 shows the estimated annual growth rates for the fuel consumption that are used in the projections shown in Figure 2D-6. Overall, the average annual growth rate in marine bunkers associated with future U.S. trade flows is 3.4 percent between 2005 and 2020.

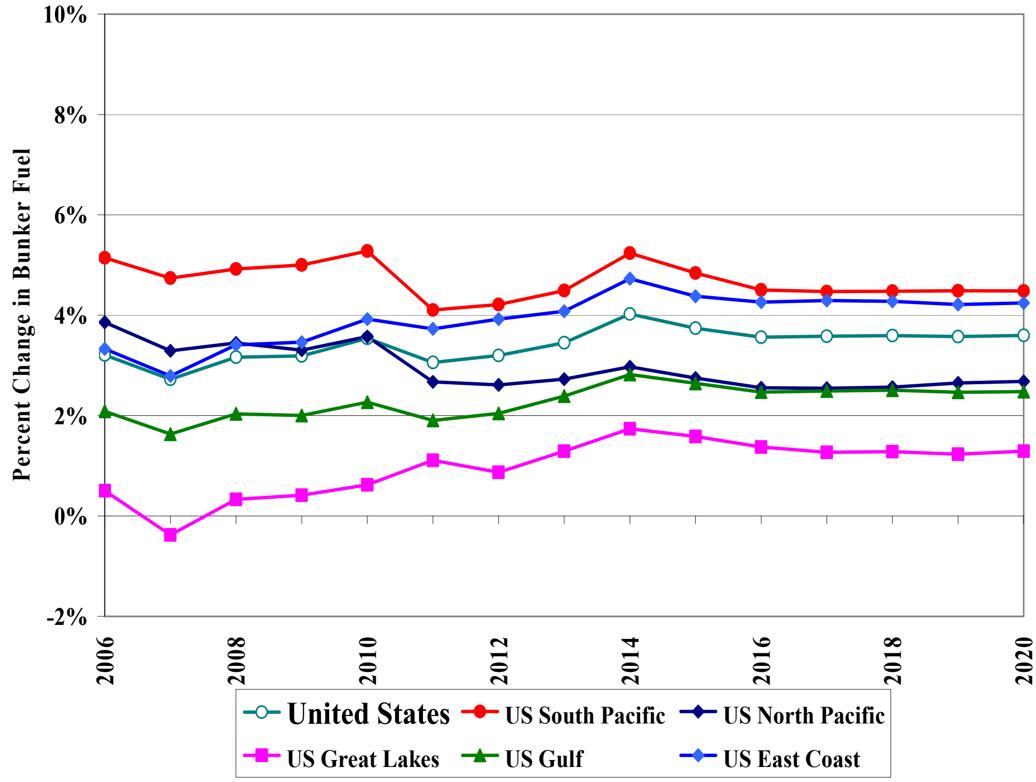


Figure 2D-7 Annual Growth Rates for Bunker Fuel Used to Import and Export Cargo by Region of the United States

2020 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. 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.

Mapping the RTI Regional Results to the Nine Region Analysis

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 2-1. The association of the RTI regions to the emission inventory regions is shown in Table 2D-9.

Table 2D-9 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)

Growth Factors for the Emission Inventory Analysis

Emission inventories for 2020 are estimated 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, i.e., 18 years. The resulting multiplicative growth factors for each emission inventory region and the associated RTI average annual growth rates are presented in Table 2D-10 for 2020.

Table 2D-10 Regional Emission Inventory Growth Factors for 2020

EMISSION INVENTORY REGION	2002-2020 AVERAGE ANNUALIZED GROWTH RATE (%)	MULTIPLICATIVE GROWTH FACTOR RELATIVE TO 2002
Alaska East (AE)	3.3	1.79
Alaska West (AW)	3.3	1.79
East Coast (EC)	4.5	2.21
Gulf Coast (GC)	2.9	1.67
Hawaii East (HE)	5.0	2.41
Hawaii West (HW)	5.0	2.41
North Pacific (NP)	3.3	1.79
South Pacific (SP)	5.0	2.41
Great Lakes (GL)	1.7	1.35

[48] National Oceanic and Atmospheric Administration, *Exclusive Economic Zone*, Available online at http://nauticalcharts.noaa.gov/csdl/eez.htm.

[49] U.S. Department of Interior, *North American Atlas – Political Boundaries*, Available online at http://www.nationalatlas.gov/mld/bound0m.html.

[50] RTI International (December 2006). Global Trade and Fuels Assessment – Future Trends and Effects of Designation Requiring Clean Fuels in the Marine Sector: Task Order No. 1, Draft Report, prepared for the U.S. Environmental Protection Agency, EPA Report Number EPA420-D-07-006, Docket ID EPA-HQ-OAR-2007-0121-0063.3.

[51] RTI International (April 24, 2006). RTI Estimates of Growth in Bunker Fuel Consumption, Memorandum with spreadsheet from Michael Gallaher and Martin Ross, RTI, to Barry Garelick and Russ Smith, U.S. Environmental Protection Agency.

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CHAPTER 3: Impacts of Shipping Emissions on Air Quality, Health and the Environment

Designation of this Emission Control Area (ECA) would significantly reduce emissions of NO_X, SO_X and $PM_{2.5}$ and thereby reduce ambient levels of particulate matter and ground-level ozone in Puerto Rico and the U.S. Virgin Islands. The improvement in ambient air quality would result in benefits to human health and the environment. This chapter describes the pollutants that would be reduced due to the ECA designation and their impacts on human health and the environment.

3.1 Pollutants Reduced by the ECA

3.1.1 Particulate Matter

Ships that operate in the proposed ECA generate emissions that increase on-land concentrations of harmful air pollutants such as particulate matter (PM). 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 (UFPs) 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 numerous 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., NO_X, SO_X and volatile organic compounds (VOC)) 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 chemicals 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]

3.1.2 Ozone

Ground-level ozone pollution is typically formed by the reaction of VOC and NO_X in the lower atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway and nonroad motor vehicles and engines, including ships, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone 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.

3.1.3 NO_2 and SO_2

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. Ships emit both NO_2 and SO_2. SO_2 and NO_2 can dissolve in water vapor and further oxidize to form sulfuric and nitric acid which reacts 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 3.2.1. NO_X along with non-methane hydrocarbons (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section 3.2.2.

3.1.4 Diesel Exhaust PM

Ship 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.[2] These compounds include diesel PM.

Marine diesel engines emit diesel exhaust (DE), a complex mixture comprised of carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter (DPM) present in diesel exhaust consists of fine particles (< 2.5μm), including a subgroup with a large number of ultrafine particles (< 0.1 μm). These particles have 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. Marine diesel engine emissions consist of a higher fraction of hydrated sulfate (approximately 60-90%) due to the higher sulfur levels of the fuel, organic carbon (approximately 15-30%), and metallic ash (approximately 7-11%) than are typically found in land-based engines.[3] 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.[4] 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.[5] 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.

3.2 Health Effects Associated with Exposure to Pollutants Reduced by the ECA

3.2.1 PM Health Effects

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 information and conclusions in the Integrated Science Assessment (ISA) for Particulate Matter (December 2009) prepared by EPA's Office of Research and Development (ORD).[B]

The ISA concludes that ambient concentrations of PM are associated with a number of adverse health effects.[C] The ISA characterizes the weight of evidence for different health effects associated with three PM size ranges: $PM_{2.5}$, $PM_{10-2.5}$, and UFPs. The discussion below highlights the ISA's conclusions pertaining to these three size fractions of PM, considering variations in both short-term and long-term exposure periods.

Information specifically related to health effects associated with exposure to diesel exhaust PM is included in Section 3.2.5 of this document.

3.2.1.1 Effects Associated with Short-term Exposure to $PM_{2.5}$

The ISA concludes that cardiovascular effects and all-cause cardiovascular- and respiratory-related mortality are causally associated with short-term exposure to $PM_{2.5}$.[6] It also concludes that respiratory effects are likely to be causally associated with short-term exposure to $PM_{2.5}$, including respiratory emergency department (ED) visits and hospital admissions for chronic obstructive pulmonary disease (COPD), respiratory infections, and asthma; and exacerbation of respiratory symptoms in asthmatic children.

3.2.1.2 Effects Associated with Long-term Exposure to $PM_{2.5}$

The ISA concludes that there are causal associations between long-term exposure to $PM_{2.5}$ and cardiovascular effects, such as the development/progression of cardiovascular disease (CVD), and premature mortality, particularly from cardiopulmonary causes.[7] It also concludes that long-term exposure to $PM_{2.5}$ is likely to be causally associated with respiratory effects, such as reduced lung function growth, increased respiratory symptoms, and asthma development. The ISA characterizes the evidence as suggestive of a causal relationship for associations between

[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 ISA is available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546

[C] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determination: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.5 of the ISA. The following text summarizes only those health effects with at least a "suggestive" weight of evidence determination.

long-term $PM_{2.5}$ exposure and reproductive and developmental outcomes, such as low birth weight and infant mortality. It also characterizes the evidence as suggestive of a causal relationship between $PM_{2.5}$ and cancer incidence, mutagenicity, and genotoxicity.

3.2.1.3 Effects Associated with $PM_{10-2.5}$

The ISA summarizes evidence related to short-term exposure to $PM_{10-2.5}$. $PM_{10-2.5}$ is the fraction of PM_{10} particles that is larger than $PM_{2.5}$.[8] The ISA concludes that available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and cardiovascular effects, such as hospitalizations for ischemic heart disease. It also concludes that the available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and respiratory effects, including respiratory-related ED visits and hospitalizations and pulmonary inflammation. The ISA also concludes that the available literature suggests a causal relationship between short-term exposures to $PM_{10-2.5}$ and mortality. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to $PM_{10-2.5}$.[9]

3.2.1.4 Effects Associated with Ultrafine Particles

The ISA concludes that the evidence is suggestive of a causal relationship between short-term exposures to ultrafine particles (UFP) and cardiovascular effects, including changes in heart rhythm and vasomotor function (the ability of blood vessels to expand and contract).[10]

The ISA also concludes that there is suggestive evidence of a causal relationship between short-term UFP exposure and respiratory effects. The types of respiratory effects examined in epidemiologic studies include respiratory symptoms and asthma hospital admissions, the results of which are not entirely consistent. There is evidence from toxicological and controlled human exposure studies that exposure to UFPs may increase lung inflammation and produce small asymptomatic changes in lung function. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to UFPs.[11]

3.2.2 Ozone Health Effects

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.[12,13] 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

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[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.

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.[14] 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.[15, 16, 17, 18, 19, 20] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[21, 22, 23, 24, 25] 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.[26, 27, 28, 29]

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.[30] 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.[31] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported statistically significant reductions in lung function in children who are active outdoors.[32, 33, 34, 35, 36, 37, 38, 39] 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.[40, 41, 42, 43]

3.2.3 SO_2 Health Effects

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 EPA Integrated Science Assessment for Sulfur Oxides.[44] 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. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. 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 ≥ 0.4 ppm in asthmatics engaged in moderate to heavy levels of exercise, with more limited evidence of respiratory effects among exercising asthmatics exposed to concentrations as low as 0.2-0.3 ppm. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 0.2 and 1.0 ppm, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults (≥ 65 years), and for asthma. 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 for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these 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.

3.2.4 NO_2 Health Effects

Information on the health effects of NO_2 can be found in the EPA Integrated Science Assessment (ISA) for Nitrogen Oxides.[45] The 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. 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. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. 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 following 30-minute exposures of asthmatics to

NO_2 concentrations as low as 0.26 ppm. In addition, small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. 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 of asthmatic subjects. Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the 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. These include all-cause (nonaccidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

3.2.5 Diesel Exhaust PM Health Effects

A large 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. Diesel exhaust PM (including the associated organic compounds which are generally high molecular weight hydrocarbons but not the more volatile gaseous hydrocarbon compounds) is generally used as a surrogate exposure measure for whole diesel exhaust.

Diesel exhaust has been found to be of concern by several groups worldwide including the U.S. government. The IPCS (International Programme on Chemical Safety) has established environmental health criteria for diesel fuel and exhaust emissions. In these criteria, the IPCS recommends that for the protection of human health diesel exhaust emissions should be controlled. The IPCS explicitly states that urgent efforts should be made to reduce emissions, specifically of particulates, by changing exhaust train techniques, engine design and fuel composition.[46]

3.2.5.1 Potential Cancer Effects of Exposure to Diesel Exhaust

The U.S. 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 U.S. EPA cancer guidelines.[47, 48] In accordance with earlier U.S. EPA guidelines, exposure to diesel exhaust would similarly be classified as probably carcinogenic to humans (Group B1).[49,50] 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.[51, 52,53,54,55] The Health Effects Institute has prepared numerous studies and reports on the potential carcinogenicity of exposure to diesel exhaust.[56,57,58]

More specifically, the U.S. EPA Diesel HAD states that the conclusions of the document apply to diesel exhaust in use today including both onroad and nonroad engines including marine diesel engines present on ships. The U.S. 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, the U.S. 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.[59,60,61]

The U.S. EPA recently assessed air toxic emissions and their associated risk (the National-Scale Air Toxics Assessment or NATA for 1996 and 1999), and concluded that diesel exhaust ranks with other emissions that the national-scale assessment suggests pose the greatest relative risk.[62,63] This national assessment estimates average population inhalation exposures to DPM for nonroad and on-highway sources. These exposures are the sum of ambient levels weighted by the amount of time people spend in each of the locations.

In summary, 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.

3.2.5.2 Other Health Effects of Exposure to Diesel Exhaust

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. The Diesel HAD established an inhalation Reference Concentration (RfC) specifically based on animal studies of diesel exhaust exposure. An RfC is defined by the U.S. 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." The U.S. EPA derived the RfC from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects.[64,65,66,67] 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 Diesel HAD states, "With DPM [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing DE [diesel exhaust] noncancer database to identify all of the pertinent DE-caused noncancer health hazards" (p. 9-19).

While there have been relatively few human studies associated specifically with the noncancer impact of exposure to 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."[68] There is also evidence for an immunologic effect such as the exacerbation of allergenic responses to known allergens and asthma-like symptoms.[69,70,71]

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 3.2.1.1 of this document), 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.

3.2.5.3 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.

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.

3.2.5.3.1 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, [72] rail yards, [73] and marine ports[74] 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. The percentage of total port emissions that come from ships varies by port. However, ships contribute to the DPM concentrations at ports, and elsewhere, which influence exposures.

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. Recent studies conducted in the continental United States have looked at air quality impacts of diesel engine emissions from ports. Although this proposed ECA is for Puerto Rico and the U.S. Virgin Islands, the contribution from ports to elevated ambient concentrations of diesel exhaust in populated areas on the U.S. mainland is relevant since there are also ports near populated areas of Puerto Rico and the U.S. Virgin Islands.

A 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.[75] 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. This port study highlights the substantial contribution these facilities make to ambient concentrations of DPM in large, densely populated areas.

The U.S. EPA updated an initial screening-level analysis[76,77] of selected marine port areas to better understand the populations that are exposed to diesel particulate matter (DPM) emissions from these facilities.[E] The results of this study are summarized here and are also available in the public docket.[78,79] 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 at least 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.

[E] 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.

3.2.6 Puerto Rico Asthma Rates

Emissions of PM, SO_X and NO_X from ships contribute to ambient concentrations of PM, ozone, SO_X and NO_X. As explained above, there are well established links between ambient concentrations of PM, ozone, SO_X and NO_X and asthma. Two studies by the Puerto Rico Department of Health in collaboration with the Puerto Rico Asthma Coalition found a higher asthma mortality rate in Puerto Rico than for the continental United States for the period since 1980. For the period 1980 to 1998, these researchers find that the asthma mortality rate for Puerto Rico was 2.5 times higher than in the continental U.S. While the Puerto Rican asthma mortality rate experienced a decreasing and then stable pattern from 2000-2004, it remains about two times higher than that in the continental U.S. for that same time period. The more recent of the two studies also looked at the lifetime asthma prevalence in Puerto Rico, defined as those individuals who at some time in their life have been diagnosed with asthma. This study found the lifetime asthma prevalence rate over the period 2000-2007 to be 1.5 times higher in Puerto Rico than in the continental U.S. The reductions in PM, NO_X, and SO_X emissions as a result of this proposed ECA would aid in reducing the prevalence of and mortality from asthma in Puerto Rico. In addition to helping reduce asthma rates, lowering ships emissions of NO_X, SO_X, and PM would also have a positive impact on the many other serious health problems detailed in this section.

3.3 Ecosystem Impacts Associated with Exposure to Pollutants Reduced by the ECA

In addition to their health impacts, emissions of NO_X, SO_X, and PM from ships are also of concern in Puerto Rico and the U.S. Virgin Islands because they cause harm to ecosystems. As mentioned above, Puerto Rico and the U.S. Virgin Islands are rich in biodiversity and contain many sensitive ecosystems ranging from bioluminescent bays and tropical mangrove swamps to coral reefs. This section looks at ecosystem impacts of NO_X, SO_X and PM emissions including deposition, acidification and nutrient enrichment, ozone impacts on plants and trees and visibility degradation.

3.3.1 Deposition

Ship engines emit large amounts of NO_X, SO_X and direct PM over a wide area. Depending on prevailing winds and other meteorological conditions, these emissions may be transported hundreds and even thousands of kilometers across the entire width of Puerto Rico and the U.S. Virgin Islands and impact not only ambient air concentrations but also contribute to deposition of nitrogen and sulfur in many sensitive ecological areas.

Ships operating on high sulfur fuel emit both SO_2 and sulfate PM. The sulfur in marine fuel is primarily emitted as sulfur dioxide (SO_2), with a small fraction (about two percent) being converted to sulfur trioxide (SO_3).[80] SO_3 almost immediately forms sulfate, which is emitted as primary PM by the engine, and consists of carbonaceous material, sulfuric acid, and ash (trace metals). These particles also react in the atmosphere to form secondary PM such as sulfuric acid aerosols, or sulfate particles.

Ships also emit large amounts of nitric oxide (NO) and nitrogen dioxide (NO_2) which are carried into the atmosphere where they may be chemically altered and transformed into new compounds. For example, NO_2 can 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 or deposited onto land surfaces where it subsequently runs off and is transferred into downstream waters.

Deposition can occur either in a wet or dry form. Wet deposition includes rain, snow, sleet, hail, clouds, or fog. Dry deposition includes gases and dust. 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, sulfate). Together these emissions from ships are deposited onto terrestrial and aquatic ecosystems across Puerto Rico and the U.S. Virgin Islands contributing to ecosystem problems.

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.[81]

The lifetimes of particles vary with particle size. Accumulation-mode particles such as 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.

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_X 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.[82]

3.3.1.1 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 and nutrient enrichment.

Deposition of nitrogen and sulfur species causes acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across Puerto Rico and the U.S. Virgin Islands. Major effects include a decline in sensitive tree species 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 the earth's geology.

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 also contribute to declines in coral reefs, zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems. Across Puerto Rico and the U.S. Virgin Islands, ecosystems continue to be acidified by current NO_X and SO_X emissions from stationary sources, area sources, and mobile sources.

In addition to the role nitrogen deposition plays in acidification, it also causes ecosystem nutrient enrichment and eutrophication that alters biogeochemical cycles and harms animal and plant life such as native lichens and alters biodiversity of terrestrial ecosystems, such as forests and grasslands. Nitrogen deposition contributes to eutrophication of estuaries and coastal waters which result in toxic algal blooms and fish kills.

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.[83]

3.3.1.1.1 Ecological Effects of Acidification

As described in the INF paper, ambient air quality monitoring data collected from Puerto Rico and the U.S. Virgin Islands between 2002 and 2007 indicate that wet deposition levels of both sulfate and nitrate compounds are significant and elevated, especially for sulfate.[F] The principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is geology (particularly surficial geology).[84] 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.[85,86,87,88,89] Other factors contributing to the sensitivity of soils and surface waters to acidifying deposition, include: topography, soil chemistry, land use, and hydrologic flow path.

Terrestrial

Acidifying deposition can alter biogeochemical processes 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.[90] 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

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[F] The National Atmospheric Deposition Program (NADP)/National Trends Network operated by the University of Illinois (http://nadp.sws.uiuc.edu) serves as the repository for annual data for wet deposition for the entire U.S. including Puerto Rico and the U.S. Virgin Islands.

pests and disease[91] leading to increased mortality of canopy trees. Emissions from ships contribute to nitrogen and sulfur deposition levels and can therefore impact trees and forests.

Lichens and bryophytes are among the first components of the terrestrial ecosystem to be affected by acidifying deposition.[92] There are over 1000 species of lichens known to occur in Puerto Rico and related offshore islands.[93] Vulnerability of lichens to increased nitrogen input is generally greater than that of vascular plants.[94] 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.[95] 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.[96] Emissions from ships contribute to nitrogen and sulfur deposition levels and can therefore impact lichens.

Aquatic Ecosystems

Aquatic effects of acidification have been well studied 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.[97] Biological effects in aquatic ecosystems can be divided into two major categories: effects on health, vigor, and reproductive success; and effects on biodiversity.

Coral reef ecosystems in Puerto Rico and the U.S. Virgin Islands comprise diverse habitats, including coral reefs, sea grass beds, and mangroves, that host abundant and diverse marine organisms (Rohmann, 2005). These biologically rich ecosystems play an important role in the socio-economic activities of coastal areas. For example, the reef habitats support the valuable fishing and tourism industries. However, the reef habitats are negatively impacted by these industries, including emissions from ships including cruise ships.

Complex reef ecosystems in Puerto Rico and the U.S. Virgin Islands with significant amount of live coral have experienced steep declines in overall population and in coral species

(Waddell and Clarke, 2008). As a result, the percentage of mean live hard coral cover[G] today is no greater than 10%.[H] Increases in CO_2, NO_X and SO_X emissions likely contribute to ocean acidification which results in less available calcium carbonate for shell deposition and growth of marine organisms. If this trend continues it may prevent future coral reef growth altogether and result in the permanent alteration of these important ecosystems.

Coral Reefs in Puerto Rico

Along with the main island of Puerto Rico, there are two uninhabited small islands off the east coast (Culebra and Vieques), and three uninhabited islands (Mona, Monito, Desecheo) off the west coast. Most coral reefs occur on the east, south and west coasts of the main island, with fringing reefs being the most common type. The western two-thirds of the north coast consists of mainly hard ground and reef rock with low to very low coral cover and some small, sparse, low coral colonies. Coral reefs cover approximately 3,370 km^2 within three nautical miles of the coasts. The main islands of Puerto Rico, including Culebra and Vieques, are almost completely encircled by reefs, although coral reef abundance is highly variable, depending on the local conditions. Figure 3-1 shows the distribution of coral reefs in Puerto Rico as developed by the U.S. National Oceanic and Atmospheric Administration (NOAA).

[G] Coral cover is a measure of the proportion of reef surface covered by live stony coral instead of sponges, algae, or other organisms.

[H] NOAA's Healthy Reefs for Healthy People program defines coral cover levels of 10% or lower as 'red flags' and recognizes a target level of 30% and above for reefs in the Mesoamerican Reef Region (http://healthyreefs.org/healthy-reef-indicators/coral-cover.html)

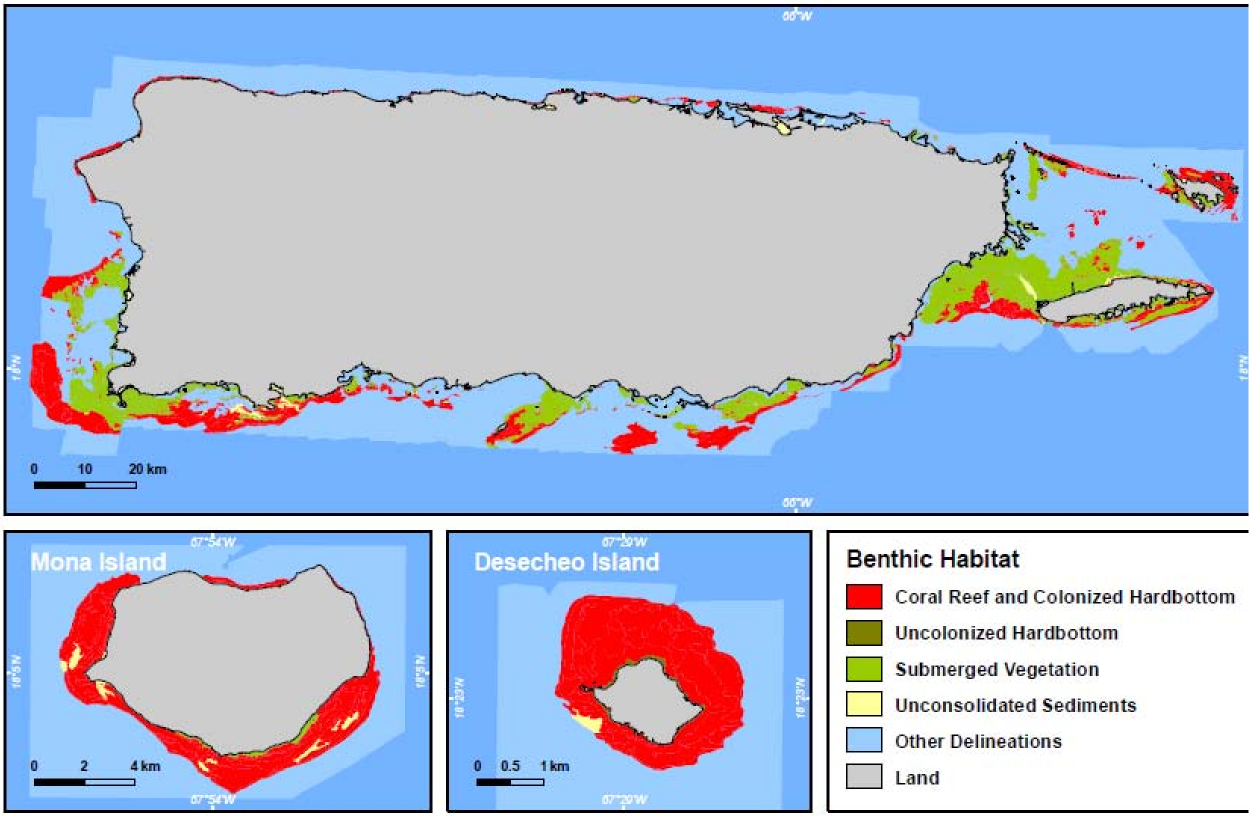

Figure 3-1 Distribution and Extent of Coral Reef Ecosystems in Puerto Rico [a]

Notes:

[a] Map developed by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) based on visual interpretation of aerial photography and hyperspectral imagers. For more information, see: http://biogeo.nos.noaa.gov.

The Puerto Rico Coral Reef Ecosystem Monitoring Program monitors 12 reefs from six Marine Preserve Areas (MPAs), and is sponsored by NOAA and has been administered by Puerto Rico's Department of Natural and Environmental Resources (DNER) since 1999 (Garcia, 2008). The MPAs include reef sites at Isla Desecheo, Rincon, Mayaguez, Guanica, Isla Caja de Muerto, and Ponce. Data from the program show that the benthic community at some of the reef systems are experiencing decline – including decline in live coral cover as well as a general trend of decline in the abundance of fish populations (statistically significant in seven of the 12 reef stations surveyed).

The declines in the health of key reef-building corals have become a concern to the U.S. Government. In 2004, NOAA received a petition to protect Elkhorn (Acropora palmata), Staghorn (A. cervicornis) and fused staghorn (A. prolifera) corals under the Endangered Species Act (ESA) of 1973, as amended. NOAA found that petition had merit and convened a Biological Review Team (BRT) to review the status of these species. Based on the results of the status review, in 2006 NOAA's National Marine Fisheries Service issued a final rule listing Elkhorn and Staghorn corals as threatened throughout their known range.

Coral Reefs in the U.S. Virgin Islands

In the U.S. Virgin Islands, coral reefs occur around all the major islands of St. Croix, St. John, and St. Thomas, as well as the offshore bays, as depicted in Figure 3-2 below. Fringing reefs, deep reefs (wall and shelf-edge), patch reefs, and spur and groove formations are present, although only St. Croix has barrier reefs. Bank reefs and scattered patch reefs with high coral diversity occur deeper offshore. The U.S. Departments of Interior, and Commerce, and the Virgin Islands Government have jurisdiction over submerged lands with coral reefs within the U.S. Virgin Islands. In 2001, NOAA completed maps of U.S. Virgin Islands coral reefs and associated ecosystems to a depth of 20 m. Of the 485 km^2, 61% consisted of coral reefs and hard-bottom habitats[I], 33% were seagrass beds (labeled as submerged vegetation), and the rest was sand or rock.

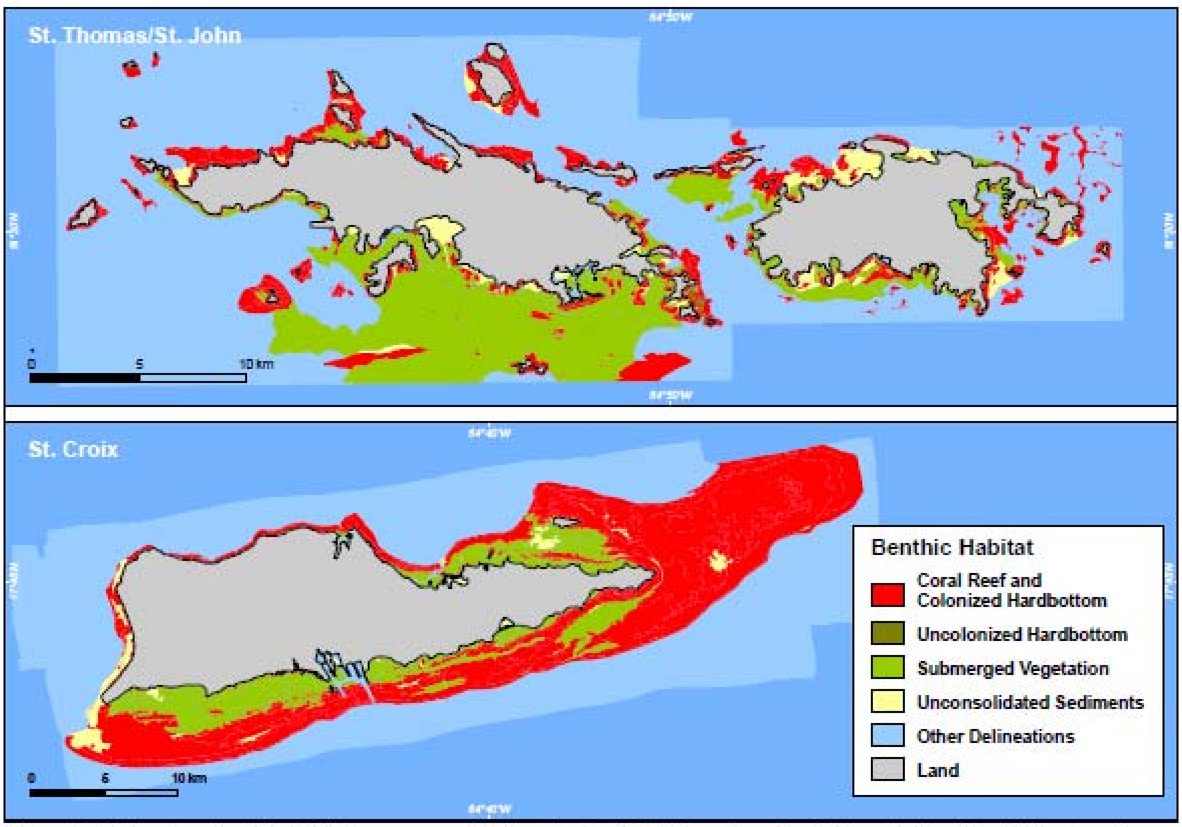

Figure 3-2 Benthic Habitat Maps[a] - Distribution and Extent of Coral Reef Ecosystems in U.S. Virgin Islands (Rothenberger, 2008)

[I] Sonar technology was used to generate the benthic habitat maps in Figures 2-1 and 2-2 and does not distinguish whether or not coral reefs exist on hard-bottom substrate; nor does it distinguish live coral from denuded skeleton. Hard-bottom substrate does not necessarily have corals on it nor does a reef necessarily exist where hard-bottom substrate exists. Hard-bottom is the only substrate where coral reefs might exist (but don't necessarily exist).

Notes:
[a] Near shore benthic habitat maps were developed by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) based on visual interpretation of aerial photography and hyperspectral imagers. For more information, see: http://biogeo.nos.noaa.gov.

Coral reefs in the U.S. Virgin Islands have changed dramatically in the last three decades. Insights into these changes come from long-term monitoring of sites ranging in depth from sea level to 40 m. Live coral cover has declined; coral diseases have become more numerous and prevalent; macroalgal cover has increased; fish of some species are smaller, less numerous or only rarely seen; and the long spined black sea urchins *Diadema antillarum* are less abundant. Coral cover has declined on most if not all reefs in the U.S. Virgin Islands for which there are quantitative data. In the 1970s and 1980s coral cover on some reefs was over 40% and even higher in some shallow Elkhorn coral zones (Gladfelter et al. 1977, Gladfelter 1982, Rogers et al. 1983, Edmunds 2002). By the 1990s, many long-term monitoring sites had coral cover of about 25% or less, and macroalgal cover, although variable, often reached much higher values than in the past. Coral cover continued to decline or remain stable until the major 2005 bleaching /disease event.[J] Now coral cover is less than 12% on many reefs, including five long term study sites in St. John and St. Croix covering over 10 ha of reefs that formerly had high coral cover and diversity.

3.3.1.1.2 Ecological Effects of 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.[98,99,100,101] As a consequence, some native species can be eliminated by nitrogen deposition.[102,103,104,105] Note the terms "low" and "high" are relative to the amount of bioavailable nitrogen in the ecosystem and the level of deposition.

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.[106,107,108] 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

[J] Coral bleaching is associated with a variety of stresses including increased sea surface temperatures. This causes the coral to expel symbiotic micro-algae living in their tissues – algae that provide corals with food. Losing their algae leaves coral tissues devoid of color, and thus appearing to be bleached. Prolonged coral bleaching (over a week) can lead to coral death and the subsequent loss of coral reef habitats for a range of marine life. August 2005 saw the beginning of a record-breaking coral bleaching event throughout the Caribbean region. The U.S. Virgin Islands were hit particularly hard: up to 95 percent of the corals bleached, and some areas saw 40 percent of the coral area killed.

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.

Most terrestrial ecosystems are nitrogen-limited, therefore they are sensitive to perturbation caused by nitrogen additions.[109] 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. Figure 3-3 below indicates some of the terrestrial ecosystems located on Puerto Rico.

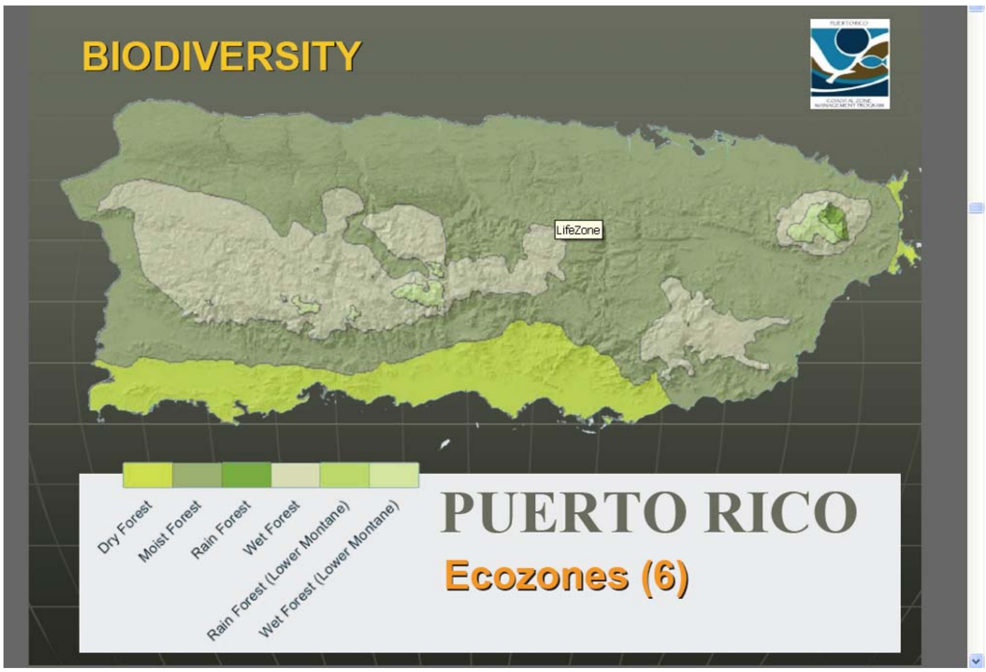

Figure 3-3 Puerto Rico Ecozones

Freshwater Aquatic

Nitrogen deposition alters species richness, species composition and biodiversity in freshwater aquatic ecosystems.[110] 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.

Wetland

Given the relatively small size of Puerto Rico and the U.S. Virgin Islands, the acreage of wetlands cannot be compared to those in the mainland United States. For instance wetlands in the U.S. Virgin Islands are confined to narrow coastal fringes. Although small, these wetlands are vital to migratory birds and native wildlife.[111] Nitrogen deposition alters species richness, species composition and biodiversity in wetland ecosystems. 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.

Estuarine Aquatic

Nitrogen deposition also alters species richness, species composition and biodiversity in estuarine ecosystems.[112] 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.[113,114,115,116,117,118] 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.[119] 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.

Estuaries and coastal waters tend to be nitrogen-limited and are therefore inherently sensitive to increased atmospheric nitrogen loading.[120,121] The U.S. EPA issued the National Estuary Program Coastal Condition Report (NEPCCR) in June 2007.[122] The NEPCCR concludes that 37% of estuaries in the National Estuary Program are in poor condition, including Puerto Rico's San Juan Bay Estuary. This rating is based on four indicators of estuarine condition – a water quality index, a sediment quality index, a benthic index and a fish tissue contaminants index. The report notes that water quality is rated fair for San Juan Bay but that one of the most common and widespread impairments to the estuary's waters are nutrient enrichment/eutrophication. The significant contribution by ships to emission inventories in Puerto Rico and the U.S. Virgin Islands means that these ships also have a significant contribution to nitrogen deposition levels which can contribute to nutrient enrichment and eutrophication.

Historically Puerto Rico had 60,000 acres of estuaries, 30,000 of which were mangroves.[123] Marshes and mangroves support a great variety of juvenile fish and invertebrates and provide food and nesting habitat for many different bird species. The preservation of marsh and mangrove habitats is an objective in the San Juan Bay Management Plan.[124] The NEPCCR also includes information on Puerto Rico's ecosystems of seagrass and submerged aquatic vegetation, some of the most diverse ecosystems in the North Atlantic Ocean.

3.3.1.2 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.[125,126,127] 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.[128] 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.

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.[129,130,131,132,133] 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.[134,135] 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.

3.3.2 Impacts of Ozone on Plants and Ecosystems

There are a number of environmental or public welfare effects associated with the presence of ozone in the ambient air.[136] Ship emissions of NO_X contribute to ambient ozone concentrations in Puerto Rico and the U.S. Virgin Islands. 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”.[137] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called “uptake”.[138] 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.[139,140] 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,[141] 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.[142,143]

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)[144,145,146] 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.[147]

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.[148,149] 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.[150,151]

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.[152] 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.[153,154,155] 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."[156] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[157,158,159]

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.[160] 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.[161] 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.[162]

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.[163,164] 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 ten 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.[165, 166]

3.3.3 Visibility

Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities. Airborne particles degrade visibility by scattering and absorbing light. Ship emissions of primary $PM_{2.5}$ and SO_X and NO_X (which contribute to the formation of secondary $PM_{2.5}$) contribute to poor visibility in Puerto Rico and the U.S. Virgin Islands.

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 and wilderness areas which are categorized as Mandatory Class I Federal areas. Virgin Islands National Park is a Mandatory Class I Federal area. The national park covers over 5,900 hectares, approximately 60% of the island of Saint John in the U.S. Virgin Islands, plus a few isolated sites on the neighboring island of St. Thomas.

Studies done for the continental U.S. have shown that ship emissions contribute to sulfate particles, which degrade visibility in Mandatory Class I Federal areas. For instance, one study concluded that shipping and port emissions from the Pacific Coast showed significant contributions to atmospheric sulfate concentrations over large areas of the western U.S. and that reducing those emissions is important in controlling haze at Mandatory Class I Federal areas.[167]

The emissions reductions associated with this proposed ECA would improve visibility in Puerto Rico and the U.S. Virgin Islands as a whole, as well as in sensitive areas such as the Virgin Islands National Park.

3.3.3.1 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 one of the 156 Mandatory Federal Class I areas across the country. This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of PROtected Visual Environments).

Annual mean deciview levels and natural haze (or background levels of visibility that would occur without manmade air pollution) levels for the Virgin Islands National Park are available on the IMPROVE website. Figure 2-4 below presents annual mean deciview data from 2001-2008 alongside natural haze levels. The ECA emission reductions being proposed here will help Virgin Islands National Park to reach natural haze levels.

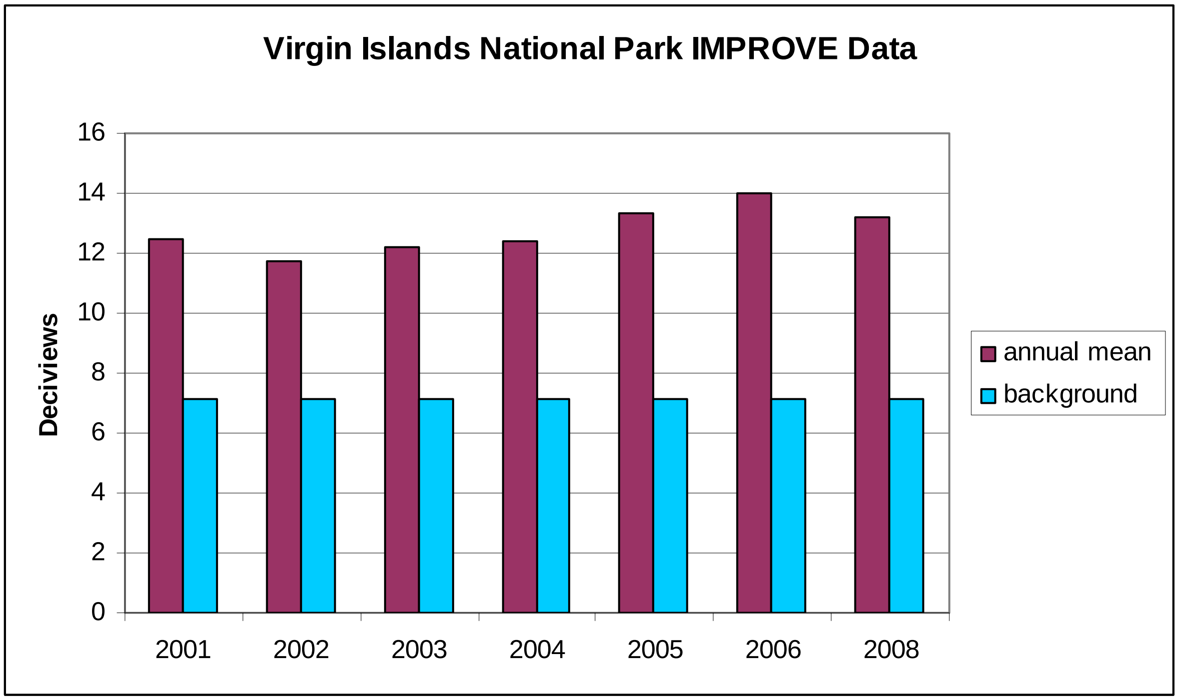

Figure 3-4 Virgin Islands National Park IMPROVE Data

Note:
Data from http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

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CHAPTER 4: Costs

The reduction of NO_X, SO_X, and PM emissions from ships has an associated cost that can reach beyond the shipping industry to marine fuel suppliers and companies who rely on the shipping industry. Though these cost impacts do exist, analyses presented in this document indicate that the costs associated with the proposed ECA are expected to have a minimal economic impact and to be relatively small compared to the resulting improvements in air quality. This chapter describes the analyses used to evaluate the cost impacts of Tier III NO_X requirements and the use of lower sulfur fuel on vessels operating within the proposed ECA; including estimates of lower sulfur fuel production costs. This chapter also presents cost per ton estimates for ECA-based NO_X and fuel sulfur standards and compares these costs with established land-based control programs. The costs presented here are based on the compliance with ECA standards in 2020. All costs are presented in terms of 2006 U.S. dollars.

4.1 Fuel Production Costs

This section presents our analysis of the impact of the proposed ECA on marine fuel costs. Distillate fuel will likely be needed to meet the 0.1 percent fuel sulfur limit, beginning in 2015, for operation in ECAs.[A] As such, the primary cost of the fuel sulfur limit 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. Distillate fuel costs may be affected by the need to further refine the distillate fuel to meet the 0.1 percent fuel sulfur limit. To investigate these effects, studies were performed on the impact of the North American ECA on global fuel production and costs. These studies, which are summarized below, include economic modeling to project bunker fuel demand and refinery modeling which can be used to assess the impact of the proposed U.S. Caribbean ECA on fuel costs.

4.1.1 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.[1] 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

[A] 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 distillate fuel. Therefore we are only estimating the cost of compliance using distillate fuel here as we believe this is the most likely approach.

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, tonnes 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.

For this analysis, total fuel costs are derived using estimated fuel consumption values and per-tonne incremental cost projections of using lower sulfur fuel. The fuel consumption estimates are those developed in the inventory analysis and presented in Chapter 2. The per-tonne fuel cost projections were developed using the World Oil Refining Logistics and Demand (WORLD) model, in support of the North American ECA proposal. These estimates are based on fuel price projections estimated by the Energy Information Administration (EIA) in 2008. We believe the use of these fuel cost estimates is appropriate for three reasons. First, use of these fuel cost estimates allows for a comparable analysis between the two programs. Second, the WORLD modeling was performed recently, which is especially important given the uncertainty associated with making projections of cost impacts in 2020. Third, based on sensitivity modeling performed on fuel volumes, the impact of additional distillate demand as a result of the proposed ECA would be small on the ECA WORLD fuel cost estimates. As such, the price pressures as a result of the proposed ECA would be negligible. This is especially true for this analysis, given that the volume of fuel consumed by ships operating in the proposed ECA is small (approximately 3.6 percent) relative to the North American ECA.

4.1.2 Bunker Fuel Cost Modeling

4.1.2.1 Methodology

To assess the impacts of the proposed ECA on fuel costs, the 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.[2] 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.

4.1.2.2 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.[3] 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, with 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;[B]
- allow for variation where necessary in (regional) sulfur standards on specific bunker grades; and

[B] Specifically, the following seven grades were implemented: Marine Gas Oil (MGO), plus distinct high- and low-sulfur blends for Marine Diesel Oil (MDO) and the main residual marine fuels Intermediate Fuel Oil (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.

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.

4.1.2.3 Updates for ECA Analysis

To determine the impact of the proposed 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 0.1 percent in the U.S. and Canadian EEZs.[4] 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 0.1 percent sulfur fuel. These benefits, and costs, would be much higher in the early years of the program before the 0.5 percent fuel sulfur 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 0.5 percent 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 3.5 percent fuel sulfur global standard, which begins in 2012, is higher than the current residual fuel sulfur average of 2.7 percent.

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.[5] Since that time, oil prices have fluctuated greatly. Using new information, EIA has updated its projections of oil price for 2020.[6,7] 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 were imputed based on the differences in the costs to the refining industry that occur between the Base Cases and ECA cases in 2020.

4.1.2.4 Overall Increases Due to Fuel Switching and Desulfurization

Global fuel use in 2020 by international shipping is projected to be 500 million 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 intermediate fuel oil (IFO) to distillate was projected to lead to a reduction in the total global <u>tonnes</u> of bunker fuel required but also led to a projected increase in the <u>barrels</u> required. These effects are evident in the WORLD case results. Based on our estimates, the volume of marine fuel affected by the proposed Caribbean ECA would be about 0.14 percent of total world residual volume. 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 0.1 percent fuel sulfur 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.[C] 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 4-1 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 proposed ECA, all fuel volumes are modeled as MGO.

Table 4-1 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

4.2 Operational Costs

Operational costs refer to those which are incurred whenever the vessel is operating. This analysis considers operating costs associated with both the low sulfur fuel requirement and the Tier III NO_X standards that would go into place in the proposed ECA for new vessels beginning in 2016.

[C] 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).

With respect to the low sulfur fuel requirement, we assume that all vessels in 2020 will comply with the standards by switching to low sulfur distillate fuel when operating in the proposed ECA. As an alternative, an exhaust gas cleaning unit may be used. It is expected that this alternative equivalent technology would only be used in the case where the operator determines that it would result in a cost savings relative to the use of distillate fuel. To the extent that operators choose an alternative technology, the costs may be overstated in this analysis.

4.2.1 Operational Costs Associated with the Use of Lower Sulfur Fuel

There are two main cost components projected to increase as a result of compliance with the fuel requirements of the proposed 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 second is a small cost associated with further desulphurizing distillate fuel to meet the 0.1 percent fuel sulfur standard in the ECA. The methodology used to develop these cost estimates is described in detail in the Technical Support Document developed for the North American ECA proposal. The estimated average increase in costs associated with switching from marine residual to distillate fuel will be $145 per tonne.[D] 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 remaining $140 is due to switching from residual fuel to distillate fuel. The cost differential is modeled based on costs to the refinery and assumes the market is in equilibrium.

The estimated increase in operational costs associated with the use of lower sulfur fuel was determined using the incremental cost of using distillate fuel instead of residual fuel, the increase in the cost of using distillate fuel, and the fuel consumption estimates provided in Chapter 2 of this document. The change in residual fuel usage is approximately $169 million, while the increase in cost of distillate fuel usage is estimated to be $233 million, resulting in the total estimated increase in fuel costs in 2020 to be $64 million, as a result of this proposed ECA.

Table 4-2 Estimated Operational Costs Associated With the Use of Lower Sulfur Fuel in 2020 in the Proposed ECA

FUEL TYPE	SCENARIO	ESTIMATED COST IN 2020 (MILLION)
Residual Fuel Usage	Baseline (Without the ECA)	$169
	With the ECA	$0
Distillate Fuel Usage	Baseline (Without the ECA)	$19
	With the ECA	$252
Total Additional Fuel Costs Associated with the ECA		$64

[D] 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).

4.2.2 Operational Costs Associated with SCR

For vessels built on or after January 1, 2016, we assume that the engines comply with the Tier III NO_X standards through the use of SCR. We recognize that other technologies may be used to meet the Tier III NO_X standards. For instance, development work has been performed with the goal of meeting these standards using exhaust gas recirculation and water injection strategies. If these technologies are used, then operating costs would be lower as urea would not be consumed in the vessel. As such, this analysis may overstate costs associated with the proposed ECA. At the same time we consider SCR technology because, at this time, it appears to be the most developed approach. Urea consumption for vessels equipped with SCR is expected to be 7.5 percent of the fuel consumption. The urea operational costs are based on a price of $1.52 per gallon with a density of 1.09 g/cc. The cost per gallon was estimated for a 32.5 percent urea solution delivered in bulk to the ship through research completed by ICF International for the U.S. Government, combined with historical urea price information.[8,9,10,11,12] The total operational costs associated with the proposed ECA are based on the amount of fuel consumed within the proposed ECA in the year 2020. Fuel consumption estimates for 2020 are presented in Chapter 2 of this technical support document including how the amount of fuel used in this area was determined.

The types of propulsion engines including: medium speed diesel, low speed diesel, gas and steam turbine, were determined using the percentages that occur in the current global fleet, and are shown below in Table 4-3.[13] These percentages were applied to the total fuel consumption estimated for 2020, resulting in an estimate of amount of fuel used by each engine type. Next, the "Age Distribution" data from Chapter 2 of this document was applied to these percentages to estimate what percentage of each engine type would be built after 2015. As discussed above, both medium-speed and low-speed main propulsion engines are assumed here to use SCR as the Tier III NO_X control strategy. The resulting percentage of vessels built after 2015 was then applied to the estimated fuel consumption values per engine-type to estimate the amount of fuel used in vessels equipped with SCR.

Table 4-3 Percentage of Vessels by Engine Type Estimated to Use SCR in 2020

TYPE OF ENGINE	PERCENT OF GLOBAL FLEET	PERCENT OF EACH ENGINE TYPE ESTIMATED TO HAVE BEEN BUILT AFTER 2015
Slow-Speed Diesel	80%	31%
Medium-Speed Diesel	17%	36%
Gas Turbine	0.4%	95%
Steam Turbine	2.6%	34%

The result for this proposed ECA is that the operational costs associated with the use of urea in 2020 by ships built as of 2016 are based on total urea consumption of nearly 4 million gallons are shown in Table 4-3 and estimated to be approximately $6 million.

Table 4-4 Estimated Operational Costs Associated with the Use of SCR as a Tier III NO_X Control Strategy

ESTIMATED GALLONS OF DISTILLATE FUEL USED IN 2020 (MILLION)	
Slow-Speed Diesel Powered Vessels	138
Medium-Speed Diesel Powered Vessels	29
Gas Turbine Powered Vessels	0.67
Steam Turbine Powered Vessels	4.5
ESTIMATED GALLONS OF DISTILLATE FUEL USED IN TIER III SCR EQUIPPED VESSELS IN 2020 (MILLION)	
Slow-Speed Diesel Powered Vessels	42
Medium-Speed Diesel Powered Vessels	10
Total Gallons of Distillate Attributable to Tier III	52
TOTAL ESTIMATED UREA USAGE AND COST IN 2020 IN THE PROPOSED ECA (MILLION)	
Estimated Gallons of Urea Used with Tier III Engines in 2020	3.9
Total Estimated Cost of Urea Used in the Proposed ECA in 2020	$6

4.3 Vessel Costs

The cost analysis for the proposed ECA does not include equipment costs associated with vessel modifications to accommodate ECA fuel for new and existing vessels or costs associated with the Tier III NO_X limits for vessels built after 2016. This is reasonable for two reasons. First, as noted in Chapter 1 of this document, approximately 55 percent of commercial shipments to Puerto Rico and the U.S. Virgin Islands originate in the continental United States, and approximately 90 percent of shipments from these areas are destined to the continental United States. All vessels that carry these goods will already be equipped to comply with the ECA requirements, as they will operate in the North American ECA. Second, the proposed ECA extends a maximum of about 60 nm from the baseline. Ship positional data presented in Section 7 of the Information Document suggests that there is little transit activity within the proposed ECA, and such transit activity that occurs is likely at the outer boundary of the ECA where ships have a lesser impact on air quality[E] and where it would be possible to reroute to avoid the proposed ECA. It is expected that those vessels transiting through the area that do not have Puerto Rico and the Virgin Islands as a destination will reroute, and therefore these vessels would also not incur equipment costs associated with ECA compliance.

4.4 Total Estimated ECA Costs in 2020

The total costs associated with improving ship emissions from current performance to ECA standards in 2020 include both the incremental fuel and urea operational costs presented above. The operational costs associated with the use of urea are estimated to be $6 million in 2020. The operational costs associated with the use of lower sulfur fuel for the proposed ECA

[E] See Section 5 of the Information Document for a discussion of back trajectory analysis and the impacts of ship emissions on shore.

are estimated to be $64 million in 2020. Therefore, the total costs associated with the proposed ECA in 2020 are expected to be $70 million, Table 4-5 summarizes these costs.

Table 4-5 Total Estimated U.S. ECA Costs in 2020

TOTAL ESTIMATED OPERATIONAL COSTS ASSOCIATED WITH THE PROPOSED ECA IN 2020 (MILLION)		
Residual Fuel Usage	Baseline (Without the ECA)	$169
	With the ECA	$0
Distillate Fuel Usage	Baseline (Without the ECA)	$19
	With the ECA	$252
Total Additional Fuel Costs Associated with the ECA		$64
Total Urea Costs Associated with the ECA		$6
Total Additional Operational Costs Associated with the ECA		$70

4.5 Cost Effectiveness

As discussed in Chapter 3, the proposed ECA is expected to bring many air quality and environmental benefits. Sections 4.1 through 4.2, above, summarize the various costs of the proposed ECA. However, this does not shed light on how cost effective the proposed ECA will be, compared to other control programs, at providing the expected emission reductions.

One tool that can be used to assess the value of the proposed ECA is the measure of cost effectiveness; a ratio of engineering costs incurred per tonne of emissions reduced. The U.S. Government has compared the ECA cost effectiveness to the ratio of costs per tonne of emissions reduced for other control programs. As is shown in this section, the NO_X, SO_X and PM emissions reductions from the proposed ECA compare favorably—in terms of cost effectiveness—to other land-based control programs that have been implemented.

4.5.1 ECA Cost Effectiveness

Chapter 2 of this document summarizes the inventory analyses from which the projections of pollutant reductions are drawn. The projected emission reductions due to the proposed ECA are presented below in Table 4-6.

Table 4-6 C3 Emission Inventories for Proposed ECA in 2020

EMISSION TYPE	ANNUAL EMISSIONS (METRIC TONNES)[a,b]						
	NO_X	PM_{10}	$PM_{2.5}$[c]	HC	CO	SO_2	CO_2
Reference	36,950	3,793	3,488	1,509	3,609	29,568	1,797,909
Control	27,032	512	471	1,509	3,609	1,075	1,711,452
Delta Emissions	*-9,919*	*-3,342*	*-3,017*	*0*	*0*	*-28,493*	*-86,457*
Delta Emissions (%)	*-27%*	*-86%*	*-86%*	*0%*	*0%*	*-96%*	*-5%*

Note that $PM_{2.5}$ is estimated to be 92 percent of the more inclusive PM_{10} emission inventory for marine vessels. In Chapter 2, 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.

Using the costs associated with NO_X, SO_X and PM control described in sections 4.1 through 4.2 above, and the emission reductions shown in Table 4-6 above, we calculated the cost per tonne, or cost effectiveness, of the proposed ECA. As described above, the costs of the proposed ECA include costs to refiners to produce additional distillate fuel, as well as costs for reductants to reduce NO_X emissions. Operational costs are incurred over time.

The resultant cost per tonne numbers depend on how the costs are allocated to each pollutant. We have allocated costs as closely as possible to the pollutants for which they are incurred. The costs to apply engine controls to meet Tier III NO_X standards, including reductants, have been allocated to NO_X. In our analyses, we have allocated half of the costs of fuel switching, to PM and half to SO_X because the costs incurred for control measures to reduce SO_X emissions directly reduce emissions of PM as well.

The resultant estimated cost effectiveness numbers are shown in Table 4-7. These include costs and emission reductions that are expected to occur due to compliance with the proposed ECA in the year 2020.

Table 4-7 Aggregate Long Term ECA Cost per Tonne (2006 U.S. Dollars)

POLLUTANT	COST PER TONNE IN 2020
NO_X	$600
SO_X	$1,100
$PM_{2.5}$	$11,000[F]

4.5.2 Land-Based Control Program Cost Effectiveness

The U.S. Government has already imposed restrictions on emissions of NO_X, SO_X, PM and other air pollutants, from a wide range of land-based industrial (stationary) and transportation (mobile) sources as well as consumer and commercial products. We have applied a wide range of programmatic approaches to achieve significant air pollution reductions. Regulatory regimes typically either mandate or incentivize emissions aftertreatment, cleaner fuels or raw materials, improved practices, as well as new processes or technologies.

Significant emission reductions of NO_X and SO_X in the U.S. have been achieved via performance standards for new combustion sources and market-based programs that cap emissions at the regional level. Since 1996, the Acid Rain Program and NO_X Budget Trading Program have been highly successful at drastically reducing both NO_X and SO_X from power plants in the Eastern U.S. Since 2004, NO_X, SO_X and PM emissions from highway and nonroad heavy duty trucks and equipment have been decreasing with performance and emission standards

[F] Converting to PM_{10} the cost per tonne would be 10,000. This figure is used in Table 4-8 below.

that will be completely phased in by 2010. To allow technology to advance, diesel fuel for use in vehicles in the U.S. has been reduced to less than 0.0015 percent sulfur (15 parts per million by weight), and diesel fuel for use in off-road equipment, locomotives and domestic marine vessels will be reduced to this level by 2012.

Advanced technology is already required on stationary sources in the U.S., including electricity generation produced by combustion; oil and gas; forest products (including pulp and paper and wood products); smelting and refining (including aluminum, alumina, and base metal smelting); iron and steel; iron ore pelletizing; potash; cement; lime; and chemicals production, including fertilizers. On mobile sources, advanced technology to reduce NO_X is fully phased in as of 2010 for engines on heavy duty trucks and will be phased in by 2015 for engines on harborcraft.

Programs that are designed to capture the efficiency of designing and building new compliant sources tend to have better cost-effectiveness than programs that principally rely on retrofitting existing sources. Even considering the retrofitting programs, the control measures that have been implemented on land-based sources have been well worthwhile when considering the benefits of the programs.

The cost of reducing air pollution from these land-based sources has ranged greatly, depending on the pollutant, the type of control program and the nature of the source. A selection of programs and their cost effectiveness is presented in Table 4-8. Unless otherwise noted, the programs named in the table address newly built sources only.

Table 4-8 Land-Based Source Control Program Cost Per Tonne[a] Comparisons

SOURCE CATEGORY[14]	IMPLEMENTATION DATE	NO_X COST/TONNE	SO_X COST/TONNE	PM_{10} COST/TONNE
Highway Diesel Fuel Program [d] 55 *Fed Reg* 34120, August 21, 1990	1993	-	-	11,000
Stationary Diesel (CI) Engines [c] 71 *Fed Reg* 39154, July 11, 2006	2006	600 - 22,000	-	4,000 - 46,000
Locomotives and Harborcraft (Both New and Retrofits) [d] 73 *Fed Reg* 25097, May 6, 2008	2015	800[b]	-	9,300 (New) 50,000 (Retrofit) [c]
Heavy Duty Nonroad Diesel Engines[d] 69 *Fed Reg* 38957, June 29, 2004	2015	1,200 [b]	900	14,000
Heavy Duty Onroad Diesel Engines [d] 66 *Fed Reg* 5001, January 18, 2001	2010	2,400 [b]	6,400	16,000
International Shipping (U.S. ECA) (Both New and Retrofits) [d]	**2016**	**2,600**	**1,200**	**10,000**
Proposed Puerto Rico/Virgin Islands ECA[e]	**2016**	**600**	**1,100**	**10,000**
Light Duty Gasoline/Diesel Engines [d] 65 *Fed Reg* 6697, February 10, 2000	2009	2,800 [b]	6,600	14,000
Fossil Fuel Fired Power Plants (Retrofits) [c] 58 *Fed Reg* 3590, January 11, 1993; 63 *Fed Reg* 57356, October 27, 1998	2000 to 2010	3,400	300	-
Other Stationary Sources (Both New and Retrofits) [c] 67 *Fed Reg* 80186, December 31, 2002	Ongoing	4,000 - 12,000	300 - 6,000	Variable

Notes:
[a] Units are 2006 U.S. dollars per metric ton. To convert to $/short ton, multiply by 0.907.
[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] Annualized costs of control for individual sources, except SO_X for Power Plants is a typical auction price.
[d] Aggregate program-wide cost/tonne over 30 years, discounted at 3%, except Light Duty and Highway Fuel aggregate costs were discounted at slightly higher rates, yielding slightly lower cost estimates.
[e] Estimate includes the year 2020 only.

Another example of one of the earlier programs is the 1990 regulation promulgated by the U.S. Government to reduce the sulfur content of highway diesel fuel. The cost effectiveness of PM reductions from that program varied depending on how the benefit of reduced wear on the engines was credited. Because the cleaner fuel with 0.05% sulfur (500 ppm) lengthened the useful life of the engines, the program could be characterized as having negative costs (with savings up to $100,000 per tonne) if the maximum engine wear credit was attributed to the program. If no engine wear credit was included, the program was estimated to cost a maximum of $11,000 per tonne of PM reduced.

As shown above, the projected cost per tonne of the proposed ECA falls well within the respective ranges of the other programs. The proposed ECA cost-effectiveness is comparable to the cost per tonne of current programs for new land-based sources, and has favorable cost effectiveness compared to land-based retrofit programs.

[1] 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. (Available at http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r08021.pdf)

[2] International Maritime Organization, Note by the Secretariat, "Revision of MARPOL Annex VI and NOX 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.

[3] International Maritime Organization, Note by the Secretariat, "Revision of MARPOL Annex VI and NOX 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.

[4] EnSys Energy & Systems, Inc. and RTI International 2009. Global Trade and Fuels Assessment—Additional ECA Modeling Scenarios. prepared for the U.S. Environmental Protection Agency.

[5] Energy Information Administration, 2006. "Annual Energy Outlook 2006" (DOE/EIA-0383(2006)); Washington, DC. (Available at: http://www.eia.doe.gov/oiaf/aeo/archive.html)

[6] Energy Information Administration, 2008. "Annual Energy Outlook 2008" (DOE/EIA-0383(2008)); Washington, DC. (Available at: http://www.eia.doe.gov/oiaf/aeo/)

[7] Energy Information Administration, 2008. "International Energy Outlook 2008" (DOE/EIA-0484(2008)); Washington, DC. (Available at: http://www.eia.doe.gov/oiaf/ieo/)

[8] ICF International, "Costs of Emission Reduction Technologies for Category 3 Marine Engines," prepared for the U.S. Environmental Protection Agency, December 2008. EPA Report Number : EPA-420-R-09-008.

[9] "Nonroad SCR-Urea Study Final Report" July 29, 2007 TIAX for Engine Manufacturers Association (EMA) can be found at:http://www.enginemanufacturers.org/admin/content/upload/198.pdf

[10] http://www.adblueonline.co.uk/air_1/bulk_delivery

[11] http://www.factsaboutscr.com/documents/IntegerResearch-Ureapricesbackto2005levels.pdf

[12] http://www.fertilizerworks.com/fertreport/index.html

[13] www.sea-web.com Lloyd's Register of Ships accessed September, 2008.

[14] Regulation of Fuels and Fuel Additives: Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years, 55 *Fed Reg* 34120, August 21, 1990.
Standards of Performance for Stationary Compression Ignition Internal Combustion Engines, 71 *Fed Reg* 39154, July 11, 2006.
Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder, 73 *Fed Reg* 25097, May 6, 2008.
Control of Emissions of Air Pollution From Nonroad Diesel Engines and Fuel 69 *Fed Reg* 38957, June 29, 2004.
Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements 66 *Fed Reg* 5001, January 18, 2001.
Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements 65 *Fed Reg* 6697, February 10, 2000.
Acid Rain Program; General Provisions and Permits, Allowance System, Continuous Emissions Monitoring, Excess Emissions and Administrative Appeals, 58 *Fed Reg* 3590, January 11, 1993; Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone, 63 *Fed Reg* 57356, October 27, 1998.
Prevention of Significant Deterioration (PSD) and Nonattainment New Source Review (NSR): Baseline Emissions Determination, Actual-to-Future-Actual Methodology, Plantwide Applicability Limitations, Clean Units, Pollution Control Projects, 67 *Fed Reg* 80186, December 31, 200270

CHAPTER 5: Economic Impacts

Chapter 4, above, provides the engineering costs associated with complying with the Tier III NO_X limits and the ECA fuel sulfur limits for all ships operating in the proposed ECA in 2020. In this chapter, we examine the economic impacts of these costs. 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. All costs are presented in terms of 2006 U.S. dollars.

The total estimated social costs associated with the proposed ECA in 2020 are equivalent to the estimated compliance costs of the program, at approximately $70 million. 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 their 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 higher prices for those goods.

We estimate that these costs added to the total cost of shipping goods to or from Puerto Rico or the U.S. Virgin Islands will result in only a modest increase in the costs of goods transported by ship. In most cases, ships that operate in the proposed ECA also operate in the North American ECA and/or the North Sea and Baltic SECAs. This means there are no additional equipment costs associated with the proposed ECA and therefore no impacts on the price of a vessel. With regard to operating costs, the total costs associated with improving ship emissions from current performance to ECA standards in 2020 include the differential costs of using lower sulfur fuel, and the use of urea on vessels equipped with selective catalytic reduction (SCR) systems to meet Tier III NO_X standards. The total estimated costs incurred as a result of using lower sulfur fuel in the proposed ECA are US$64 million, and the total estimated cost associated with the use of urea are US$6 million. The total estimated additional costs associated with the Caribbean ECA are approximately $70 million in 2020.

The economic impacts of complying with the program on ships engaged in international trade are expected to be modest. With regard to container ships, improving from current performance to ECA standards would increase the cost of shipping a twenty-foot-equivalent container by about US$0.33 to US$1.35 depending on the size of the ship and the length of the route. This represents an increase of less than one percent in the cost of shipping a 20-foot container. The price impacts on oil tanker services are also expected to be small, with a price impact of less than US$0.002 per barrel. With regard to cruise ships, we estimate that the price impacts of the proposed ECA on a large cruise ship that operates from the U.S. East Coast throughout the Caribbean would be approximately US$0.40 per passenger per day for a 14-day cruise; this represents a less than one percent increase in the price of a cruise. The price impacts on a medium sized cruise ship that operates a route between the U.S. and Puerto Rico will be approximately US$0.60 per passenger per day for a 5-day cruise; this represents a less than one percent increase in the price of the cruise. The impacts on a small cruise ship that spends nearly one-quarter of the time in the proposed ECA is estimated to be approximately US$1.30 per passenger per day for an 8-day trip; this represents a less than one percent increase in the price of the cruise.

It should be noted that this economic analysis holds all other aspects of the market constant except for the designation of the proposed ECA. It does not attempt to predict equilibrium market conditions for 2020 or the impacts of any other programs or economic conditions that may affect marine transportation. 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 remainder of this chapter provides detailed information on the methodology we used to estimate these economic impacts and the results of our analysis.

5.1 The Purpose of an Economic Impact Analysis

An Economic Impact Analysis (EIA) is prepared to provide information about the potential economic consequences of a regulatory action. Such an analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders.

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 economic welfare analysis, we look at the total social costs associated with the program and their distribution across key stakeholders. 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.

5.2 Economic Impact Analysis Methodology

Economic impact analysis is rooted in basic microeconomic theory. We use the laws of 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 construct the social costs of the program and identify how those costs will be shared across the markets and, thus, across stakeholders. The relevant concepts are summarized below and are presented in greater detail in Appendix 5A to this chapter.

Before the implementation of a control program, a market is assumed to be in equilibrium, with producers producing the amount of a good that consumers desire to purchase at the market price. The implementation of a control program results in an increase in production costs by the amount of the compliance costs. This generates a "shock" to the initial equilibrium market conditions (a change in supply). Producers of affected products will try to pass some or all of the increased production costs on to the consumers of these goods through price increases, 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 market, 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, especially 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.

In this analysis, the price elasticity of demand is nearly perfectly inelastic. This stems from the fact that, that, for most goods, there are no reasonable alternative shipping modes. In most cases, transportation by rail or truck is not feasible, and transportation by aircraft is too expensive. 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.[1] 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."[2] 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.

The economic impacts described below rely on the estimated engineering compliance costs presented in Chapter 4. These include the expected increases in operating costs for vessels operating in the ECA. These increased operating costs include 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.

5.3 Expected Economic Impacts of the Proposed ECA

5.3.1 Engine and Vessel Market Impacts

The market analysis explores the impact of a regulatory program on the prices and quantity of goods produced in directly affected markets. In this case, the vast majority of vessels that operate in the proposed ECA also operate in the North American ECA and/or the Baltic or North Sea SECAs. The equipment costs associated with ECA compliance are already incurred as a result of those programs, and therefore the proposed ECA would not be expected to result in any change to the prices of affected marine diesel engines or vessels, or the quantities of vessels produced.

Table 5-1 and Table 5-2 present the estimated price impacts for a sample of engine and vessel combinations that were developed for the North American ECA, for medium speed and slow speed engines, respectively. These tables are provided to show the expected engine and vessel impacts for the limited number of vessels that would not already operate in any other ECA. These new engine and new vessel costs are unlikely to be incurred, however, as owners of vessels that do not operate in any other ECA would be expected to find ways to redistribute their fleets to avoid them. These price impacts reflect the impacts of the costs that will be incurred when the most stringent ECA standards are in place in 2020. These estimated price impacts are small when compared to the price of a new vessel.

Table 5-1 Summary of Estimated Market Impacts – New Medium Speed Engines and Vessels (2020; $2006)

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW TIER III ENGINE PRICE IMPACT)[a]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[b]	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

[a] Medium speed engine price impacts are estimated from the cost information presented in Chapter 4 using the following formula: ((10%*(Mechanical Fuel Injection to Common Rail)+(30%*(Electronic Fuel Injection to Common Rail))+(T3 Engine Modifications)+(T3 SCR))
[b] Assumes 32 percent of new vessels would require the fuel switching equipment.

Table 5-2 Summary of Estimated Market Impacts – Slow Speed Engines and Vessels (2020; $2006)

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW ENGINE PRICE IMPACT)[a]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[b]	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

[a] Slow speed engine price impacts are estimated from the cost information presented in Chapter 4 using the following formula: (5%*(Mechanical Fuel Injection to Common Rail))+(15%*(Electronic Fuel Injection to Common Rail))+(T3 Engine Modifications)+(T3 SCR))
[b] Assumes 32 percent of new vessels would require the fuel switching equipment

A selection of new vessel prices that were developed for the North American ECA is provided in Table 5-3, and range from about $40 million to $480 million. The estimated price increases range from about $600,000 to $1.5 million. A price increase of $600,000 to comply with the ECA requirements would be an increase of approximately two percent for a $40 million vessel. The largest vessel price increase noted above, for passenger vessels, is about $1.5 million; this is a price increase of less than one percent for a $478 million passenger vessel. Price increases of this magnitude would be expected to have little, if any, effect on the quantity sales of new vessels, all other economic conditions held constant. Again, these impacts are presented for illustration only; most vessels that operate in the proposed ECA will have incurred these costs as result of the North American ECA and/or the North Sea and Baltic Sea SECAs.

Table 5-3 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

VESSEL TYPE	VESSEL SIZE CATEGORY	SIZE RANGE (MEAN) (DWT)	NEWBUILD
	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)			

5.3.2 Fuel Market Impacts

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 program are set out in Table 5-4. 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 5-4 are adjusted for this impact.

Table 5-4 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 5-4 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.

5.3.3 Marine Transportation Market Impacts

We used the above information to estimate the impacts on the prices of marine transportation services. This analysis, presented in Appendix 5B to this chapter, 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 III standards.

Estimates of the impacts of these increased operating costs were performed using a representative fleet, estimated fuel consumption, actual operational parameters, and sea-route data for three types of ocean going vessels: container, tanker, and cruise liner. Data obtained in 2010 from Lloyd's of London for ships that call on the proposed ECA were used to develop a representative range of ships for this analysis. The characteristics used to develop these representative ships include: gross tonnes (GT), engine power (kilowatt – hour (kW-hr)), cruise speed, cargo and passenger capacities, and ship call data for each vessel type. Additionally, to develop a representative sea-route for our price estimations, we created theoretical trips for both cruise ships and for cargo carrying vessels. Three different hypothetical cruises were developed based on actual cruises that visit the proposed ECA; these routes reflect travel between the U.S. and Puerto Rico, as well as a route that travels exclusively inside the Caribbean. The container vessel routes developed are between the U.S. and Puerto Rico, and Singapore and Puerto Rico, while the tanker vessel route developed is between La Guaria, Venezuela and San Juan, Puerto Rico. All hypothetical routes and their respective representative vessels and are shown in Table 5-5 below, more detailed information is included in Appendix 5B of this chapter.

Table 5-5 Summary of Vessels and Routes

TYPE OF SHIP	ENGINE SIZE (KW)	ROUTE	CARGO	NAUTICAL MILES IN THE PROPOSED ECA	TOTAL NAUTICAL MILES OF THE TRIP
Cruise Ship	22,000	San Juan, Puerto Rico; St. John U.S.V.I.; Basseterre, St. Kitts; Pointe-A-Pitre, Guadeloupe; Fort-de-France, Martinqiuqe; St. Georges, Grenada; Bridgetown, Barbados; St. John's, Antigua; Frederiksted, St. Croix U.S. V.I.; San Juan, Puerto Rico.	800 Passengers	300	1700
Cruise Ship	53,000	Fort Lauderdale, Florida; San Juan, Puerto Rico; Matthew Town, Bahamas, Fort Lauderdale, FL.	2,000 Passengers	100	2,000

TYPE OF SHIP	ENGINE SIZE (KW)	ROUTE	CARGO	NAUTICAL MILES IN THE PROPOSED ECA	TOTAL NAUTICAL MILES OF THE TRIP
Cruise Ship	72,000	New York, NY; Turk Islands; San Juan, Puerto Rico; St. Thomas, U.S.V.I.; Fort-de-France, Martinique; St. Georges, Grenada; Oranjestad, Aruba; Ocho Rios, Jamaica; Cozumel, Mexico; Key West, Florida; New York, New York.	3,000 Passengers	200	5,500
Container Vessel	5,000	Miami, Florida; San Juan, Puerto Rico	600 TEU	100	930
Container Vessel	15,785	Miami, Florida; San Juan, Puerto Rico	1,400 TEU	100	930
Container Vessel	36,540	Singapore to San Juan Puerto Rico	6,600 TEU	100	12,500
Tanker	10,000	La Guaria, Venezuela; San Juan, Puerto Rico	780,000 Barrels	130	530

To estimate the increase in operational costs that may be incurred as a result of this proposed ECA, we determined the amount of fuel that would be used for each of the theoretical routes and representative vessels shown in Table 5-5. We then estimated what the fuel costs would be if these vessels operated using residual fuel only, and then again if they used distillate in the proposed ECA. This estimation was performed assuming that the vessel would continue to operate on residual fuel when outside of the ECA, and that approximately 33 percent of these vessels would also use an exhaust aftertreatment technology that would require urea usage.

The overall price differences for each of these hypothetical trips were obtained by subtracting the residual fuel operational costs from the calculated ECA operational fuel / urea costs. Table 5-6 summarizes these cost increases as they relate to goods shipped and Table 5-7 summarizes these per-passenger impacts.

Table 5-6 Estimated Economic Impacts of PR/VI ECA for Cargo Ships (US$2006)

VESSEL TYPE	ROUTE	PRE-ECA FUEL COST PER TRIP	POST-ECA FUEL COST PER TRIP	PRICE INCREASE PER TEU OR BARREL
Container (600 TEU)	Miami FL – San Juan, PR (930 nm; 100 nm in ECA)	$14,900	$15,500	$1.00 (0.25%) $400 base cost
Container (1,400 TEU)	Miami FL – San Juan, PR (930 nm; 100 nm in ECA)	$47,100	$49,000	$1.35 (0.34%) $400 base cost
Container (6,600 TEU)	Singapore – San Juan, PR (12,500 nm; 100 nm in ECA)	$1,432,000	$1,434,000	$0.33 (0.04%) $800 base cost
Tanker (115,000 DWT; 780,000 bbl crude)	Venezuela – San Juan, PR (540 nm; 130 nm in ECA)	$16,700	$18,200	$0.002/barrel (negligible %)

For these commercial vessels, the expected cost increase of shipping goods to or from Puerto Rico, as measured by the increase in costs per TEU or per barrel of fuel, is expected to be small, at significantly less than one percent. We estimate that a container ship that travels between the U.S. and the proposed ECA and operates part of the time in the ECA would see an increase in operating costs of US$1.00 to US$1.35 per TEU, depending on the size of the ship and the length of the route. This represents an increase of less than one percent in the cost of shipping a 20-foot container. A container ship operating between Singapore and Puerto Rico is expected to see an increase in operating costs of about US$0.33 per TEU, or less than one percent of the cost of shipping a 20-foot container. The price impacts on oil tanker services are also expected to be small, with an estimated price increase of less than US$0.002 per barrel.

Table 5-7 Estimated Economic Impacts of PR/VI ECA for Cruise Ships (US$2006)

VESSEL AND ROUTE TYPE	ROUTE	PRE-ECA FUEL COST PER TRIP	POST-ECA FUEL COST PER TRIP	PRICE INCREASE PER PASSENGER PER DAY
Small Cruise Ship (32,000 GT and 800 passengers) Island Tour	San Juan, Puerto Rico; St. John U.S.V.I.; Basseterre, St. Kitts; Pointe-A-Pitre, Guadeloupe; Fort-de-France, Martinqiuqe; St. Georges, Grenada; Bridgetown, Barbados; St. John's, Antigua; Frederiksted, St. Croix U.S. V.I.; San Juan, Puerto Rico.	$123,000	$131,000	$1.30 ($10 per trip for the 8-day trip)
Medium Cruise Ship (80,000 GT and 2,000 passengers) Direct Trip to Puerto Rico	Fort Lauderdale, Florida; San Juan, Puerto Rico; Matthew Town, Bahamas, Fort Lauderdale, FL.	$298,000	$303,000	$0.60 ($3 per trip for the 5-day trip)
Large Cruise Ship (120,000 GT and 3,000 passengers) Long Tour of the Caribbean from the U.S. East Coast	New York, NY; Turk Islands; San Juan, Puerto Rico; St. Thomas, U.S.V.I.; Fort-de-France, Martinique; St. Georges, Grenada; Oranjestad, Aruba; Ocho Rios, Jamaica; Cozumel, Mexico; Key West, Florida; New York, New York.	$987,000	$1,002,000	$0.40 ($6 per trip for the 14-day trip)

For similar sized cruise vessels, the expected cost increase of carrying passengers to or from Puerto Rico, as measured by the increase in costs per passenger per cruise, is expected to be small, at less than one percent. We estimate that a cruise ship that operates part of the time in the ECA would see an increase in operating costs of US$0.40 to US$1.30 per passenger per night, depending on the size of the ship, the length of the route, and the number of passengers. This represents an increase of less than one percent in the cost of a stateroom per night. A large cruise ship operating between New York and Puerto Rico is expected to see an increase in operating costs of nearly US$6 per passenger per cruise. The price on a small cruise ship cruising from and returning to San Juan, Puerto Rico is expected to see an increase in operating costs of about US$10 per passenger per cruise. The price impacts on a medium sized cruise ship operating on a nearly direct route between Fort Lauderdale, Florida and San Juan, Puerto Rico are also expected to be small, with an estimated price increase of less than US$3 per passenger per cruise. The estimated increase in costs per trip per passenger incurred as a result of this proposed ECA are substantially less than the average fuel charge currently charged to passengers if the price of oil per barrel exceeds a certain threshold, this surcharge can range from US$5 to US$10 per passenger per day.

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 5-1. This figure is based on variation in fuel price among the ports of Singapore, Houston, Rotterdam, and Fujairah.

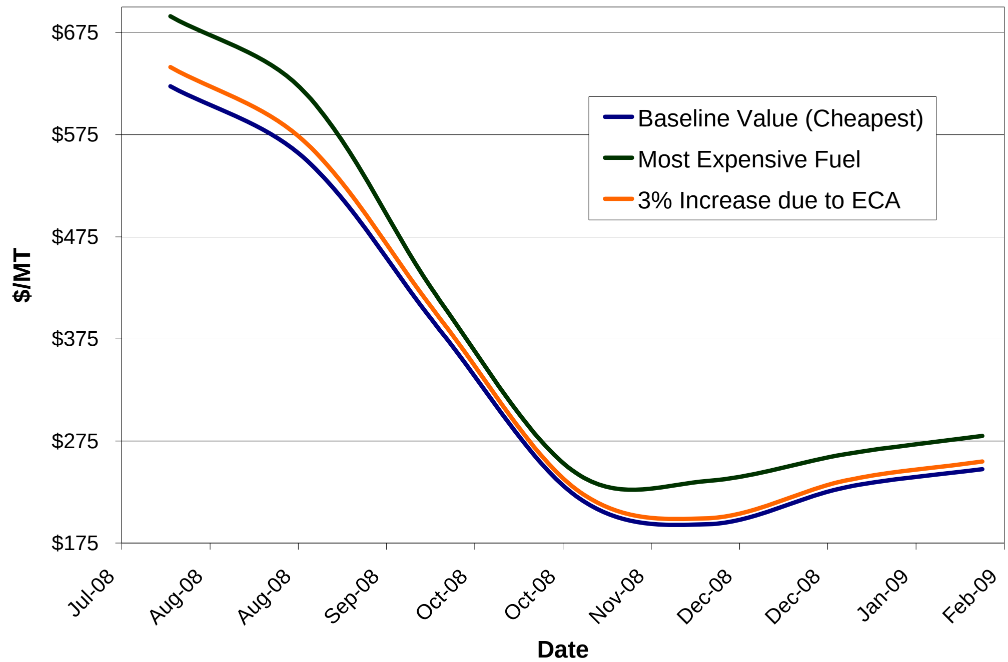

Figure 5-1 Range of Bunker Fuel Prices

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 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.

5.3.4 Social Costs of the Proposed ECA and Distribution Across Stakeholders

The total social costs associated with complying with the Tier III NO_X limits and the ECA fuel sulfur limits for all ships operating in the U.S. portion of the proposed ECA are estimated to be the same as the total engineering costs presented in Chapter 4, or about $70 million in 2020. For the reasons described above and explained more fully in the Appendix to this chapter, these costs are expected to be borne fully by consumers of international shipping services.

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]

Appendices

APPENDIX 5A

The methodology used in this Economic Impact Analysis (EIA) is rooted in applied microeconomic theory and was developed following U.S. EPA's recommended procedures.[4] This appendix 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.

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.

Multi-Market, Partial-Equilibrium Approach

The approach is *behavioral* 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[5] 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. As producers change their production levels in response to a new regulation, consumers of the affected goods are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output resulting from the market adjustments are used to estimate the distribution of social costs between consumers and producers.

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."[6]

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.

Competitive Markets

The methodology used in this EIA relies on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices. Perfect competition is widely accepted for this type of analysis and only in rare cases are other approaches used.[7] Stopford's description of the shipping market and how prices are set in this market supports this assumption.[8]

In a perfectly 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 perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[A,9] 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).

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.

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

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[A] The number of firms in a market is not a necessary condition for a perfectly competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Inc., p 333.

factors and can be represented by a vertical supply curve, as shown in Figure 5-2. 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.

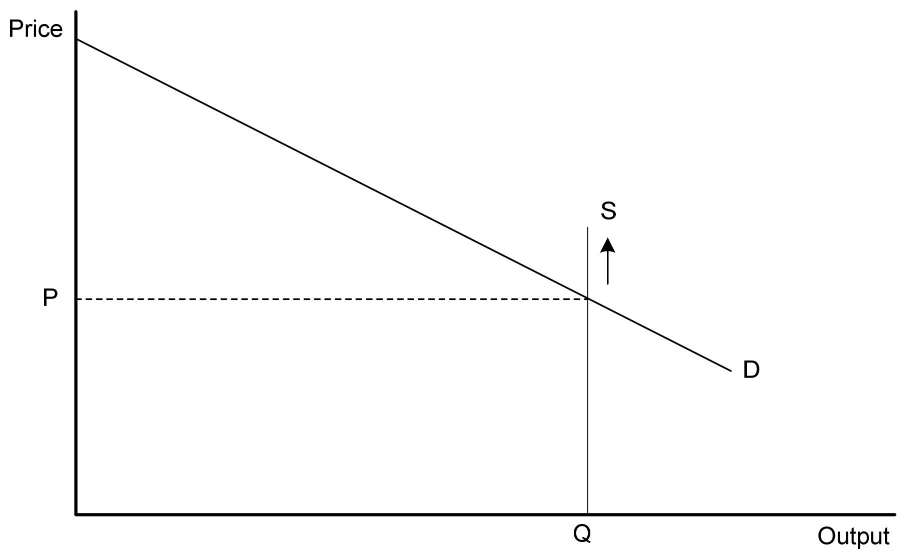


Figure 5-2 Short-Run: All Costs Borne by Producers

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 5-3 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.

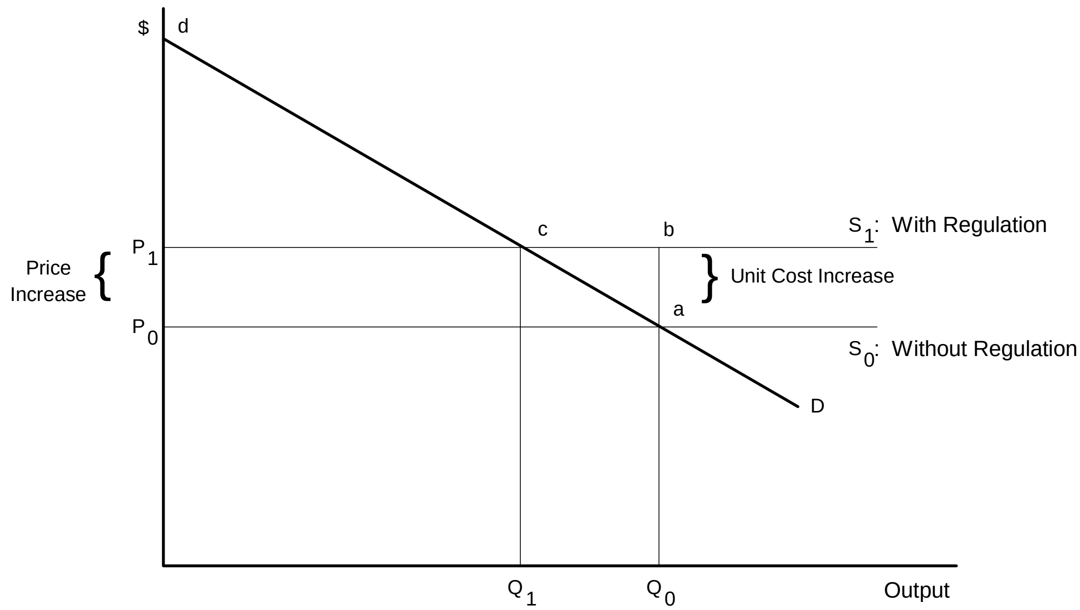


Figure 5-3 Long-Run: Full Cost Pass-Through

Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation's effect on production costs and is illustrated in Figure 5-3. 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.

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 5-4**Error! Reference source not found.**.

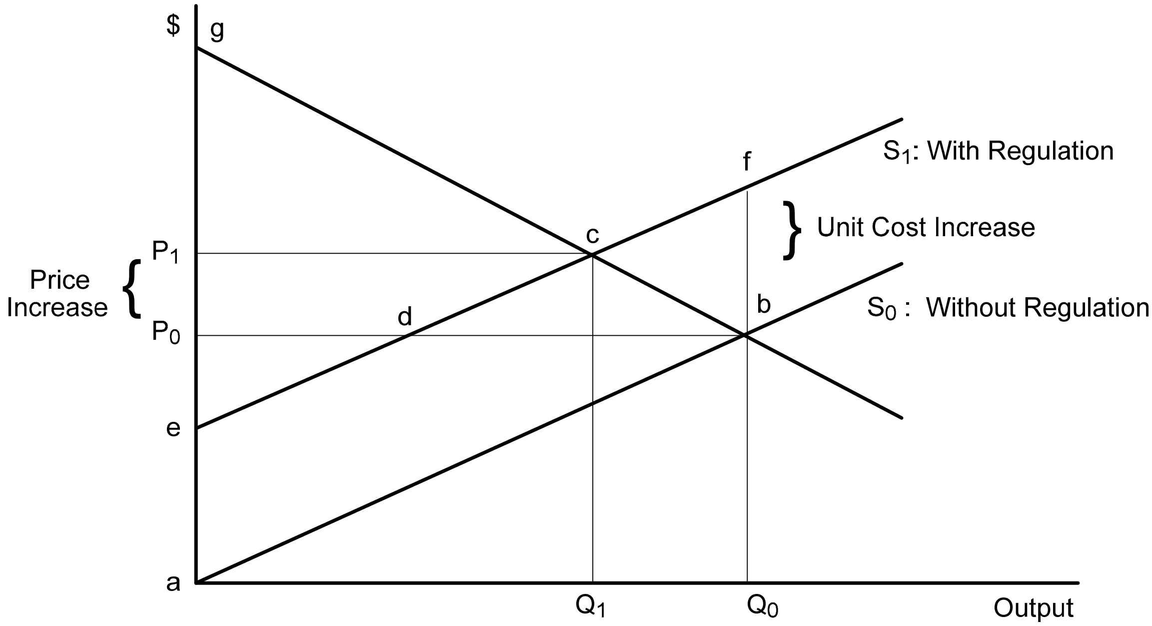


Figure 5-4 Intermediate-Run: Partial-Cost Pass-Through

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.

Economic Impacts of a Control Program – Single Market

A graphical representation of a general economic competitive model of price formation, as shown in Figure 5-5 (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.

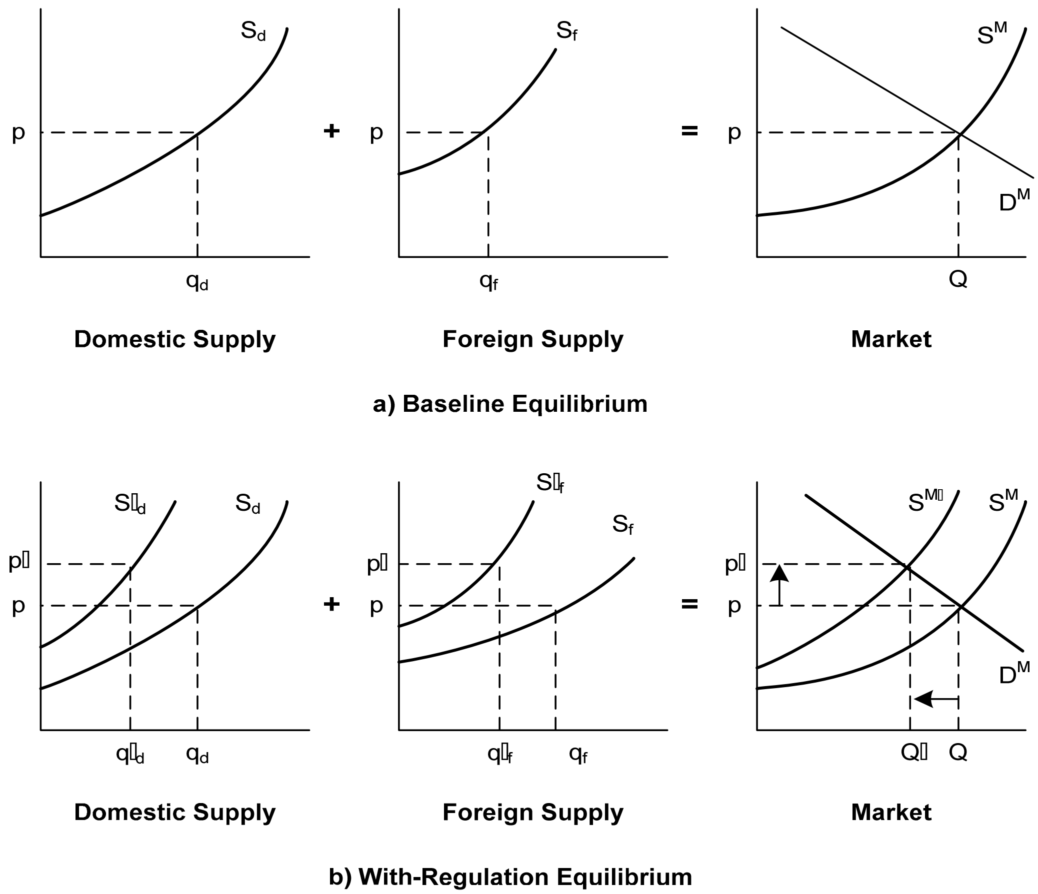


Figure 5-5 Market Equilibrium Without and With Regulation

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 5-5(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 5-5, 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.[B,10] 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.

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 5-6 illustrates how a derived demand curve is identified.

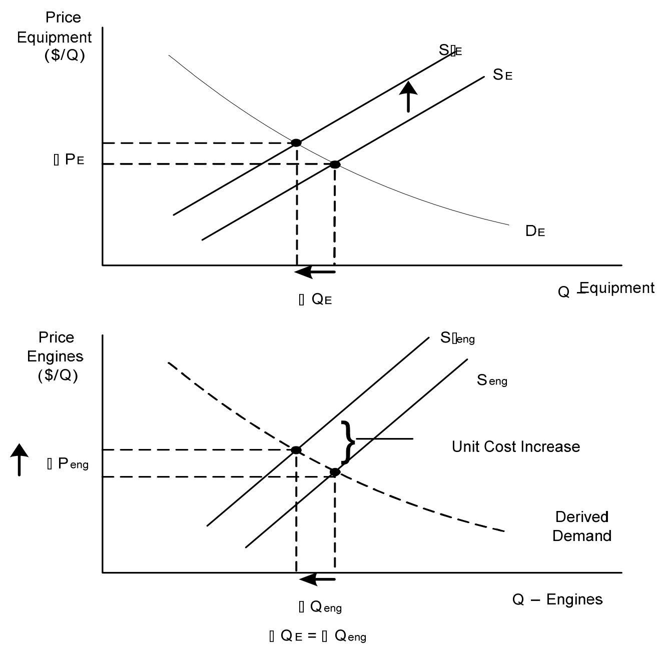


Figure 5-6 Derived-Demand Curve for Engines

[B] An accessible detailed discussion of these concepts can be found in chapters 5-7 of Nicholson's (1998) intermediate microeconomics textbook.

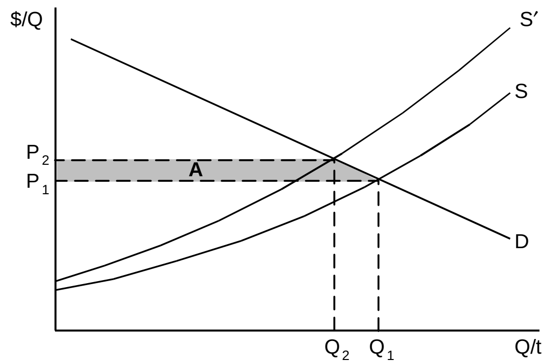
Consider an event in the engine market, such as a new technology requirement, that causes the price of an engine to increase by ΔP_{eng}. This increase in the price of an engine will cause the supply curve in the engine market to shift up, leading to a decreased quantity (ΔQ_{eng}). The change in engine 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.

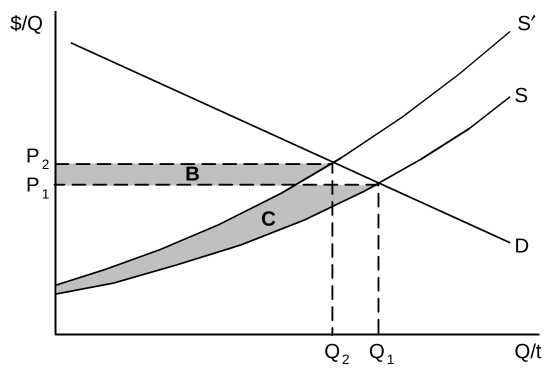
Using Economic Theory to Estimate the Social Costs of a Control Program

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.

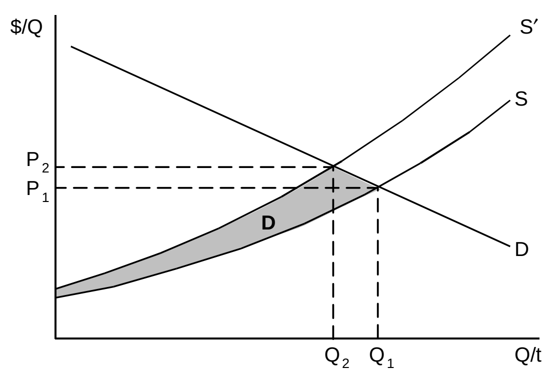
The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 5-7).



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

Figure 5-7 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 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 5-7, 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 5-7(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 5-7(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 5-7(c) shows the net (negative) change in economic welfare associated with the regulation as area D.

How the 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.

The price elasticity of demand is expected to be near perfectly inelastic because 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. As a result, over 90% of the world's traded goods are currently transported by sea.[11] 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.

A nearly perfectly inelastic price elasticity of demand simplifies the analysis described above. Figure 5-8 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.

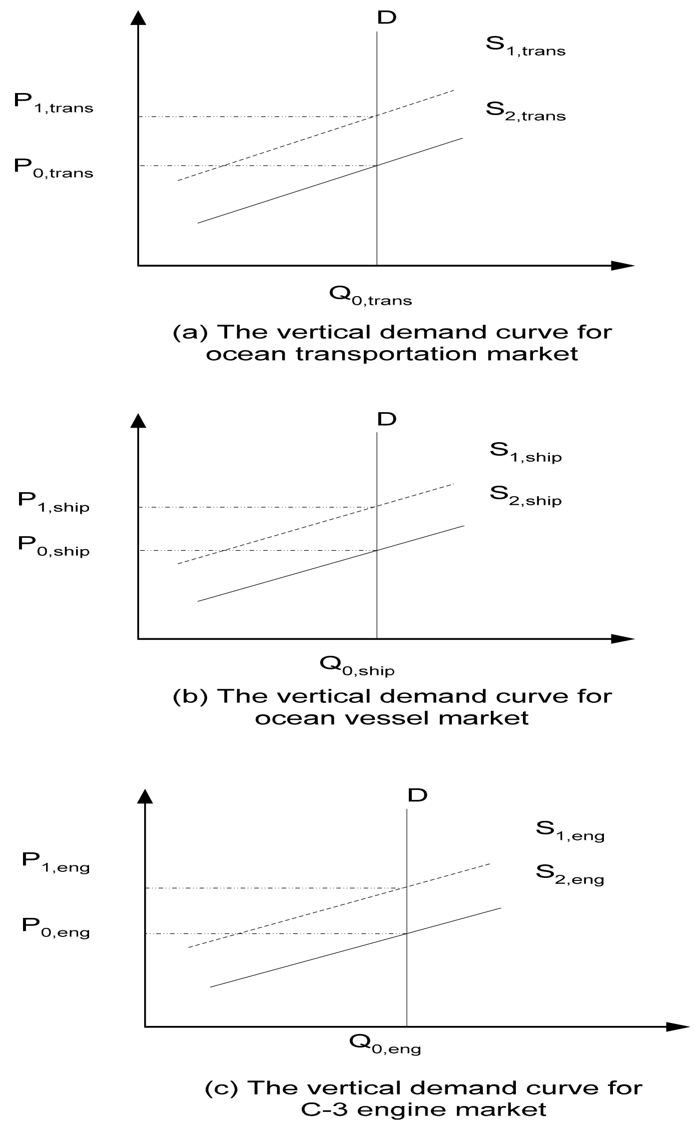


Figure 5-8 Market Impacts in Markets with Nearly Perfectly Inelastic Demand

As indicated in Figure 5-8, 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 5.3.3 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.

APPENDIX 5B

Estimation of Transportation Market Impacts

The U.S. has submitted a proposal to IMO to designate an emission control area in which ships would need to comply with stringent fuel sulfur limits and Tier III NO_X standards. To characterize the increase in vessel operating costs due to the proposed ECA, and therefore the impacts on transportation market prices, calculations were performed for three types of ocean going vessels, including: container, tanker, and cruise liner. Our estimates were developed using typical vessel characteristics, projected fuel and urea costs, and worst case sea-route data. This appendix presents the methodology used for these calculations.

Container and Tanker Vessels

A series of representative container and tanker vessels were derived using data obtained from the Lloyd's of London Sea-Web Database and Army Corps of Engineer (ACE) data.[12,13] The ACE database is composed of port entrances and exits and was used to identify actual ships that have visited the proposed ECA. Lloyd's database was used to identify the characteristics of these ships and to provide information on existing vessels in the world fleet including: vessel size (Gross Tonnes (GT)), main and auxiliary engine power (kilowatt – hour (kW-hr)), number of TEUs or barrels carried, etc. Theoretical routes were developed that these ships could travel based on shipping lane data presented in Chapter 2 of the Technical Support Document. Distances traveled in each route were estimated from either www.nauticaldistance.com or Google Earth. Table 5-5 summarizes the modeled vessel characteristics and route information.

Operating costs include those associated with switching from residual fuel to 0.1% sulfur distillate fuel and urea consumption for vessels equipped with SCR. The fuel and urea costs are based on projections that are presented in the ECA proposal. These fuel cost 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% that of the fuel consumption rate, with a urea price estimate of $1.52/gallon.

To develop representative cruise ship routes for our price estimations, we looked at Army Corps of Engineer data to find the actual makeup of the fleet of cruise ships that have visited Puerto Rico and the U.S. Virgin Islands, from there we researched the actual routes these vessels take and used these routes to develop hypothetical routes. We also used the characteristics of these actual vessels obtained from Lloyd's Sea-Web Database to develop representative ship configurations and numbers of passengers aboard.[14]

Baseline Operating Costs

In order to estimate the increase in the cost to operate over select routes, we needed to establish the fuel usage and costs 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 on cargo vessels and tankers. Baseline estimations of the fuel used for the routes and ships were determined by multiplying the engine power of the average sized containership (in kilowatts (kW)) by the average estimated engine efficiency, and the appropriate brake-specific fuel consumption (BSFC) value consistent with the inventory analysis in Chapter 2 of this document (see Equation 5B-1 below). This value was then multiplied by the distance of the trip, and divided by the average vessel speed to find the total fuel consumed over the trip, see Equation 5B-2. As average values are represented here, it is possible that these values could vary slightly from actual measured values depending on a vessel's speed, engine efficiency, and specific fuel consumption, but we believe that these estimates provide a reasonable forecast of container vessels in operation today with similar characteristics as those modeled here.

Equation 5B-1

$$Engine\_Power(kW) \times Engine\_Efficiency \times BSFC(g_{resid}/kW\text{-}hr) = Fuel\_Consumption\_Rate(g_{resid}/hr)$$

Equation 5B-2

$$Fuel\_Consumption\_Rate(g_{resid}/hr) * \frac{Distance(nm)}{Vessel\_Speed(knots/hr)} \times \frac{tonne}{1{,}000{,}000g} = Fuel\_Consumed(tonne_{resid})$$

Total fuel usage for each leg of the trip was multiplied by the price of the fuel in 2006 U.S. dollars per tonne ($/tonne) which provides the baseline cost of fuel for each leg. These costs were then summed to produce an aggregate estimation of fuel cost for the entire trip. This analysis shows a per trip fuel cost of nearly $15,000 for a small container ship traveling a direct route between Miami, Fl and San Juan Puerto Rico. This analysis also shows a per trip fuel cost of over $1.4 million for a large container ship traveling between Singapore and San Juan Puerto Rico.

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 of the ECA. In addition, the ECA is assumed to have no impact on the route travelled for vessels visiting the proposed ECA.

Increased Fuel Costs

To determine the estimated fuel usage and increase in fuel costs incurred as a result of the proposed ECA for representative vessels traveling their respective theoretical routes, we used the same methodology as in our baseline analysis with the appropriate distillate fuel properties. Since distillate fuel will most likely only be used in the proposed ECA, the remainder of the trip is assumed to continue to operate using residual fuel which is reflected in this analysis. Equation 5B-3 provides the approximation of the amount of distillate fuel used per hour given a ship's engine power and fuel consumption. 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 5B-3. Equation 5B-2 was then used to estimate the actual tonnes of distillate fuel used.

Equation 5B-3

$$Engine\_Power(kW) \times Engine\_Efficiency \times \frac{BSFC(g_{distil}/kW-hr)}{1-0.05} = Fuel\_Consumption\_Rate(g_{distil}/hr)$$

Urea Costs

Switching to a distillate marine fuel will achieve reductions only in sulfur and particulate emissions. In order to meet the required Tier III Nitrogen Oxides (NO_X) emission reductions, new vessels built as of 2016 may be equipped with SCR.[C] Using an SCR system requires dosing exhaust gases with urea, which adds some additional costs to the operation of the vessel. Urea consumption for vessels equipped with SCR is expected to be 7.5 percent of the fuel consumption. The urea operational costs are based on a price of $1.52 per gallon with a density of 1.09 g/cc. The cost per gallon was estimated for a 32.5 percent urea solution delivered in bulk to the ship through research completed by ICF International for the U.S. Government, combined with historical urea price information.[15,16,17,18,19] The estimated cost of using urea is based on an estimated dosing rate of seven and a half percent (7.5%) per gallon of distillate fuel used. Subsequently, to estimate the volume of urea required for our routes, we multiplied the distillate quantity determined above by the estimated urea consumption value. As we expect these costs to be incurred several years in the future, we used the analysis performed for the EPA by EnSys which predicted that in 2020, 33.2% of the fuel used in ECAs will be on vessels equipped SCR.[20]

Total Increase in Operating Costs

To estimate the total increase in the operating costs of a vessel incurred while operating in the proposed ECA, we then multiplied the fuel and urea quantities used by their corresponding prices ($322.48/tonne for residual, $467.92/tonne for distillate, and $1.52/gal for the urea). In order to estimate how the increase in operational costs may affect the price per TEU, we divided the increase in cost by the number of TEUs each representative ship would carry (or in the case of a Tanker Vessel – the number of barrels of oil).

Cruise Ship

We also conducted an analysis to determine the estimated increase in operating costs for different cruise ships that may visit the proposed ECA. To conduct this analysis, we used ship

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[C] 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 distillate fuel. Therefore we are only estimating the cost of compliance using distillate fuel here as we believe this is the most likely approach.

characteristics and route data from actual vessels that travel to Puerto Rico and the U.S. Virgin Islands. Three cruise ship vessels were developed with representative vessel characteristics including: engine power, GT, number of passengers, vessel speed, and fuel consumption rates. A separate hypothetical route was developed for each representative ship type. A hypothetical route that a small cruise ship may take was developed based on actual routes and ports visited by cruise ships today. [14] The itinerary includes: San Juan, Puerto Rico; St. John U.S.V.I.; Basseterre, St. Kitts; Pointe-A-Pitre, Guadeloupe; Fort-de-France, Martinqiuqe; St. Georges, Grenada; Bridgetown, Barbados; St. John's, Antigua; Frederiksted, St. Croix U.S. V.I.; San Juan, Puerto Rico, and an example is shown in Figure 5-9 below.

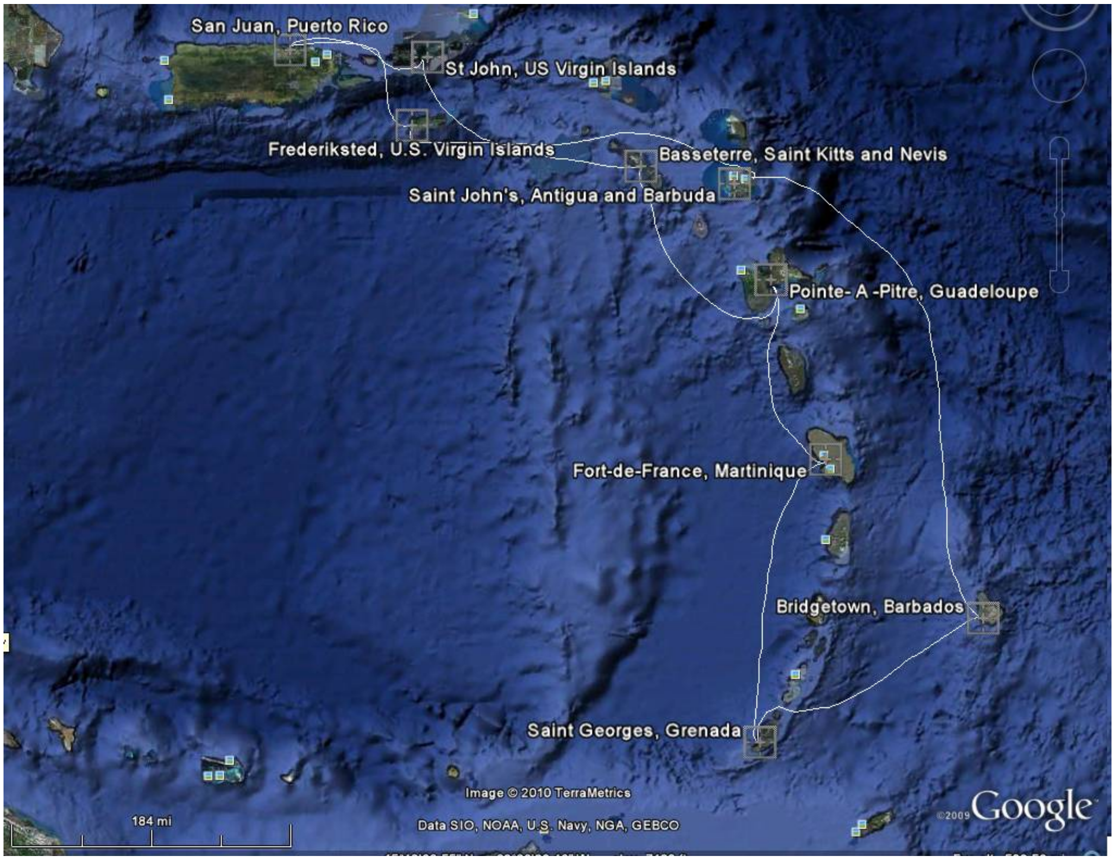

Figure 5-9 Hypothetical Route Developed for a Small Cruise Ship

The hypothetical route that a medium sized cruise ship may take was also based on actual routes and ports visited by cruise ships today. [14] The route was developed to model a nearly direct trip between Puerto Rico and Florida and includes the following stops: Fort Lauderdale, Florida; San Juan, Puerto Rico; Matthew Town, Bahamas, Fort Lauderdale, FL; an example is shown below in Figure 5-10.

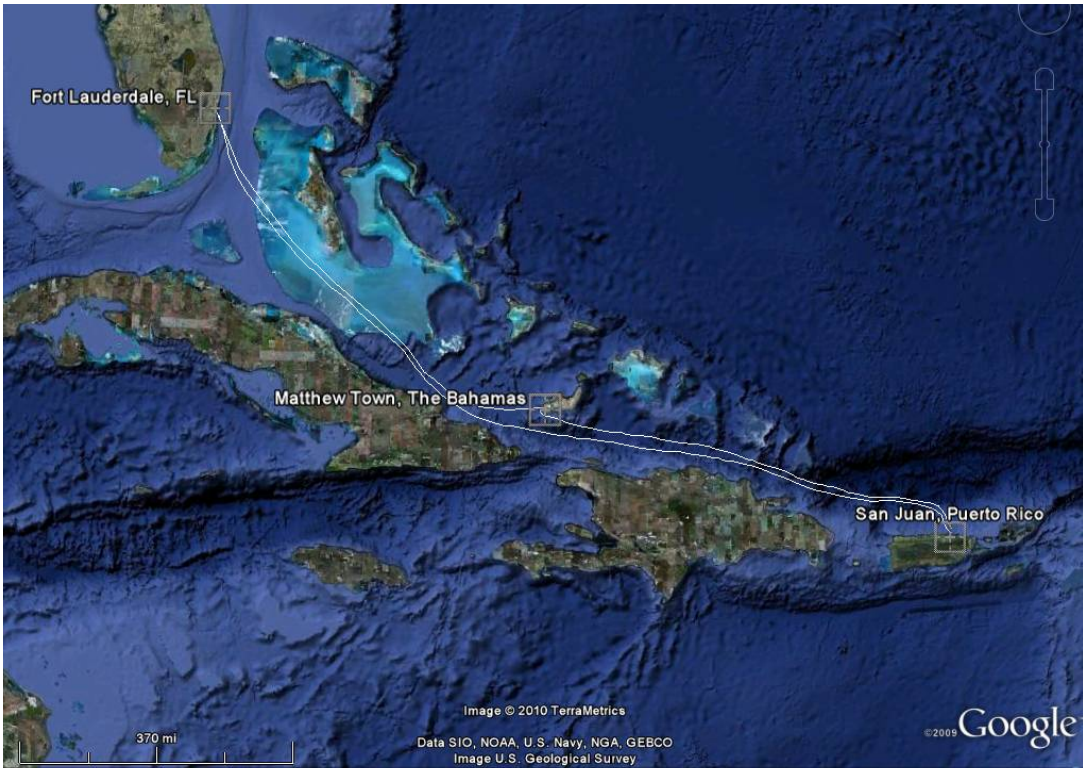

Figure 5-10 Hypothetical Route Developed for a Medium Sized Cruise Ship

A hypothetical route that a large cruise ship may take was developed based on actual routes and ports visited by cruise ships today.[14] This route was developed to represent a long cruise taken from the East Coast of the U.S. throughout the Caribbean. The itinerary includes: New York, NY; Turk Islands; San Juan, Puerto Rico; St. Thomas, U.S.V.I.; Fort-de-France, Martinique; St. Georges, Grenada; Oranjestad, Aruba; Ocho Rios, Jamaica; Cozumel, Mexico; Key West, Florida; New York, New York and an example is shown in Figure 5-11 below.

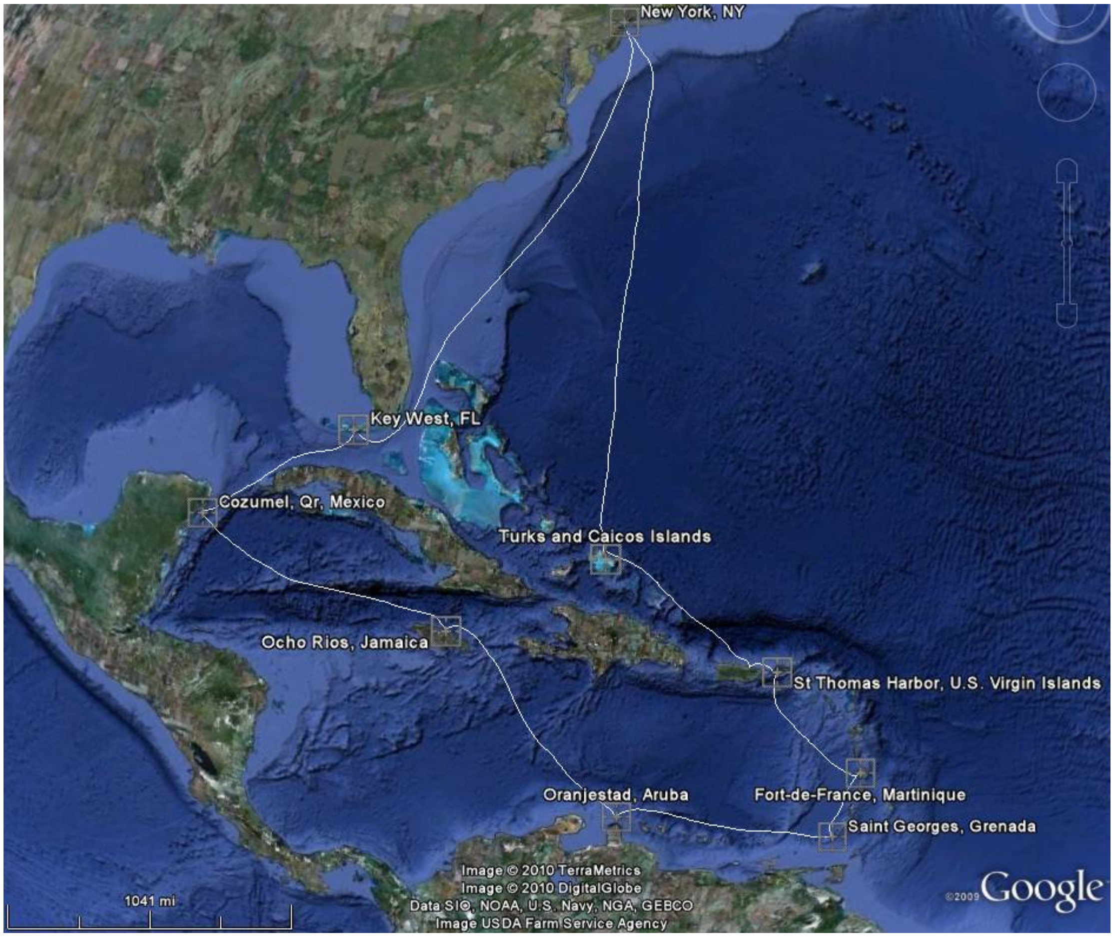

Figure 5-11 Hypothetical Route Developed for a Large Cruise Ship

In order to estimate the amount of fuel used during these hypothetical routes, the mileage during each leg of the journey was estimated, and used in conjunction with average main and auxiliary engine power, average cruise speeds, and brake specific fuel consumption. The average cruise speed for each representative ship was derived from data on similar sized vessels that visit the Caribbean. The brake specific fuel consumption values used were from the inventory chapter of this document (Chapter 2) where 195 g/kW-hr was used for large slow-speed diesel engines such as those found in large cruise ships, and 210 g/kW-hr was used for medium-speed diesels found in the small and medium sized cruise ships and also used for all auxiliary engines. The required power estimation used here was developed for the "2005-2006 BC Ocean-Going Vessel Emissions Inventory" and was shared with several cruise ship operators for their input and validation.[21] 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 are presumably operated independently of the vessel's main diesel-electric power generation, and are assumed to operate at an average of 50% power for the entire voyage.

Table 5-8 Representative Cruise Ship Characteristics

VESSEL TYPE	ROUTE	MAIN ENGINE POWER	Auxiliary Engine Power	Gross Tonnage	Vessel Maximum Speed (knots)	Number of Passengers
Small Cruise Ship	San Juan, Puerto Rico; St. John U.S.V.I.; Basseterre, St. Kitts; Pointe-A-Pitre, Guadeloupe; Fort-de-France, Martinqiuqe; St. Georges, Grenada; Bridgetown, Barbados; St. John's, Antigua; Frederiksted, St. Croix U.S. V.I.; San Juan, Puerto Rico.	22,000 kW	4,100 kW	32,000	22	800
Medium Cruise Ship	Fort Lauderdale, Florida; San Juan, Puerto Rico; Matthew Town, Bahamas, Fort Lauderdale, FL.	53,000 kW	1,500 kW	80,000	23	2,000
Large Cruise Ship	New York, NY; Turk Islands; San Juan, Puerto Rico; St. Thomas, U.S.V.I.; Fort-de-France, Martinique; St. Georges, Grenada; Oranjestad, Aruba; Ocho Rios, Jamaica; Cozumel, Mexico; Key West, Florida; New York, New York.	72,000 kW	2,000 kW	120,000	24	3,000

The methodology used above to estimate fuel and urea costs (see Equation 5B-1 through 5B-3) were also used here. Additionally, the operational cost increases for the fuel used by auxiliary engines were estimated as well as the cost increases incurred as a result of dosing the engine exhaust with urea using the same methodology as for main propulsion engines. The total estimated price increase for the cruise was divided by the length of the cruise to estimate the increased cost per day.

To put the estimated price increases in perspective, we also developed the percent increase for the various stateroom types available on the vessel. The estimated stateroom prices used for the different hypothetical cruises are shown in Table 5-9.

Table 5-9 Representative Cruise Liner Stateroom Prices and Estimated Increase in Prices

CRUISE SHIP TYPE	STATEROOM TYPE	ORIGINAL AVERAGE PRICE PER NIGHT ($)	PERCENTAGE INCREASE
Large Cruise Ship	Interior	$100	0.4%
	Ocean View	$130	0.3%
	Balcony	$150	0.2%
	Suite	$220	0.2%
Medium Cruise Ship	Interior	$100	0.6%
	Ocean View	$140	0.4%
	Balcony	$200	0.3%
	Suite	$240	0.3%
Small Cruise Ship	Interior	$200	0.6%
	Ocean View	$230	0.6%
	Balcony	$290	0.4%
	Suite	$450	0.3%

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[2] Stopford, Martin. Maritime Economics, 3rd Edition. Routledge, 2009. p. 163.

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