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Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level

Final Report

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Prepared for

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Executive Summary

The U.S. economy is dependent on an efficient and reliable freight transportation system. Our highways, ports, waterways, railways, airports, and intermodal facilities make up a complex system that shippers rely on to move products to markets. The performance of that system has direct implications for the productivity of the U.S. and regional economies, the costs of goods and services, and the global competitiveness of our industries. Yet, there is significant and growing concern on the part of both the private and public sectors about the future performance of our freight transportation system. Demand for freight transportation has been rising steadily and forecasts show continued growth over at least the next several decades, while expansion of freight system capacity has been relatively limited.

Prompted by these trends, federal, state, and local agencies are undertaking a variety of initiatives to ensure that the performance of the nation's freight system does not significantly deteriorate. These initiatives include new efforts to fund freight system improvements and efforts to mainstream freight into the transportation planning and programming process. As freight becomes more integrated with overall transportation decision making, there is greater need to consider the air quality impacts of freight at all stages of planning and project development.

Over the last two decades, freight has become a more significant source of air pollution. One reason for this is the robust growth in freight activity, particularly trucking, intermodal rail, foreign waterborne shipments, and air cargo. The other factor is the relatively less stringent regulation on emissions from the freight sector, particularly emissions from locomotives and marine vessels.

At the same time that freight transportation is growing in its contribution to air pollution, there is a heightened concern about the health and environmental effects of diesel engine emissions. Most freight trucks, locomotives, and ships are powered by diesel engines, which are a major source of emissions of nitrogen oxides (NOx) and particulate matter (PM). Freight transportation is also a large and growing source of greenhouse gas (GHG) emissions that contribute to global climate change. These concerns, and the implementation of the 8-hour ozone and fine particulate (PM-2.5) standards, will require many regions across the country to find new ways to control NOx and PM emissions from freight transportation sources.

This study is intended to help fill a void in the current understanding of the air quality impacts of freight transportation. This report discusses freight transportation activity and emissions at the national level and in six metropolitan areas (Baltimore, Chicago, Dallas-Fort Worth, Detroit, Houston, and Los Angeles). The report draws on a variety of existing studies and data sources and develops new emissions estimates to fill data gaps.

Summary of National Freight Transportation Emissions

This study shows that freight is a major source of national NOx and PM-10 emissions. As illustrated in Table ES-1, freight transportation accounts for approximately half of mobile source NOx emissions and 27 percent of all NOx emissions at the national level. Freight transportation accounts for 36 percent of U.S. mobile source PM-10 emissions and less than 1 percent of all U.S. PM-10 emissions. (The vast majority of PM-10 emissions comes from agricultural fields, wildfires, and fugitive dust.)

Heavy-duty vehicles (trucks) are by far the largest contributor to freight emissions nationally, producing two-thirds of the NOx and PM-10 from the freight sector. Marine vessels are the next largest source, accounting for 18 percent of freight NOx emissions and 24 percent of freight PM-10 emissions, followed by railroads at 15 percent of NOx and 12 percent of PM-10. Air freight accounts for only 0.1 to 0.2 percent of total freight emissions of NOx and PM-10, respectively.

Table ES-1: U.S. Freight Transportation NOx and PM-10 Emissions by Mode, 2002

	NOx Emissions				PM-10 Emissions			
			As percent of:				As percent of:	
Mode	Tons	Percent	All Mobile Sources	All Sources	Tons	Percent	All Mobile Sources	All Sources
Heavy-duty Vehicles	3,782,000	66.8%	33.0%	17.9%	120,000	64.7%	23.3%	0.5%
Freight Railroads	857,200	15.1%	7.5%	4.1%	21,300	11.5%	4.1%	0.1%
Marine Vessels	1,011,000	17.9%	8.8%	4.8%	44,000	23.7%	8.5%	0.2%
Air Freight	8,200	0.1%	0.1%	0.0%	300	0.2%	0.1%	0.0%
Total	5,658,400	100%	49.4%	26.8%	185,600	100%	36.0%	0.8%

Source: U.S. EPA, National Emission Inventory; total mobile source emissions and total emissions obtained from state air quality agencies. Freight railroad emissions estimated as 96.4% of total railroad NOx emissions and 96.7% of total railroad PM-10 emissions, based on passenger locomotive fraction in U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document,* April 1998; Air freight emissions estimated as 10.1% of total aircraft emissions, based on air estimated aircraft departures attributable to air freight, as described in report text.

The strict new EPA emission standards for heavy-duty trucks and off-road equipment (such as port cargo handling equipment) will dramatically reduce NOx and PM emissions from these sources starting in 2007. Similar strict standards are expected to be adopted for locomotives and U.S.-flagged commercial marine vessels, but slow fleet turnover means that the full impact of these standards will not be felt for several decades. As a result of the EPA standards, emissions from freight transportation are generally expected to decline over the next several decades, although emissions from some modes will decline more rapidly than others. By 2020, the commercial marine and rail sectors will account for a much larger share of freight NOx and PM-10 emissions than they do currently.

Summary of Regional Freight Transportation Emissions

Freight is also a major source of NOx and PM-10 emissions at the regional level. Among the six regions included in this study, emissions are greatest in magnitude in Los Angeles, followed by Chicago and Detroit. Trucking dominates urban freight movement and related emissions. Heavy-duty trucks are responsible for more than three-quarters of freight emissions in all six regions, as shown in Table ES-2. In Detroit and Dallas-Fort Worth, trucking accounts for virtually all freight emissions – 97 percent of the freight total in Detroit and 93 percent in Dallas-Fort Worth.

The six regions show considerable diversity in terms of freight emissions from other modes. Freight rail NOx emissions in Chicago are nearly twice that in any other region and make up almost 20 percent of Chicago’s total freight emissions. In the other five regions, freight rail accounts for less than 10 percent of the total. Marine freight NOx emissions are greatest in the Los Angeles region, where they account for 14 percent of the freight total, and in Houston, where they account for 17 percent of the total. Air freight emissions are dwarfed by the other modes in all six regions. Air freight NOx emissions are greatest in the Los Angeles region, making up 0.5 percent of the region’s freight total.

Table ES-2: Regional NOx Emissions from Freight by Mode, 2002

	Trucking		Freight Rail		Marine Freight		Air Freight		Freight Total	
Region	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%
Baltimore	29,081	83%	2,655	8%	3,315	9%	26	0.1%	35,078	100%
Chicago	96,291	79%	23,212	19%	2,199	2%	462	0.4%	122,164	100%
Dallas-Ft. Worth	53,718	93%	4,157	7%	0	0%	155	0.3%	58,030	100%
Detroit	98,195	97%	2,106	2%	468	0%	40	0.0%	100,809	100%
Houston	64,590	77%	5,163	6%	14,351	17%	85	0.1%	84,189	100%
Los Angeles	130,341	78%	12,744	8%	22,610	14%	870	0.5%	166,564	100%

Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies, MPOs, and ports; see report text for details.

Freight transportation also contributes significantly to regional PM-10 emissions. Trucking is still the largest contributor, although less dominant than with NOx emissions. Marine freight accounts for a major portion of freight PM-10 emissions in regions with large seaports – 40 percent of the total in Houston, 37 percent in Los Angeles, and 19 percent in Baltimore, as shown in Table ES-3. This contribution in part reflects the high PM emission rates of large marine vessels that burn residual fuel and have little or no emission controls.

Table ES-3: Regional PM-10 Emissions from Freight by Mode, 2002

	Trucking		Freight Rail		Marine Freight		Air Freight		Freight Total	
Region	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%
Baltimore	734	74%	71	7%	190	19%	1	0.1%	996	100%
Chicago	2,641	73%	792	22%	173	5%	10	0.3%	3,616	100%
Dallas-Ft. Worth	884	88%	113	11%	0	0%	4	0.4%	1,002	100%
Detroit	2,382	96%	58	2%	27	1%	2	0.1%	2,469	100%
Houston	1,256	54%	141	6%	915	40%	2	0.1%	2,314	100%
Los Angeles	2,210	54%	346	8%	1,521	37%	14	0.3%	4,091	100%

Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies, MPOs, and ports; see report text for details.

In the six study regions, total freight emissions account for 40 to 52 percent of all mobile source NOx emissions and 29 to 39 percent of all NOx emissions, as shown in Table ES-4. These regional percentages are significantly higher than the national freight share of NOx emissions (26.8 percent).

Freight accounts for 22 to 47 percent of PM-10 emissions from mobile sources in the study regions. Compared to emissions from all sources, freight accounts for 1.0 to 5.8 percent of regional PM-10 emissions. Again, this is higher than the national freight share (0.8 percent). Freight accounts for the largest share of total PM-10 emissions in the Chicago region, which likely reflects the intensive railroad activity there. Note, however, that the vast majority of PM-10 emissions come from agricultural fields, wildfires, and fugitive dust. The total PM-10 emissions in the six regions, and the portions attributable to freight, therefore, depend heavily on the amount of undeveloped land within the nonattainment boundaries. Note also that the PM emissions from combustion sources like diesel engines are a greater health concern than the coarse particulates from sources like fugitive road dust. Current emission inventories do not provide an accurate estimate of fine particulates, so it is difficult to assess the freight sector contribution to these emissions.

Table ES-4: Total Regional NOx and PM-10 Emissions from Freight, 2002

	NOx Emissions from Freight			PM-10 Emissions from Freight		
		As a percent of:			As a percent of:	
Region	Tons	All Mobile Sources	All Sources	Tons	All Mobile Sources	All Sources
Baltimore	35,078	N/A	N/A	996	N/A	N/A
Chicago	122,164	50.6%	34.1%	3,616	39.9%	5.8%
Dallas-Ft. Worth	58,030	40.5%	34.9%	1,002	22.3%	1.0%
Detroit	100,809	51.2%	30.8%	2,469	41.5%	2.2%
Houston	84,189	52.1%	28.9%	2,314	47.2%	1.7%
Los Angeles	166,564	43.4%	39.1%	4,091	26.9%	1.8%

Note: total emissions data were not available for Baltimore.
Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies, MPOs, and ports; see report text for details.

Mitigation Strategies

Strategies to reduce emissions from freight transportation can be grouped in two major categories:

- *Technological strategies*, which modify a piece of equipment or its fuel to reduce emissions, and
- *Operational strategies*, which change the way a piece of equipment is used, resulting in lower emissions.

Technological strategies focused on pollutant emission reductions are often summarized as the “Five Rs” – Retrofit, Repower, Refuel (with alternative fuels), Replace, and Repair/Rebuild. A retrofit typically involves the addition of an after-treatment device to remove emissions from the engine exhaust. Repowering involves replacing an existing engine with a new engine. Alternative fuels include those that require little or no modification to the engine (such as emulsified diesel or biodiesel) and those that require engine conversion or replacement (such as natural gas). Replacement involves retiring older, higher polluting equipment from service to be replaced with newer equipment that meets more stringent emission standards. Repairing and rebuilding offer the opportunity to reduce freight emissions during regular engine service intervals through routine maintenance or major engine overhauls.

In addition to the “Five Rs” strategies described above, technological strategies that improve fuel economy typically have the added benefit of reducing emissions. Table ES-5 lists some examples of technological options for improving the fuel efficiency of trucks, locomotives, ships, and aircraft.

Table ES-5: Technological Strategies for Improving Freight Fuel Efficiency

Trucking	Rail	Marine	Air
Fuel efficient lubricants	Tare weight reduction	Larger vessels	Aerodynamic improvements
Tare weight reduction	Low-friction bearings	Improved hull design	Lighter weight materials
Aerodynamic improvements	Steerable rail car trucks		More efficient engines
Reduced tire rolling resistance	Improved track lubricants		

Operational strategies change the way that trucks, locomotives, ships, and aircraft operate, resulting in fewer pollutant emissions. Many of these strategies, though not all, reduce fuel use and result in lower operating costs for the equipment owner. Table ES-6 summarizes some operational strategies that can reduce emissions from freight transportation.

Table ES-6: Operational Strategies for Reducing Freight Fuel Use and Emissions

Trucking	Rail	Marine	Air
Reduced overnight idling	Reduced switchyard idling	Cold ironing (electrification)	Increased load factors
Reduced pick-up/drop-off idling	Reduced line haul speeds	Reduced port equipment idling	Reduced vertical separation minimums
Port access improvements	Reduced empty mileage	Reduced hotelling time	Reduced use of aircraft APUs
Reduced highway speeds	Double tracking	Reduced vessel speeds	Improved runway efficiency
Arterial signal synchronization	Train clearance improvement	Use of larger ships	Use of continuous descent approach
Grade crossing separation	Elimination of circuitous routings	Hull cleaning	Electrification of ground support equipment
Driver training			
Reduced empty mileage			

Reducing idling is one of the most promising opportunities to reduce freight emissions. For trucks, overnight idling can be reduced through the use of auxiliary power units (APUs) or truck stop electrification, as well as driver training and incentive programs. Switch yard locomotives can be installed with APUs or automatic shut-down devices to limit freight rail idling. Ships can minimize the use of diesel-powered auxiliary engines while in port through “cold ironing,” which involves retrofitting ocean-going vessels to allow them to receive shore power to meet their energy needs while docked. For aircraft, providing electricity and air conditioning to aircraft directly at the gates reduces the need for aircraft APUs and decreases emissions.

Recommendations for Further Research

In order to more comprehensively consider the emissions effects of freight transportation in the planning and project development process, additional research is needed in a number of areas. In particular, there are some significant shortcomings in the current practices for estimating regional freight emissions:

- The process for estimating regional truck emissions typically ignores long-term truck idling.

- Regional truck activity is usually estimated through a process that does not fully account for differences between passenger vehicle and truck behavior.
- The standard approach for calculating freight railroad emissions is simplistic and potentially subject to significant errors.
- In the case of many ports, the process for estimating marine vessel emissions is very simplistic and subject to error.
- Most regions have not developed emission inventories for port cargo handling equipment, which prevents an accurate assessment of mitigation strategies focused on these sources.
- The standard model used for estimating airport emissions cannot currently be used to estimate aircraft PM emissions.
- The emission factors and methodologies for estimating emissions of fine particulates and toxic air contaminants are less robust than for other criteria pollutants.

The other major area for improvement is the understanding of the effects of operational strategies on emissions. Assessing the effect of operational strategies can be difficult because it often requires modeling the performance of an integrated transportation system. A more complete understanding of these effects is needed to support public agencies that are considering investments to improve freight operating efficiency in the name of reducing emissions. Some specific areas for research include:

- The effects of changes in roadway congestion on emissions are sometimes unclear or are not properly captured in the tools for estimating emissions. Generally, congested roadway conditions increase emissions because they cause idling and more frequent short bursts of acceleration. But, because emission rates increase with average speed in the MOBILE model, congestion can sometimes result in lower modeled emissions on certain roadway segments. There is a need to better understand how highway improvements that reduce congestion affect emissions.
- In freight systems that are highly integrated, such as railroads or aviation, the emissions effects of congestion are often difficult to assess. Congestion in one location can cause delays to ripple throughout the system, so an increase in emissions might occur far from the bottleneck that triggered it. Research is needed to better understand how changes in freight congestion affect emissions under these conditions.
- There is often a poor understanding of the extent of idling, particularly the extent of idling that can be eliminated through control strategies. More research is needed to assess how operational and technology-oriented strategies can be applied most effectively to reduce idling associated with freight movement.
- There is little information on the emissions effects of strategies such as better logistics practices, which can improve the productivity of freight movement, resulting in less fuel consumption and emissions per ton-mile.

Public agencies must continue to better integrate freight into the transportation and air quality planning processes and improve their understanding of the linkages between freight transportation and air quality. Through a more integrated approach to planning and better knowledge about freight emissions impacts, agencies can help to ensure the continued efficiency and reliability of the freight system while, at the same time, supporting societal goals related to public health and the environment.

1 Introduction

The U.S. economy is dependent on an efficient and reliable freight transportation system. Our highways, ports, waterways, railways, airports, and intermodal facilities make up a complex system that shippers rely on to move products to markets. The performance of that system has direct implications for the productivity of the U.S. and regional economies, the costs of goods and services, and the global competitiveness of our industries. Yet, there is significant and growing concern on the part of both the private and public sectors about the future performance of our freight transportation system. Consider the following trends:

- Growth in highway travel, and truck travel in particular, has far outpaced highway capacity additions over the last two decades. While the extent of the nation's roadway system is impressive, highway lane miles increased by only 3 percent between 1983 and 2003. During this period, passenger VMT grew by 73 percent and truck VMT grew by 86 percent.[1] This has contributed to a significant increase in roadway congestion. According to the Texas Transportation Institute's *Urban Mobility Study*, peak period delay per traveler has tripled since 1982 in the nation's 85 largest urban areas.

- Utilization of railroad track infrastructure has increased substantially in recent years, leading to significant bottlenecks in some cases. Before deregulation and the Staggers Rail Act of 1980, the rail industry was widely considered to have significant levels of excess capacity. From 1980 to 2003, however, Class I railroads consolidated from 22 carriers to seven (four of which have 96 percent of Class I revenue), and the amount of Class I rail line contracted substantially, from 271,000 to 169,000 miles, a decrease of 38 percent. During that period, Class I freight ton-miles grew by 69 percent.[2] A recent forecast by the American Association of State Highway and Transportation Officials (AASHTO) for the rail industry suggests that, absent significant new investment, the rail industry will not be able to handle the proportion of goods movements that it carries today, although the absolute level of freight carried by the railroads will continue to increase.[3] According to the AASHTO study, the rail industry is likely to lose market share to trucking, adding 15 billion truck VMT to the nation's highways.

- Globalization and growth in international trade are placing more demands on our seaports. Between 1970 and 1999, international trade's share of GDP increased from 10.7 percent to 26.9 percent. As a result, our nation's ports and channels are becoming increasingly congested as ever greater amounts of freight are moved through a system with limited means for physical capacity expansion. From 1990 to 2003, tonnage at U.S. ports increased by 11 percent, and waterborne import tonnage grew by 67 percent.[4] Container movements at some of the nation's largest ports are growing at an even faster pace. For example, container traffic through the Port of Los Angeles has nearly doubled in just the last five years.[5]

- Landside access is a problem of increasing importance to our ports and is becoming one of the primary bottlenecks for the movement of goods from ships to the rest of the transportation system. Once ships arrive at a port it makes little difference how productive the rest of the port is if goods cannot be unloaded efficiently. In 2001, several of the top 15 U.S. deepwater ports reported unacceptable flow conditions on landside elements of the intermodal access system.[6] Compounding this problem is the fact that many ports do not have sufficient room to expand landside access nor do they have the funds required to maintain this additional capacity if it were acquired.

- The U.S. inland waterways are an important but aging component of the nation's transportation system. These waterways transport approximately 20 percent of the nation's coal and 60 percent of the nation's grain movements. Investment in the infrastructure (e.g., locks) required to support these waterways has not been adequate to maintain the system. In 1997, the U.S. Army Corps of Engineers reported that the median age of all lock chambers was 35 years. This survey also concluded that lock-specific delays have been increasing throughout the inland waterway system, and that delays averaged around six hours at the most congested locks and sometimes much longer.

- Air freight is by far the fastest growing mode of freight transportation. Domestic air cargo ton-miles increased by more than 5 percent annually between 1980 and 2003.[7] Available forecasts predict air freight will continue to grow at rates of 4.0 percent to 5.2 percent through 2020. Growth at these rates will put considerable strain on an aviation system already characterized by frequent delays, traffic control safety concerns, and heightened security measures. To date, however, this growth in air freight has yet to severely constrain the system as a whole, although certain hubs are beginning to experience chronic problems. In the first eight months of 2004, for example, more than 30 percent of arrivals and departures at Chicago O'Hare were delayed in excess of 15 minutes or cancelled.[8]

Prompted by these trends, federal, state, and local agencies are undertaking a variety of initiatives to ensure that the performance of the nation's freight system does not significantly deteriorate. For example, government agencies are exploring a variety of opportunities to fund freight system improvements, including expanded use of discretionary surface transportation funds, new public-private partnerships, and development of new sources of revenue for freight projects. Metropolitan Planning Organizations (MPOs) and state Departments of Transportation (DOTs) are working to mainstream freight into the transportation planning and programming process. Integration efforts include greater involvement of freight stakeholders throughout the planning process, application of project selection criteria that explicitly account for freight benefits, and use of performance measures to track progress toward freight mobility goals. At the federal level, the Federal Highway Administration (FHWA) and other agencies are supporting professional development related to freight transportation through training and information sharing; federal agencies are also developing a number of analytical tools to assist in freight transportation planning and impact assessment.

As freight becomes more integrated into the transportation planning and programming process, there is greater need to consider the air quality impacts of freight at all stages of planning and project development. Over the last two decades, freight has become a more significant source of air pollution. One reason for this is the robust growth in freight activity described above. The other factor is the relatively less stringent regulation on emissions from the freight sector compared to passenger vehicles. Although the U.S. Environmental Protection Agency (EPA) has recently issued strict new nitrogen oxides (NOx) and particulate matter (PM) emission standards for heavy-duty trucks, these standards do not begin to take effect until 2007 and then will take some time to ripple throughout the nation's truck fleet. The major non-road freight modes (locomotives and marine vessels) were virtually unregulated until the late 1990s, and today remain much less regulated than on-road sources. Fortunately, many locomotives, ships, and aircraft have become more fuel efficient over time, which tends to reduce pollutant emissions.

The implications of these trends can be summarized as follows:

- As a result of technological and operational improvements, freight transportation has generally become more fuel efficient in terms of fuel use per ton-mile of freight moved. Fuel efficiency gains are greatest in air and rail modes.[9]
- Due to efficiency gains and emission regulations, freight pollutant emissions per mile and per ton-mile are generally declining. However, these emission rates are declining more for trucks than for the other freight modes.[10]
- The growth in freight transportation activity has, in some cases, outpaced the decline in per vehicle emission rates. For example, total U.S. NOx emissions from trucking, commercial marine vessels,

and aircraft have risen over the last 20 years.[11] In other cases, the decline in emission rates has more than compensated for growth in freight activity and led to a drop in total U.S. emissions, particularly volatile organic compounds (VOCs) and carbon monoxide (CO).

- Pollutant emissions from other major sources, such as light duty vehicles and power plants, are declining in many cases.[12] As a result, freight transportation is contributing a growing share of the total emissions of some pollutants. For example, freight was responsible for 20 percent of the nation's total NOx emissions in 1980; today that percentage is 27 percent.[13]

At the same time that freight transportation's contribution to air pollution is growing, there is a heightened concern about the health and environmental effects of diesel engine emissions. Most freight trucks, locomotives, and ships are powered by diesel engines, which are a major source of emissions of NOx and PM. Freight transportation is also a large and growing source of greenhouse gas (GHG) emissions that contribute to global climate change, particularly carbon dioxide (CO2) emissions. These concerns, and the implementation of the 8-hour ozone and fine particulate (PM-2.5) standards, will require many regions across the country to find new ways to control NOx and PM emissions from freight transportation sources.

This study is intended to help fill a void in the current understanding of the air quality impacts of freight transportation. A large body of research has looked at multimodal freight flows from a transportation and economic perspective, and many other studies have examined the air quality impacts of freight transportation for a single mode. A smaller number of studies have compared fuel efficiency or emissions across two or more freight modes in an intercity context, but very few studies have examined freight transportation and emissions within urban areas. Furthermore, emission inventories prepared for air quality planning purposes, many of which were reviewed for this study, typically do not distinguish between freight and non-freight activity and may not allow comparison across modes or cities.

This report discusses freight transportation activity and emissions at the national level and in six metropolitan areas (Baltimore, Chicago, Dallas-Fort Worth, Detroit, Houston, and Los Angeles). The report draws on a variety of existing studies and data sources and develops new emissions estimates to fill data gaps. The study findings were documented in six detailed technical memoranda prepared by ICF Consulting for FHWA over the course of 2004. This report presents selected highlights from those memoranda.

The remainder of this report is organized into four sections:

- Chapter 2 reviews freight transportation activity and emissions at the national level, including freight movement trends by mode, emissions standards that affect freight transportation, and national-level emissions from freight transportation.
- Chapter 3 presents estimates of freight transportation emissions in the six study areas by mode, including trucking, freight rail, marine vessels, port cargo handling equipment, aircraft, and airport ground support equipment.
- Chapter 4 describes strategies to reduce emissions from freight transportation, including technology-oriented strategies and operational strategies.
- Chapter 5 discusses conclusions and recommendations for future research.

Several appendices provide supporting technical information.

2 National Freight Transportation Trends and Emissions

This section provides an overview of national-level freight transportation activity and associated emissions. Section 2.1 presents the current volume of freight transportation by mode, reviews recent trends, and discusses primary data sources. Section 2.2 discusses forecasts of freight growth developed by several different organizations and synthesizes these to present plausible freight growth rates by mode. Section 2.3 discusses emissions regulations that affect the freight sector and how emission rates for trucks, locomotives, marine vessels, and aircraft may change over the next 20 years. Section 2.4 presents current and future estimates of national-level freight emissions by mode.

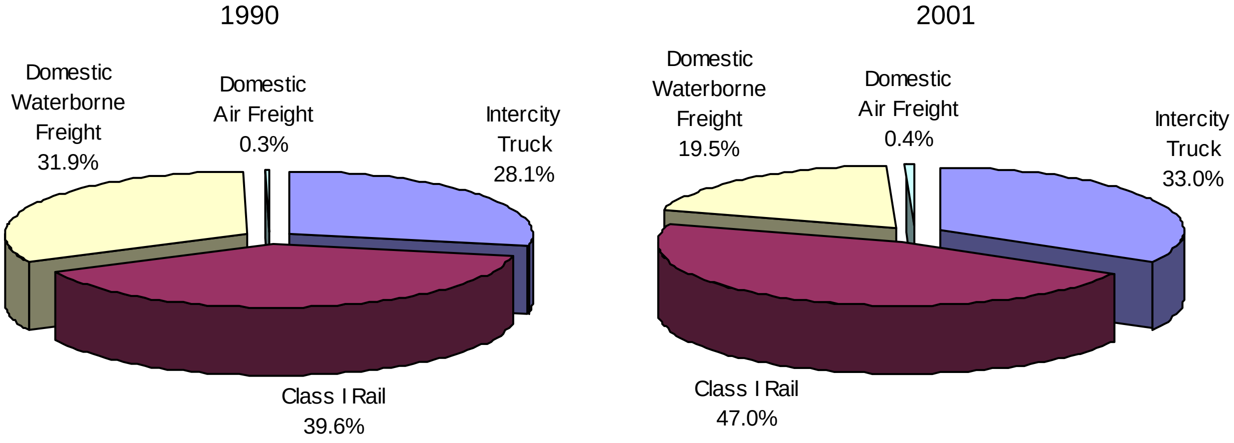
2.1 Freight Transportation Activity and Trends

Although the U.S. economy is becoming more service-oriented, demand for freight transportation has been rising steadily, and forecasts show continued growth at least over the next several decades. In 2001, the Bureau of Transportation Statistics reports that more than 3.18 trillion ton-miles of freight were moved over the nation’s domestic transportation system, up almost 22 percent from the 2.61 trillion ton-miles of freight moved in 1990, an annual growth rate of 2.0 percent.[14]

National Freight Mode Shares

During the period from 1990 to 2001, trucking and rail continued to capture a larger portion of the domestic freight market as measured in ton-miles. As shown in Figure 2-1, trucking market share has grown from 28 percent in 1990 to 33 percent in 2001. Similarly, rail ton-mile market share has continued to grow and represents the largest portion of the inter-city freight market at 47 percent, up from 40 percent in 1990. Trends for domestic waterborne freight have followed an opposite path, with modal share declining during this period from 32 percent of ton-miles in 1990 to 20 percent in 2001. (As discussed later in this section, waterborne imports have grown rapidly.) Air freight has increased in mode share over this eleven year period, from 0.3 percent to 0.4 percent, but still represents a small fraction of overall freight ton-miles.

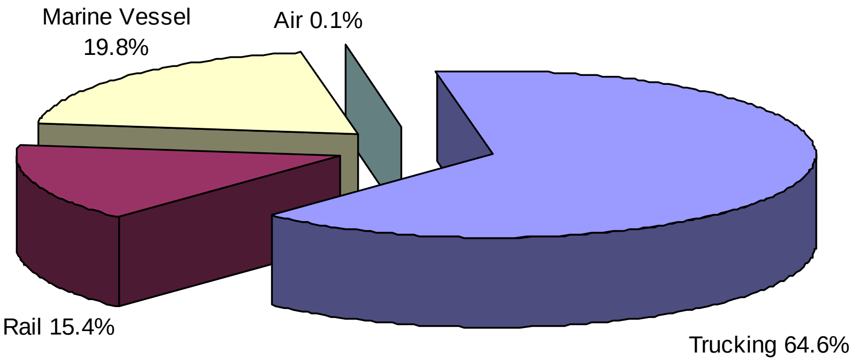
Figure 2-1: Modal Share of Domestic Ton-Miles, 1990 and 2001



Source: Bureau of Transportation Statistics, *National Transportation Statistics 2004*.

Figure 2-2 shows the modal share of freight shipment tonnage, including international air freight and waterborne shipments. Trucking moves approximately two-thirds of freight tonnage nationally. Marine vessels move nearly 20 percent of freight tonnage, a large portion of that international shipments. Rail moves 15 percent of U.S. freight tonnage, and aircraft move only 0.1 percent.

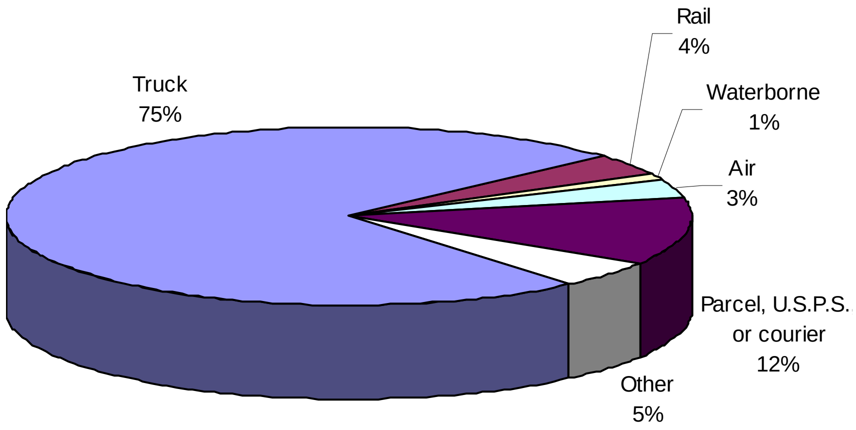
Figure 2-2: Modal Share of Freight Tonnage, 2002



Source: Bureau of Transportation Statistics, *National Transportation Statistics 2004*.

In value terms, trucking is by far the dominant domestic freight mode. Figure 2-3 shows the value of 2002 freight shipments by mode. Trucking accounts for three-quarters of freight shipment value, followed by parcel, postal, and courier shipments (12 percent), which often move by truck or a combination of air and truck.

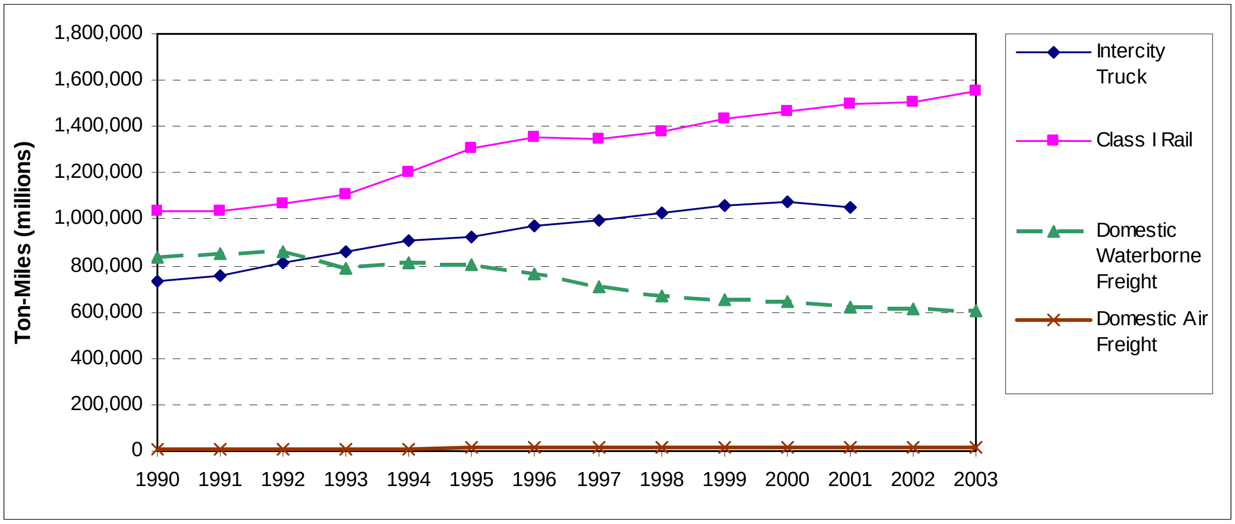
Figure 2-3: Domestic Freight Shipment Value by Mode, 2002



Source: Bureau of Transportation Statistics and U.S. Census Bureau, *2002 Commodity Flow Survey*, Preliminary United States Data, December 2003.

Figure 2-4 depicts trends in domestic ton-miles for the four primary freight modes. This figure illustrates rising volumes for the intercity truck and rail modes, and declines in domestic waterborne freight. Air freight, which appears flat in Figure 2-4 due to the scale of the graph, has actually increased 65 percent since 1990.

Figure 2-4: Domestic Freight Ton-Miles, 1990 – 2003



Source: Bureau of Transportation Statistics, *National Transportation Statistics 2004*. Intercity truck data not available for 2002 and 2003.

Trucking Activity

The standard measure of trucking activity, and the measure used to assess air quality effects, is vehicle miles traveled (VMT). Nearly all national VMT estimates are derived from the Highway Performance Monitoring System (HPMS), a national data collection and reporting system administered by FHWA in cooperation with state transportation departments. HPMS contains information on the mileage, usage and capacity of various roadway functional types. FHWA processes HPMS data and, using other sources such as the Vehicle Inventory and Use Survey (VIUS), reports national VMT in the *Highway Statistics* series. These VMT figures are broken down by

- vehicle type, including (1) single-unit, 2-axle 6-tire, or 3+ axle trucks and (2) combination trucks
- urban and rural area roadway functional type (interstate, arterial, other)

Table 2-1 shows data on VMT by vehicle type derived from HPMS data. The data show that rural roads tend to carry a much higher percentage of trucks, particularly rural Interstates, where nearly 20 percent of VMT is derived from freight trucks.

Table 2-1: Truck VMT and Total VMT by Roadway Type, 2002

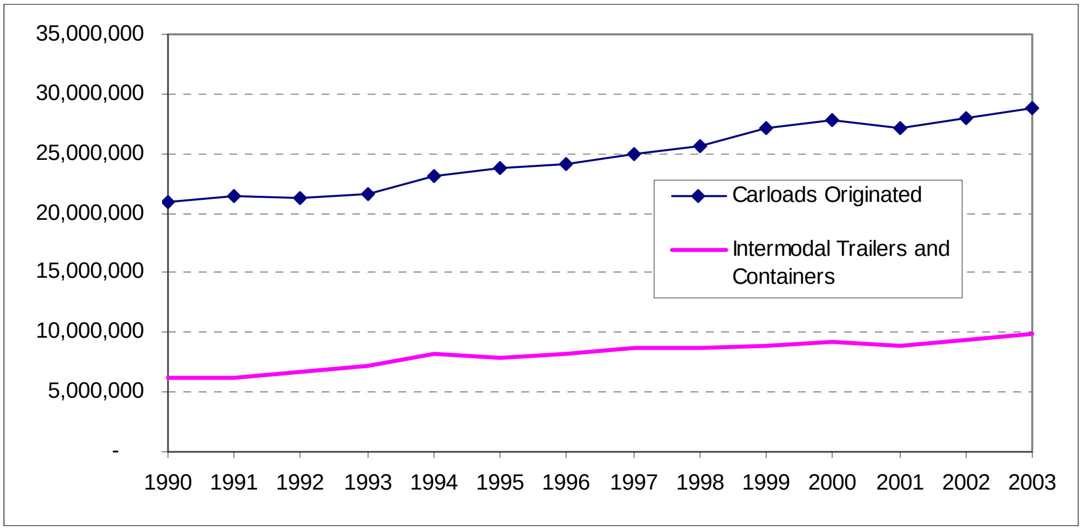
	VMT (millions)				
Roadway Type	Single-Unit Trucks [a]	Combination Trucks	Total Trucks	Total Vehicles	Truck VMT as Percent of Total
Interstate Rural	8,745	45,633	54,378	279,962	19%
Other Arterial Rural	14,606	27,818	42,424	433,805	10%
Other Rural	14,963	14,090	29,053	414,393	7%
Interstate Urban	9,106	23,887	32,993	408,618	8%
Other Urban	28,467	27,215	55,682	1,318,978	4%
Total	75,887	138,643	214,530	2,855,756	8%

Note a: Includes only two-axle six-tire vehicles and single-unit trucks with three or more axles.
Source: Federal Highway Administration, *Highway Statistics*.

Railroad Freight Activity

Freight railroad activity in the U.S. is dominated by the five U.S. and two Canadian Class I railroads.[15] Class I railroads carry more than 90 percent of U.S. railroad ton-miles, consuming more than 94 percent of railroad fuel. The Association of American Railroads (AAR) reports various operating statistics for the Class I railroads, including fuel consumption, tons carried, ton-miles, length of haul, and carloads, in its annual *Railroad Facts*. Figure 2-5 shows recent trends in railroad traffic. The Class I railroads move nearly 29 million carloads annually, up 38 percent since 1990. Intermodal traffic is growing more rapidly. By 2003, the railroads moved nearly 10 million intermodal trailers and containers, up 60 percent since 1990.

Figure 2-5: Railroad Carloads and Intermodal Traffic, 1990 – 2003



Source: American Association of Railroads, *Railroad Facts 2004*.

There is limited data available on the operations of Class II and III railroads (regional and short-line carriers). EPA has estimated that the Class II and III railroads consume approximately 6 percent of the fuel used in freight movement by rail, based on information provided by the American Short Line and Regional Railroad Association.[16]

Waterborne Freight Activity

Waterborne freight statistics are collected and published annually by the U.S. Army Corps of Engineers in the *Waterborne Commerce of the United States* series. Data include tons shipped, ton-miles, and average length of haul. Detailed port and commodity information is also available. Table 2-2 shows U.S. waterborne freight tonnage, both foreign and domestic. In total, 2.4 billion tons of freight move by water annually. Foreign trade accounts for 58 percent of waterborne tonnage, with import tonnage nearly 2.7 times more than export tonnage. Domestic waterborne tonnage is primarily inland movements (rivers and canals), with smaller amounts moving along the coasts, in the Great Lakes, and within ports.

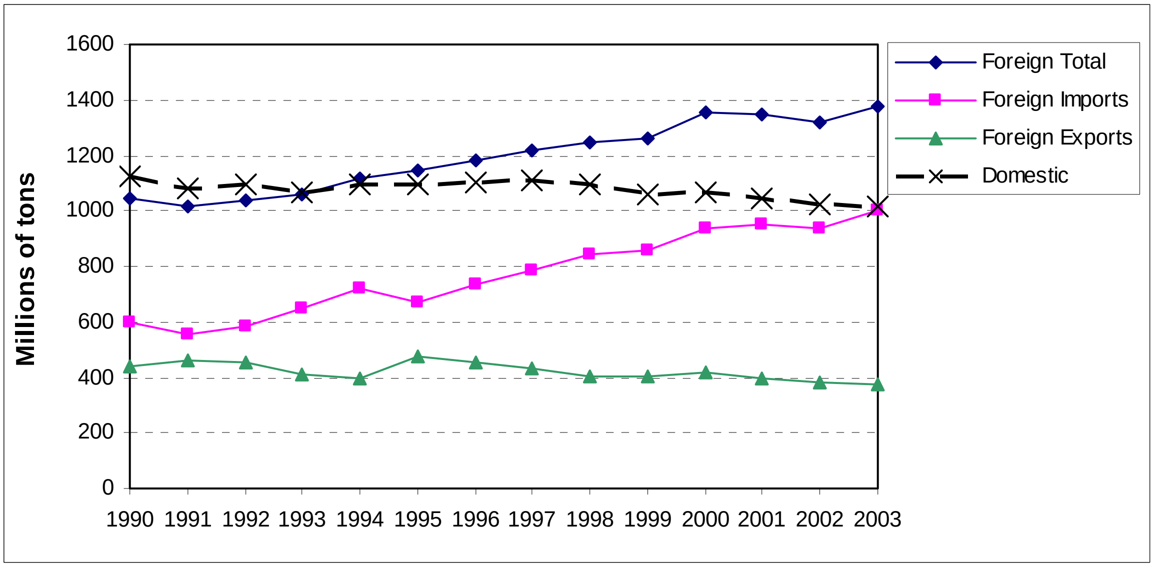
Table 2-2: U.S. Waterborne Freight Tonnage, 2003 (millions of tons)

Foreign			Domestic						Total
Imports	Exports	Sub-Total	Inland	Coastal	Great Lakes	Intra-port	Intra-territory	Sub-Total	
1,005	373	1,378	610	223	90	87	6	1,016	2,394
42%	16%	58%	25%	9%	4%	4%	0%	42%	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States.*

As shown previously in Figure 2-4, domestic waterborne freight ton-miles are declining. This can be a misleading indicator for the waterborne sector, however, because more than half of U.S. waterborne freight tonnage is international. On a tonnage basis, waterborne freight has been increasing due to the rapid growth in U.S. imports. While domestic waterborne tonnage fell 9 percent between 1990 and 2003 and U.S. waterborne export tonnage fell by 15 percent, waterborne imports grew by 67 percent over that period. As a result, total waterborne freight tonnage has actually increased since 1990 by approximately 11 percent. Figure 2-6 illustrates these trends.

Figure 2-6: Waterborne Freight Tonnage, 1990 – 2003



Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States*.

The American Association of Port Authorities (AAPA) collects and reports activity data from its members, which include all major U.S. deep sea ports, including data on container imports and exports. Shipping containers can be 20, 40, or 45 feet long. So to allow for comparisons of container movement, a standardized measure of twenty-foot equivalent units (TEUs) is used. The number of containers handled at U.S. ports is growing rapidly; between 1995 and 2001, the number of loaded containers moving through the top 10 U.S. ports grew by 47 percent, or 6.6 percent annually. Table 2-3 shows the total TEUs at all major U.S. ports. Nearly one-quarter of all container moves through ports involve empty containers.

Table 2-3: U.S. Port Container Traffic, 2002

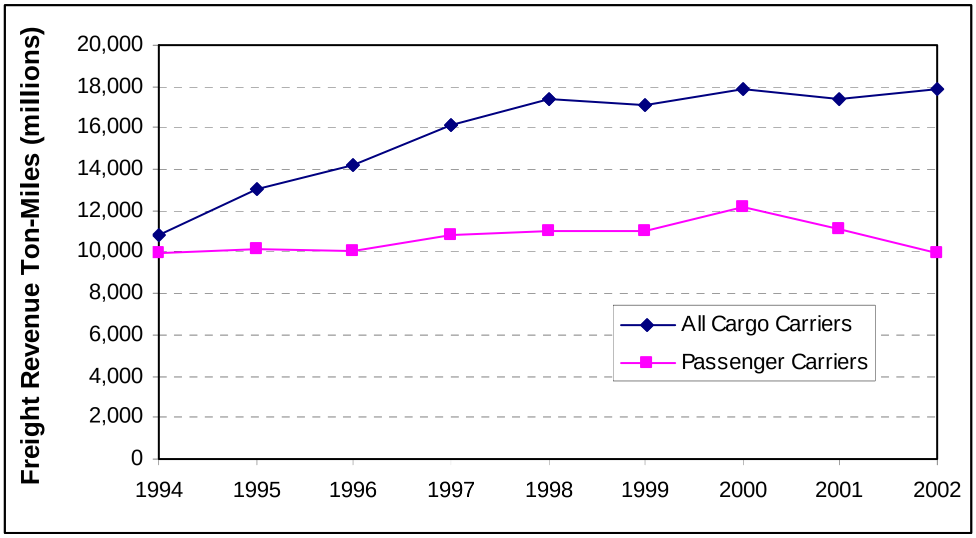
Loaded TEUs			Empty	Total
Inbound	Outbound	Sub-total	TEUs	TEUs
14,070,972	8,815,397	22,886,370	7,462,851	30,833,171

Source: American Association of Port Authorities

Air Freight Activity

Air freight is transported in dedicated cargo aircraft and in cargo space of passenger aircraft (belly cargo). All large domestic air carriers report operating annual statistics to the Federal Aviation Administration (FAA) by filing "Form 41," which includes information on revenue passenger miles, revenue ton miles, and fuel consumption. Figure 2-7 shows recent trends in air freight revenue ton-miles by U.S. carriers (domestic and international service). In 1994, passenger and all cargo carriers handled approximately equal amounts of air freight. Since that time, air freight on all cargo carriers has grown 64 percent, while air freight on passenger carriers has remained nearly constant. This is in part a reflection of the trend toward improving passenger load factors, leaving less capacity for freight. Looking at just domestic flights, air freight handled by passenger carriers has actually declined 28 percent since 1994.

Figure 2-7: Air Freight Revenue Ton-Miles by Carrier Type, 1994 – 2002



Source: FAA Aerospace Forecasts, various years

Aircraft emissions are typically calculated based on the number of take-offs and landings. Only the aircraft emissions that occur below 3,000 feet are considered to affect ground level air pollution. For this reason, national air cargo ton-miles or fuel use are not appropriate indicators of the contribution of aircraft to air quality problems.

FAA Form 41 data indicate the number of annual passenger and all-cargo aircraft departures, as well as data on the cargo tonnage and number of passengers. Because passenger aircraft carry both passengers and freight, in order to estimate national aircraft emissions attributable to freight alone, it is necessary to apportion passenger aircraft departures into a passenger and freight component. To do this, we estimated the tonnage of the passengers and the tonnage of the freight on every commercial passenger aircraft departure and used these figures to estimate tonnage-weighted departures attributable to passenger and freight activity.[17] These results are shown in Table 2-4. Using this process, air freight can be estimated to account for 10.1 percent of total U.S. aircraft departures in 2002 (7.6 percent due to all cargo aircraft and 2.5 percent due to the freight component of passenger aircraft).

Table 2-4: Aircraft Departures Attributable to Freight, 2002

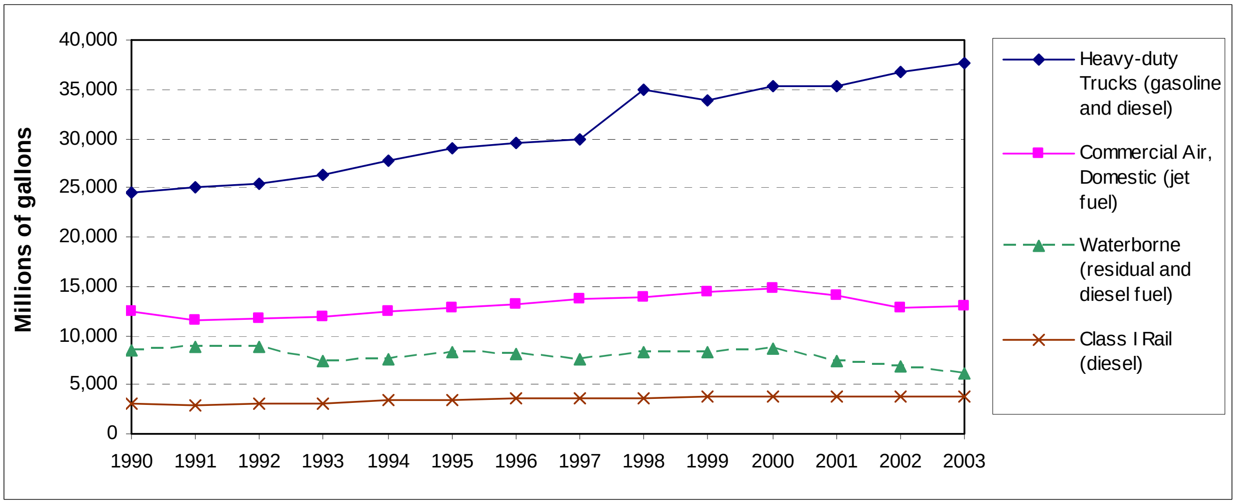
Air Cargo Aircraft		Passenger Aircraft				Total Aircraft	
		Passenger Activity		Freight Activity			
Departures	Percent	Tonnage-Weighted Departures	Percent	Tonnage-Weighted Departures	Percent	Departures	Percent
382,173	7.6%	4,490,112	89.9%	124,490	2.5%	4,996,775	100.0%

Source: Based on Bureau of Transportation Statistics, Air Carrier Statistics (Form 41Traffic).

Fuel Consumption

Fuel use is generally proportional to emissions of greenhouse gases. While freight trucks, locomotives, marine vessels, and aircraft are becoming more fuel-efficient over time, growth in freight activity has in some cases outpaced these efficiency improvements. Consequently, freight fuel use has been increasing in the trucking and rail sectors. Figure 2-8 illustrates these trends in fuel consumption. (Note that most commercial aircraft fuel use in this figure is due to passenger movements.)

Figure 2-8: Fuel Consumption by Domestic Freight Mode, 1990 – 2003



Source: Bureau of Transportation Statistics, *National Transportation Statistics 2004* (air, waterborne, rail); Federal Highway Administration, *Highway Statistics 2003* (truck).

2.2 Freight Transportation Forecasts

The contribution of freight transportation to air quality problems in future years depends on two major factors – the rate of growth in freight movement and changes in the emissions characteristics of trucks, locomotives, ships, and aircraft. This section discusses freight transportation growth forecasts at a national level. The following section discusses the effects of EPA emission standards on future emission rates.

Several recent studies have developed projections of freight transportation demand by mode. This section reviews three independent forecasts and a fourth that is based on a comparative analysis of available forecasts and historic trends. The sources of these freight forecasts are:

- **BTS, *The Changing Face of Transportation***. Published in 2000, this report from the Bureau of Transportation Statistics covers transportation developments through the last quarter of the 20th century and forecasts the demand for freight transportation by intercity truck, rail, and air in 2025.[18] The report investigates topics such as demand growth, deregulation, intermodalism, safety, globalization, technology, and national security and presents forecasts based on empirical data and various econometric methods.[19]
- **AASHTO, *Freight-Rail Bottom Line Report***. The primary goal of the *Freight-Rail Bottom Line Report* is to examine the performance and productivity of the nation's freight-rail system.[20] Based upon anticipated levels of investment in that system, the study makes the case that the rail system requires significant investment to ensure that unsustainable volumes of traffic do not spill over onto the highway system as a result of insufficient capacity and service levels in the rail industry. The Report includes forecasts for the four major modes of freight transport (truck, rail, water, and air). The demand forecasts that are reported in AASHTO's Report are based on Reebie Associates' TRANSEARCH data for the baseline year (2000) and growth rates developed under

FHWA's Freight Analysis Framework (FAF). Note that FHWA's freight transportation forecasts are based on the FAF.

- **ATA, *U.S. Freight Transportation Forecast to 2014*.** This report from the American Trucking Association provides demand forecasts for trucking, rail, water, and air from 2002 to 2014.[21] Global Insight, Inc. and Martin Labbe Associates developed the forecasts for ATA using proprietary models, databases, and other available sources. While the actual model algorithms and supporting data are not documented, the study reportedly accounts for the U.S. economic outlook, energy prices, consumer spending, foreign trade, business investment, industrial output, regional economic growth, and the world economy. The ATA forecasts are provided only in tons, rather than ton-miles.
- **ICF Consulting, *21st Century Freight Mobility Study*.** As part of NCHRP Project 20-24(33)A (21st Century Freight Mobility), ICF Consulting recently reviewed the freight transportation forecasts described above, as well as other freight industry information, and developed an estimate ton-mile growth rates by mode.[22]

A comparison of the forecasts is shown in Table 2-5. Based on the ICF Consulting results, the most rapid growth is expected to occur in the air freight sector (4 percent annual growth), followed by trucking (2.5 percent) and rail (2 percent). Domestic waterborne freight is expected to remain relatively flat (0.7 percent growth). Note that these figures do not reflect the rapidly growing international waterborne sector nor international air freight.

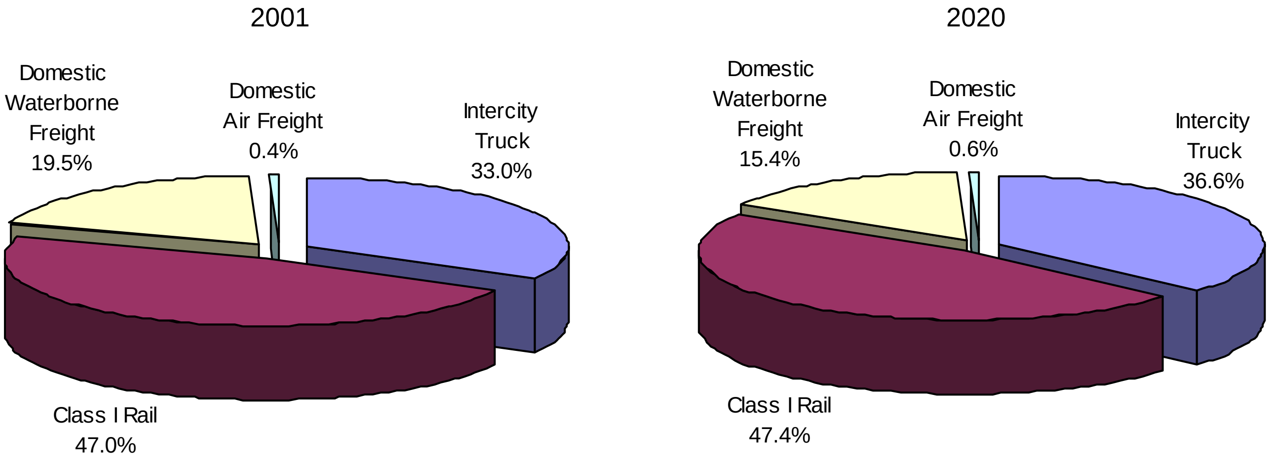
Table 2-5: Comparison of Domestic Freight Demand Forecasts

	Historic Data (ann. growth) (ton-miles) 1990-2000	Forecasts (compound annual growth rate)			
		BTS (ton-miles) 2000-2025	AASHTO (ton-miles) 2000-2020	ATA (tons) 2002-2014	ICF (ton-miles) 2000-2020
Truck	3.9% [a]	2.6% [a]	2.3%	2.2%	2.5%
Rail	3.6%	0.2%	1.9%	1.7%	2.0%
Water	-2.5%		0.7%	1.6%	0.7%
Air	5.2%	3.1%	5.7%	4.4%	4.0%

Note a: Intercity truck only.
Source: Historic data from BTS, *National Transportation Statistics 2003*; forecasts from sources described in report text.

Applying the ICF Consulting forecasts in Table 2-5 to 2001 freight ton-mileage by mode, we estimate the modal market shares of domestic freight ton-miles in 2020. The results are shown in Figure 2-9, which compares market share in 2001 and 2020. Trucking market share is expected to grow to nearly 37 percent. Rail market share remains mostly unchanged; air freight market share is expected to grow to 0.6 percent of ton-miles.

Figure 2-9: Modal Share of Domestic Ton-Miles, 2001 and 2020 Forecast



Source: 2001 data from Bureau of Transportation Statistics, *National Transportation Statistics 2003*; forecasts calculated by ICF Consulting as described in report text.

2.3 Effects of Emission Standards

Future emissions from freight transportation sources are driven primarily by two major factors. One is the growth in freight transportation activity described in the previous section. The other is the emission standards being adopted by EPA for trucks, locomotives, ships, aircraft, and other off-road equipment. The timing of these regulations and their effects vary significantly by mode. This section reviews emission standards applicable to the major freight modes and discusses their impact on future emissions.

Pollutants of Concern

Most freight trucks, locomotives, and ships are powered by diesel engines, which are a major source of emissions of nitrogen oxides (NOx) and particulate matter (PM). NOx reacts with volatile organic compounds (VOC) to form ground-level ozone, commonly known as smog. Ground-level ozone can trigger a variety of health problems including aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis. People with respiratory problems are most vulnerable, but even healthy people who are active outdoors, such as construction and port workers, can be affected when ozone levels are high. Ozone also contributes to crop damage, ecosystem damage, and other effects. NOx can also form particulate nitrate, especially in western areas of the country.

Many scientific studies have linked breathing PM to a series of significant health problems, including aggravated asthma, difficult breathing, chronic bronchitis, myocardial infarction (heart attacks), and premature death. Increases in particulate matter levels are associated with increased hospital admissions and emergency room visits for people with heart and lung disease, and increased work and school absenteeism.[23] Diesel exhaust is of specific concern, because it is likely to be carcinogenic to humans by inhalation and pose a hazard from non-cancer respiratory effects. In addition to EPA, 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 identified the serious health effects of diesel exhaust. PM is also the major source of haze that reduces visibility, and can cause erosion structures such as monuments and statues.

In this study, we focus on particulate matter less than 10 microns in diameter, or PM-10. There is significant concern about the health effects of particulates less than 2.5 microns in diameter, often called "fine particulates." The particulate matter generated by fuel combustion (such as diesel engines) tends to be smaller on average than particulate matter caused by sources such as windblown dust, to freight transportation contributes more significantly to PM-2.5 than to PM-10. However, EPA has only recently issued new ambient air quality standards for PM-2.5, and many regions have not yet developed accurate estimates of PM-2.5 emissions. This is in part because there has been less research to support the development of PM-2.5 emission factors.

Freight transportation is also a major source of greenhouse gas (GHG) emissions that contribute to global climate change. By far the most important GHG is carbon dioxide (CO2). Although CO2 emissions are not regulated by the Federal government and there is no air quality standard for CO2, numerous states have developed GHG action plans and emission inventories. Several states have specifically addressed transportation-related CO2 emissions through state energy plans, state environmental regulations, or through the transportation planning process.

Truck Emission Standards

EPA has adopted strict new emission standards for on-road heavy-duty vehicles that take effect beginning in 2007. Under these new standards, both NOx and PM emissions must be ten times lower than current (2004) levels, and the 2007 standards represent a 25-fold reduction compared to emission standards in the early 1990s (see Appendix A for details). Thus, emissions from 2007 model year and later trucks will be dramatically lower than most trucks currently in use today. To meet these standards, truck engine manufacturers will need to use exhaust after-treatment devices for the first time, much like the catalytic converters currently found on automobiles. Note, however, that the emission standards apply only to new vehicles in the year of their manufacture; there are no emission standards that apply to in-use vehicles, other than some state regulations on exhaust smoke opacity.

The emission control devices that will allow engine manufacturers to meet these new standards typically cannot tolerate high sulfur levels in fuel. EPA has adopted companion standards for diesel fuel sulfur levels. Beginning in June 2006, on-road diesel fuel must have no more than 0.15 parts per million (ppm) sulfur (ultra-low sulfur), compared to the current standard of 500 ppm. This ultra-low sulfur diesel (ULSD) will be required for off-road applications (such as locomotives and port cargo handling equipment) by 2010.

Table 2-6 illustrates the effect of these emission standards on the composite fleet average heavy-duty truck emission rates. We developed these emission factors using MOBILE6.2 for urban highway driving in 2002, 2010, and 2020. By 2020, the MOBILE model estimates that nearly all active trucks in the nation's fleet will have met the 2007 standards, so NOx and PM-10 emission rates are much lower than those for today's truck fleet. For example, the 2020 NOx emission factor for combination trucks is 20 times lower than in 2002.

Table 2-6: Fleet Average Heavy Duty Truck Emission Factors, Urban Freeway

		Urban Freeway Emission Factors (grams/mile)				
	Year	VOC	CO	NOx	PM-10 (total)	PM-10 (exhaust only)
Single-Unit Gasoline Truck	2002	1.31	51.39	8.12	0.13	0.11
	2010	0.35	12.24	5.60	0.09	0.07
	2020	0.12	7.74	2.17	0.047	0.025
Single-Unit Diesel Truck	2002	0.42	2.21	22.69	0.42	0.38
	2010	0.28	1.10	8.06	0.17	0.13
	2020	0.27	0.28	1.24	0.071	0.032
Combination Diesel Truck	2002	0.43	2.48	25.65	0.41	0.37
	2010	0.28	1.14	8.38	0.17	0.13
	2020	0.20	0.25	1.28	0.073	0.034

Source: Developed by ICF Consulting using MOBILE6.2 and an average urban highway speed of 52 mph.

Locomotive Emission Standards

In April 1998, EPA finalized emission standards for locomotives, which took effect in 2000 and involve a three-tiered system (see Appendix A). The Tier 0 emission standards apply to locomotives and engines originally manufactured from 1973 through 2001, any time the engine is manufactured or remanufactured. Tier 1 standards apply to original model years between 2002 through 2004. Tier 2 standards apply to original model years of 2005 and later. Tier 1 and 2 locomotives are required to meet the applicable standards at both the time of original manufacture and at each subsequent rebuilding. The standards will result in a 45 percent reduction in NOx emissions for Tier I locomotives and a 59 percent reduction in NOx for Tier II locomotives, compared to baseline values. Hydrocarbon (HC) and PM-10 emissions for locomotives built in 2005 and later must be 40 percent lower.

Table 2-7 shows the fleet average emission factors for all locomotives in 2002, 2010, and 2020. These factors reflect Class I line-haul and switch locomotives, Class II and III locomotives, and passenger locomotives, although the factors are dominated by the Class I locomotives. NOx and PM-10 emission rates are expected to decline, although not as dramatically as heavy-duty truck emission rates will decline. Between 2002 and 2020, locomotive NOx emission factors will decline by 44 percent and PM-10 factors will decline by 28 percent.

Table 2-7: Fleet Average Locomotive Emission Factors

	Emission Factors (grams/gallon)			
Year	HC	CO	NOx	PM-10
2002	10.7	27.4	249.4	6.8
2010	9.2	27.4	163.7	5.7
2020	8.0	27.4	140.8	4.9

Source: U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998.

In 2004, EPA announced its intent to propose more stringent emission standards for new locomotive diesel engines. The new standards are expected to be modeled after the 2007/2010 highway regulations and Tier 4 non-road diesel engine regulations (described below), with an emphasis on achieving large reductions in emissions of PM and air toxics through the use of advanced emission control technology.

Marine Vessel Emission Standards

For regulatory purposes, commercial marine engines are classified as Category 1, 2, or 3, based on size. Category 1 marine diesel engines have rated power of at least 50 horsepower and a per-cylinder displacement of less than 5 liters, similar to land-based non-road engines used in construction and farm equipment. Category 2 marine diesel engines have per-cylinder displacements of between 5 liters and 30 liters and are most similar to those engines found in land-based locomotives. Category 1 and 2 engines are used as propulsion engines (i.e., the engine that moves the vessel through the water) or as auxiliary engines to provide on-board electricity. Category 3 marine diesel engines have per-cylinder displacements of at least 30 liters and are used to propel container ships, tankers, bulk carriers, and cruise ships. Most of these engines are installed on ocean-going vessels, though a few are found on ships in the Great Lakes. Category 1 and 2 engines burn distillate diesel fuel, which is similar to non-road diesel. Category 3 engines burn residual fuel, a by-product of distilling crude oil with a high viscosity and density.

EPA established the first emission standards for these engines in 2000 to take effect between 2004 and 2007. The standards require relatively modest reductions in NOx, CO, and PM (see Appendix A). By 2020, these standards are expected to reduce commercial marine NOx emissions by 21 percent, relative to uncontrolled levels, and reduce PM-10 emissions by 11 percent.

In May 2004, EPA announced its intent to propose more stringent emission standards for all new commercial, recreational, and auxiliary marine diesel engines, except Category 3 engines. Like the new standards planned for locomotives, the new marine standards are expected to be modeled after the 2007/2010 highway and Tier 4 non-road diesel engine programs and will result in the use of advanced emission control technology. It is important to note that EPA standards apply only to U.S.-flagged vessels. While the vast majority of Category 1 and 2 engines in U.S. waters are U.S.-flagged, most Category 3 vessels are foreign-flagged and thus not subject to EPA regulations.

The International Maritime Organization (IMO) leads the development of international regulations for ships. The IMO adopted Annex VI of the International Convention on the Prevention of Pollution from Ships (MARPOL) in 1997 to set NOx emissions standards for ships. MARPOL Annex VI will come into force in May 2005, and at that time, any country that has ratified the treaty can enforce the NOx emission standards for any ships in its waters. It applies to engines on ships constructed on or after January 1, 2000. The U.S. Senate has not ratified MARPOL Annex VI. If the U.S. Senate ratifies MARPOL Annex VI, then it can be enforced against any foreign-flagged ship that visits a U.S. port, whether or not the flag state of the ship has ratified the treaty. Until Annex VI is ratified, however, only a small fraction of Category 3 marine engines in U.S. waters are subject to emission regulations.

Off-Road Equipment Emission Standards

EPA issues separate emission standards for off-road diesel engines, a category that includes most of the off-road equipment used to handle cargo at ports as well as some freight-related ground support equipment at airports. These regulations continue to be phased in under a four-tier system, with emission standards based on engine horsepower and equipment model year (see Appendix A). Tier 1, 2, and 3 standards are largely being met by enhanced engine design and manufacturing improvements, requiring little or no exhaust after-treatment, and do not address fuels. The Tier 4 standards require dramatic reductions in NOx and PM emissions, akin to the emission reductions required by 2007 standards for on-road heavy-duty diesel trucks. The non-road NOx and PM standards under Tier 4 are approximately ten times lower than the Tier 3 standards for most engines. They will be phased in between 2008 and 2015. To comply with this rule, engine manufacturers will need to produce engines with advanced emission control technologies similar to those that will be used for on-road trucks.

This ruling also requires fuel producers to reduce the sulfur content of diesel fuel used in non-road engines to 15 ppm (ULSD) by 2010. Reducing the level of sulfur in diesel fuel is necessary to prevent damage to the emission control systems. Use of ULSD in locomotives and commercial marine diesel engines (most Category 1 and 2 engines) will further reduce PM-10 emissions beyond the effects of the standards described above.

Aircraft Emission Standards

EPA works with FAA to regulate aircraft emissions, as well as the International Civil Aviation Organization (ICAO), an international body that typically leads the development of aircraft emission standards. In 1997, EPA aligned the U.S. aircraft emissions standards and test procedures with those prescribed by ICAO, which apply to commercial aircraft engines with rated thrust greater than 26.7 kilonewtons (kN) and cover NOx and CO. In 2003, EPA announced its intent to adopt the revised ICAO standards for engine NOx emissions, which require NOx emissions to be reduced by an additional 16 percent. These new standards affected new engine certifications as of December 31, 2003; EPA expects the regulations promulgating the new standards to be in place by June 2005. Furthermore ICAO has adopted a further increase in stringency of the NOx emissions standards, which will affect new engine certifications as of December 31, 2007 and require an additional 12 percent reduction in NOx emissions.

Commercial jet aircraft have service lives of 25 to 40 years, so it can take decades for a major technological improvement to appear in a majority of the commercial fleet.[24] Moreover, aircraft manufactured in the 1990s typically have *higher* NOx emissions than aircraft from the 1970s and 1980s because noise and fuel consumption reduction technologies employed in the 1990s come at the expense of increased NOx emissions. Thus, until aircraft that meet the ICAO standards begin to dominate the in-use fleet, fleet average emission rates for NOx are expected to remain constant or increase slightly as older aircraft are retired.

Table 2-8 shows an estimate of aircraft emission rates for the global average fleet in 2002 and 2015. These global figures are likely to be representative of the U.S. fleet because aircraft are fairly well integrated globally and U.S. aircraft make up a major share of the global fleet. These emission rates illustrate the expected increase in NOx emissions per unit of fuel consumption, although emission rates for other pollutants will decline. Comparable composite emission rates that reflect the latest ICAO standards are not available, but over time the new standards are expected to reverse the trend toward increasing NOx emission rates.

Table 2-8: Commercial Aircraft Emission Rates, Global Average

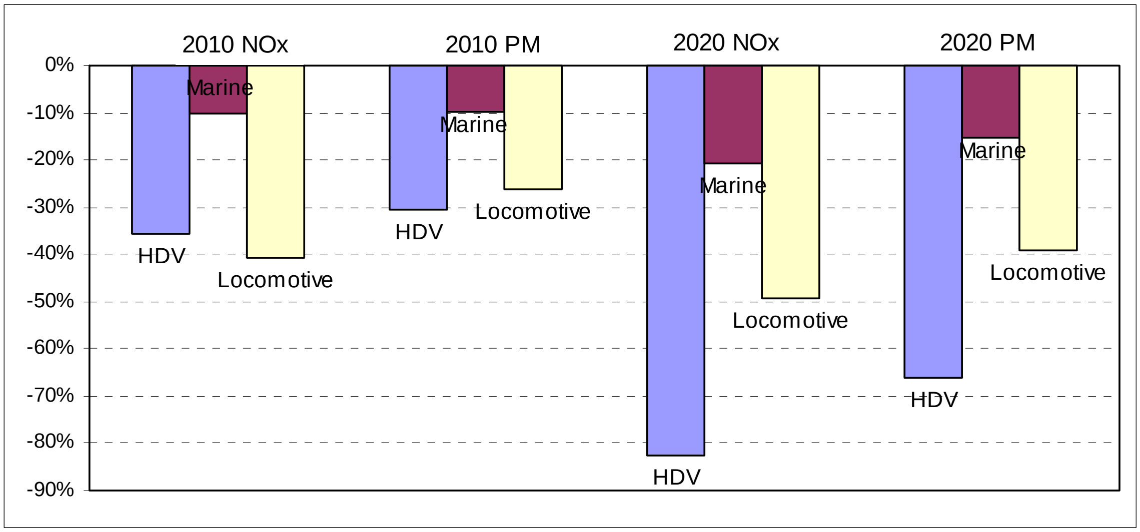
	Emission Rates (grams/kg fuel)			
	VOC	CO	NOx	SO2
2002	1.5	5.3	13.2	0.6
2015	0.7	4.4	14.1	0.4

Source: Sutkus, Donald J., Jr., Steven L. Baughcum, and Douglas P. DuBois, *Commercial Aircraft Emission Scenario for 2020: Database Development and Analysis*, Prepared for NASA, Prepared by Boeing Commercial Airplane Group, NASA/CR—2003-212331, May 2003.

Summary

Figure 2-10 shows the effects of recent EPA emission and fuel standards on heavy-duty vehicle (HDV), locomotive, and commercial marine NOx and PM-10 emissions.[25] This figure shows the percent change in emissions in 2010 and 2020 compared to a status quo baseline, as calculated by EPA. The status quo baseline reflects the expected growth in truck, rail, and marine vessel activity, but without any change in emission standards. In the case of HDVs, the baseline reflects the 1998 emission standards; in the case of locomotives and commercial marine vessels, the baseline represents uncontrolled emissions.

Figure 2-10: Change in National NOx and PM-10 Emissions from Baseline, by Mode



Source: U.S. EPA, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, EPA420-R-00-026, December 2000; U.S. EPA, *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines*, EPA420-R-99-026, November 1999; U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998; U.S. EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*, EPA420-R-04-007, May 2004.

By 2020, NOx and PM-10 emissions from heavy-duty trucks will drop 83 and 66 percent, respectively, as a result of the 2004 and 2007 emission standards. Locomotive NOx emissions will drop by 49 percent and PM-10 emissions will drop by 39 percent by 2020. The recently issued commercial marine emission standards will have less impact. By 2020, the standards will reduce commercial marine NOx and PM-10 emissions by 21 percent and 15 percent, respectively, compared to uncontrolled levels. Note that this figure does not reflect likely new emission standards for locomotives and commercial marine engines, which EPA has announced its intent to adopt. However, because of the long life of locomotive and marine engines, these standards are unlikely to have a major effect until after 2020.

It is also important to reiterate that most vessels calling on the major U.S. deep sea ports are foreign-flagged and not subject to EPA emission regulations. At these ports, NOx and PM emissions from commercial marine engines are likely to increase over the next several decades.

2.4 National Freight Transportation Emissions

The preceding sections review current and forecast freight activity levels and the influence of emission standards on current and future emission rates. This section illustrates how those two factors are likely to affect total freight emissions by mode between 2002 and 2020.

EPA develops a National Emission Inventory (NEI) that can be used to estimate freight sector emissions nationally and by county. The NEI is developed using a combination of national and local level activity data and input from state and local air agencies. Data from the NEI are used for air dispersion modeling, regional strategy development, regulation setting, air toxics risk assessment, and tracking trends in emissions over time.

Table 2-9 shows U.S. NOx and PM-10 emissions from the four major freight modes for 2002. The NEI does not distinguish between freight and non-freight activity. In the case of railroads, we estimated freight railroad NOx emissions as 96.4 percent of total railroad NOx emissions and 96.7 percent of total railroad PM-10 emissions, based on the passenger locomotive fraction in EPA's *Locomotive Emissions Standards, Regulatory Support Document*.[26] We estimated air freight emissions as 10.1 percent of total aircraft emissions, based on the estimated fraction of aircraft departures attributable to freight, as presented in Table 2-4. The marine vessel emissions in Table 2-9 reflect a small amount of non-freight activity (e.g., cruise ships and ferries), but we have not attempted to subtract this portion from the total. Note that Table 2-9 does not show emissions from off-road cargo handling equipment at ports or airport ground support equipment. No data are available to estimate these components at the national level, although metropolitan estimates of these emissions are discussed in Section 3.

Table 2-9: U.S. Freight Transportation NOx and PM-10 Emissions by Mode, 2002

	NOx Emissions				PM-10 Emissions			
			As percent of:				As percent of:	
Mode	Tons	Percent	All Mobile Sources	All Sources	Tons	Percent	All Mobile Sources	All Sources
Heavy-duty Vehicles	3,782,000	66.8%	33.0%	17.9%	120,000	64.7%	23.3%	0.5%
Freight Railroads	857,200	15.1%	7.5%	4.1%	21,300	11.5%	4.1%	0.1%
Marine Vessels	1,011,000	17.9%	8.8%	4.8%	44,000	23.7%	8.5%	0.2%
Air Freight	8,200	0.1%	0.1%	0.0%	300	0.2%	0.1%	0.0%
Total	5,658,400	100%	49.4%	26.8%	185,600	100%	36.0%	0.8%

Source: U.S. EPA, National Emission Inventory; total mobile source emissions and total emissions obtained from state air quality agencies. Freight railroad emissions estimated as 96.4% of total railroad NOx emissions and 96.7% of total railroad PM-10 emissions, based on passenger locomotive fraction in U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998; Air freight emissions estimated as 10.1% of total aircraft emissions, based on air estimated aircraft departures attributable to air freight, as described in report text.

Table 2-9 shows that freight transportation accounts for approximately half of mobile source NOx emissions and 27 percent of all U.S. NOx emissions (anthropogenic sources only). Freight transportation accounts for 36 percent of mobile source PM-10 emissions and less than 1 percent of all U.S. PM-10 emissions. (The vast majority of PM-10 emissions comes from agricultural fields, wildfires, and fugitive dust.)

Heavy-duty vehicles are by far the largest contributor to freight emissions nationally, producing two-thirds of the NOx and PM-10 from the freight sector. Marine vessels are the next largest source, accounting for 18 percent of freight NOx emissions and 24 percent of freight PM-10 emissions, followed by railroads at 15 percent and 12 percent, respectively. Air freight accounts for only 0.1 to 0.2 percent of total freight emissions of NOx and PM-10.

To determine future freight transportation emissions, we reviewed EPA documents supporting recent emission regulations.[27,28,29,30,31,32] To assess the impact of new emission standards, EPA has estimated current and future emissions from heavy-duty trucks, locomotives, and commercial marine vessels. Because these documents were developed several years ago, they typically contain a 2002 emissions estimate that is different from EPA's 2002 NEI estimate for that mode. It is inappropriate to compare future emissions from the regulatory support documents with current emissions from the NEI. Therefore, to determine future emissions, we multiplied the 2002 NEI estimate (from Table 2-9) by the percent change in emissions forecast in the EPA regulatory support documents. For example, EPA's Regulatory Support Document for the 1998 locomotive emission standards estimates that 2010 locomotive emissions will be 66 percent of the 2002 emissions. We multiplied 66 percent by the 2002 locomotive emissions in Table 2-9 to estimate 2010 emissions. (Note that as a check on these results, we also developed an independent estimate of current and future trucking activity and emissions. These results and a discussion of the methodology are included as Appendix B.)

No similar estimate of future aircraft emissions has been developed by EPA. We estimated future aircraft emissions by applying two scaling factors to the 2002 emissions shown in Table 2-9. First, we scaled up the 2002 aircraft emissions using a 4 percent annual growth rate to reflect the expected increase in activity, as presented in Section 2.2. Then, we adjusted the future emission estimates based on the change in fleet average emission factors shown in Table 2-8. In the case of NOx emissions, we assumed no change in fleet average emission factors, rather than the slight increase shown in Table 2-8, due to the expected impact of the latest ICAO emission standards. In the case of PM-10, we assumed fleet average emission factors would change in proportion to SO2 emission factors.

Based on the methodology and assumptions outlined above, Table 2-10 shows current and future NOx emissions from freight and the percent change from 2002 levels. These estimates show total freight emissions declining 63 percent by 2020. Truck emissions are estimated to experience the greatest decline (82 percent), followed by freight rail (43 percent). Commercial marine emissions are expected to decline only slightly by 2020 (7 percent), while air freight emissions are expected to increase 51 percent. While air freight emissions are estimated to increase, they represent only 0.6 percent of the total projected 2020 freight transportation NOx emissions. These figures do not show emissions from off-road cargo handling equipment at ports or airport ground support equipment.

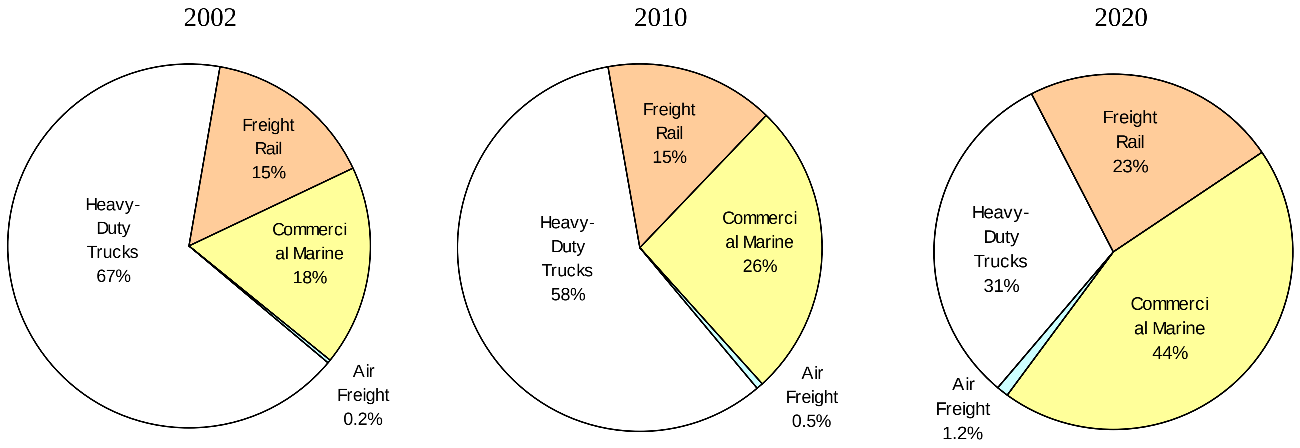
Table 2-10: Current and Future Freight Transportation NOx Emissions by Mode

	Heavy-Duty Trucks		Freight Rail		Commercial Marine		Air Freight		Freight Total	
Year	tons	chnge	tons	chnge	tons	chnge	tons	Chnge	tons	chnge
2002	3,782,000		857,200		1,011,000		8,200		5,658,400	
2010	2,186,900	-42%	563,200	-34%	987,200	-2%	10,000	22%	3,747,299	-34%
2020	662,600	-82%	486,400	-43%	938,600	-7%	12,400	51%	2,099,999	-63%

Source: 2002 data from U.S. EPA, National Emission Inventory, adjusted by ICF Consulting to reflect freight as described in report text; 2010 and 2020 estimates calculated by ICF Consulting based primarily on EPA regulatory support documents as described in report text.

Figure 2-11 compares the relative contribution of the modes to total freight NOx emission in 2002, 2010, and 2020. Currently, trucking dominates freight NOx emissions (67 percent of the total), but the trucking share is expected to decline rapidly by 2020 (31 percent of the total). In contrast, commercial marine emissions currently account for only 18 percent of the freight sector total, but are expected to account for 44 percent by 2020. Freight rail NOx emissions are expected to also grow in significance, from 15 percent today to 23 percent by 2020. The share of total freight NOx emissions for air freight is expected to increase 1.0 percentage point by 2020.

Figure 2-11: Freight Transportation NOx Emissions in 2002, 2010, and 2020



Source: 2002 data from U.S. EPA, National Emission Inventory, adjusted by ICF Consulting to reflect freight as described in report text; 2010 and 2020 estimates calculated by ICF Consulting based primarily on EPA regulatory support documents as described in report text.

Table 2-11 shows current and future PM-10 emissions from freight transportation sources and the percent change from 2002 levels, based on the assumptions and methodology outlined above.[33] Total PM-10 emissions from freight are expected to decline 50 percent. As with freight NOx emissions, the reduction is led by trucking, which is estimated to drop 71 percent in PM-10 emissions. Freight rail PM-10 emissions are expected to decline by 39 percent. Commercial marine emissions of PM-10 in 2020 are nearly identical to 2002 levels, because growth in marine activity will offset the effect of EPA emission and fuel standards. Air freight emissions of PM-10 are expected to decline by 10 percent. Again, these figures do not show emissions from off-road cargo handling equipment at ports or airport ground support equipment.

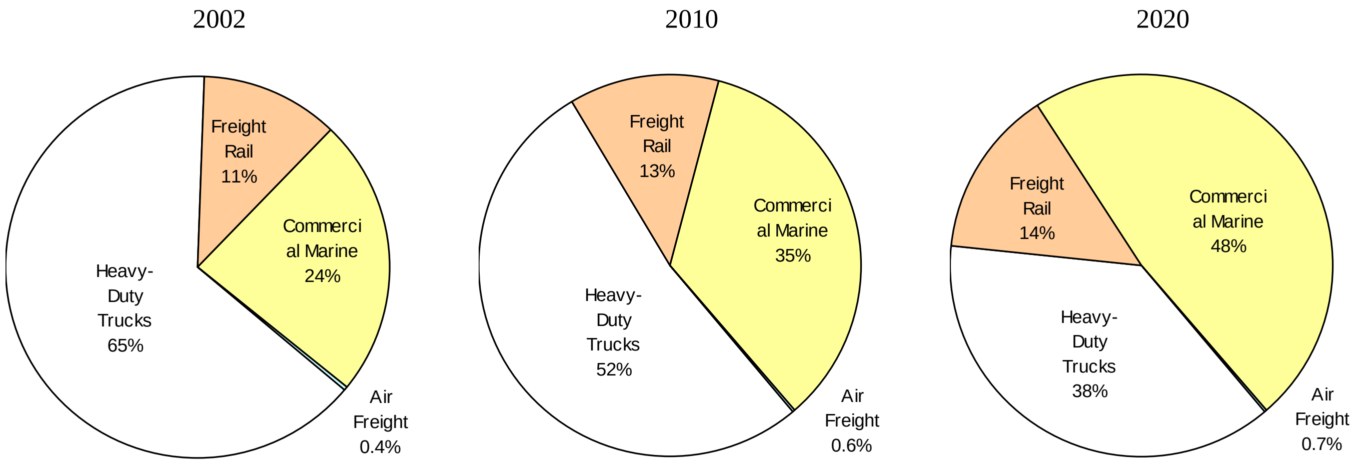
Table 2-11: Current and Future Freight Transportation PM-10 Emissions by Mode

	Heavy-Duty Trucks		Freight Rail		Commercial Marine		Air Freight		Freight Total	
Year	tons	chnge	tons	chnge	tons	chnge	tons	chnge	tons	chnge
2002	120,000		21,300		44,000		300		185,600	
2010	65,380	-46%	15,730	-26%	42,930	-2%	290	-3%	124,329	-33%
2020	34,760	-71%	12,990	-39%	44,080	0%	270	-10%	92,099	-50%

Source: 2002 data from U.S. EPA, National Emission Inventory, adjusted by ICF Consulting to reflect freight as described in report text; 2010 and 2020 estimates calculated by ICF Consulting based primarily on EPA regulatory support documents as described in report text.

Figure 2-12 compares the relative contribution of the modes to total freight PM-10 emission in 2002, 2010, and 2020. The trend is similar to NOx emissions – the trucking share of the PM-10 total from freight declines from 65 percent today to 38 percent by 2020. During this period, the commercial marine share doubles from 24 percent to 48 of all PM-10 emissions from freight. Little percentage change is seen for PM-10 emissions attributable to the freight rail and air freight sectors.

Figure 2-12: Freight Transportation PM-10 Emissions in 2002, 2010, and 2020



Source: 2002 data from U.S. EPA, National Emission Inventory, adjusted by ICF Consulting to reflect freight as described in report text; 2010 and 2020 estimates calculated by ICF Consulting based primarily on EPA regulatory support documents as described in report text.

Table 2-12 shows greenhouse gas emissions from freight transportation sources. Emissions are presented in terragrams (Tg) of CO2 equivalents.[34] Freight trucks account for more than three-quarters of freight-related GHG emissions, followed by marine vessels and freight railroads. Air freight contributes nearly three percent of freight GHG emissions, a much larger fraction than criteria pollutant emissions but still a small portion of the freight total. Overall, freight is responsible for 6.3 percent of all U.S. GHG emissions and one-quarter of GHG emissions from transportation.

Table 2-12: Greenhouse Gas Emissions from Freight Transportation, 2003

	GHG Emissions (Tg CO2 equivalents)			
			Percent of:	
Mode	Emissions	Percent	All Transportation Sources	All Sources
Heavy-duty Trucks	340.7	77.8%	19.2%	4.9%
Freight Railroads	38.2	8.7%	2.2%	0.6%
Marine Vessels	46.5	10.6%	2.6%	0.7%
Air Freight	12.4	2.8%	0.7%	0.2%
Total	437.8	100%	24.7%	6.3%

Note: Does not include marine and aviation bunker fuels (fuel sold in the U.S. for international transportation).
Source: U.S. EPA, *Draft Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2003*, February 2005, adjusted by ICF Consulting to reflect freight as described in report text.

3 Freight Transportation Emissions at the Regional Level

The previous section discusses freight transportation and emissions at the national level. Yet air pollution is primarily a regional problem, affecting major metropolitan areas in particular. Moreover, freight transportation patterns are fundamentally different when viewed at the regional level compared to the national level. To examine the linkages between freight transportation and air quality at the regional level, we selected six major metropolitan areas for a focused look at freight emissions. These six metropolitan areas (Los Angeles, Dallas-Fort Worth, Houston, Chicago, Detroit, and Baltimore) were selected because they are all major multi-modal freight activity centers but reflect diversity in terms of geographic location, economic base, and freight modal balance.

This section presents estimates of freight transportation emissions in the six study areas. We first summarize freight transportation activity in the six regions, highlighting notable differences. Emissions are then presented by mode – trucking, freight rail, marine freight, and air freight. For each mode, we briefly discuss the methodology used to develop the emissions estimates, followed by the results. The last part of the section is a summary that compares emissions across all freight modes and regions. We generally defined the regions as the 1-hour ozone nonattainment or maintenance area; in the case of the Los Angeles region, we defined the region as the South Coast Air Quality Management District and Ventura County nonattainment areas.

In a typical regional emission inventory developed for a State Implementation Plan (SIP), emissions are presented by mode (e.g., on-road vehicles, rail, commercial marine, air), and no attempt is made to distinguish between freight and non-freight activity. The estimates in this section reflect emissions caused only by freight activity, as distinct from emissions from sources such as passenger rail, passenger ferries and other non-freight vessels, and passenger air transport. In the case of trucking, we have assumed that all heavy-duty trucks are involved in freight transportation, although we recognize that a small portion of these vehicles are engaged in service and construction activities that do not, strictly speaking, involve freight movement.

Note that in some cases, there is ambiguity as to what activity should actually be attributed to freight. For example, there are marine vessels like tugboats and airport ground support equipment that support both freight and non-freight movement. In these cases, we have attempted to apportion the activity and emissions caused by the freight sector as best as possible, while recognizing that available data do not allow precise apportionment between freight and non-freight. There is also equipment that supports the freight sector but does not directly involve freight movement, such as diesel-powered sweepers to clean port areas or equipment used to maintain railroad tracks. We generally did not estimate emissions from these sources because they contribute only negligibly to the freight sector total and because of limited data on the activity of this equipment.

3.1 Regional Freight Activity

All six regions profiled in this section are major U.S. freight centers, although there are some key differences in freight activity among the regions. Like every major U.S. city, trucking is the dominant freight mode in the six regions. Table 3-1 shows heavy-duty truck VMT in the six regions. The Los Angeles region has the most truck activity among the six – more than 7.8 billion VMT – followed by Chicago and Detroit.

As a percentage of total on-road VMT, Detroit ranks first among the six regions with 12.7 percent of VMT attributable to heavy-duty trucks. Chicago also has a high percentage of truck VMT (11.1 percent). These high fractions are probably due in part to a relatively large volumes of long-distance trucks passing into, out of, and through these regions, including U.S.-Canada truck traffic in the case of Detroit. The Los Angeles region has the smallest truck VMT fraction, most likely because the very large regional population and passenger vehicle activity means that trucks are responsible for a relatively small share of the on-road total.

Table 3-1: Heavy-Duty Truck VMT in the Six Study Regions, 2002

Region	Heavy Duty Truck VMT (million)	as % of total VMT
Baltimore	1,818	7.8%
Chicago	6,424	11.1%
Dallas-Ft. Worth	3,279	7.1%
Detroit	5,924	12.7%
Houston	3,885	8.7%
Los Angeles	7,817	6.0%

Source: Data provided by MPOs and state and regional air quality agencies.

While most freight trucking activity at the metropolitan level consists of movements *within* the region, freight movements by rail, marine, and air modes are dominated by *inter-regional* traffic. Table 3-2 shows freight tonnage into and out of the six study regions. These data show major differences among the six regions in terms of freight activity by mode. For example, rail freight plays a much more significant role in Chicago (36 percent of total intercity freight tonnage) than in the other regions (7 to 17 percent of tonnage). Chicago is the only city where all six major U.S. and Canadian Class I railroads come together to interchange freight. The region boasts 74 rail marshalling yards, including 17 intermodal terminals, substantially more than any of the other five study regions.

Table 3-2: Commodity Flows Into and Out of the Six Study Regions, 2003 (thousands of tons)

	Trucking		Railroad		Marine Vessel		Aircraft		Total	
Los Angeles	378,995	64%	82,013	14%	124,791	21%	2,234	0.4%	588,033	100%
Dallas-Ft Worth	237,442	87%	33,454	12%	0	0%	840	0.3%	271,735	100%
Houston	340,435	49%	84,375	12%	269,307	39%	352	0.1%	694,468	100%
Chicago	379,532	60%	223,837	36%	22,924	4%	1,155	0.2%	627,448	100%
Detroit	166,037	75%	37,793	17%	17,449	8%	206	0.1%	221,485	100%
Baltimore	76,821	59%	8,537	7%	44,052	34%	146	0.1%	129,556	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Five of the six study regions have seaports (the exception being Dallas-Ft Worth). Waterborne freight activity is much greater in the regions with deep-sea ports (Los Angeles, Houston, Baltimore) than in the regions with Great Lakes ports (Chicago and Detroit). The Los Angeles and Houston area ports are among the largest in the nation, although they are quite different. The ports of Los Angeles and Long Beach are the leading container ports in the county, while Houston specializes in bulk petrochemicals and ranks near the top nationally on a tonnage basis.

Aircraft tend to be cost-effective only for small, high value shipments, so commodity flows by air make up only a fraction (less than 0.5 percent) of the total freight flows in every study region. In every region, the dominant passenger airport is also the dominant air cargo facility. Los Angeles International and O'Hare airports have by far the greatest air cargo activity among the six study areas. Two regions have secondary airports that are major air cargo facilities – Ontario Airport in the Los Angeles region and Alliance Airport in the Dallas-Ft Worth region.

3.2 Trucking Emissions

Trucking emissions are typically calculated as part of the total on-road vehicle emissions estimation process. Because on-road vehicles are one of the largest sources of pollutant emissions, and because of transportation conformity requirements under the Clean Air Act, the process used for estimating on-road vehicle activity and emissions is often more comprehensive and complex than for other transportation sources. All large metropolitan areas develop detailed estimates of VMT and on-road emissions by vehicle class and roadway functional class. For emission inventory purposes, most regions rely on the MPO travel demand forecasting model to determine VMT and vehicle speeds, calibrating the model to observed traffic counts. Other regions estimate VMT based directly on traffic counts.

Emission factors are developed using EPA's MOBILE6 model or, in California, the California Air Resources Board's EMFAC model. Development of the emission factors requires regionally specific information on inspection and maintenance (I/M) programs, fuel characteristics, temperature information, vehicle age distribution, and vehicle mileage accumulation by model year.

In most cases, we report the 2002 on-road inventory data developed by the MPO or state air quality agency for each region, typically developed as required by EPA's Consolidated Emissions Reporting Rule (CERR). In one case (Baltimore), a 2002 annual inventory was not available, so we estimated annual on-road emissions based on 2002 daily emissions calculated by the MPO for conformity purposes.[35]

Summary of Methodology

All six study regions use a similar methodology to estimate on-road vehicle emissions. This methodology typically involves the following steps; some MPOs may perform these steps in a slightly different order.

1. The region's MPO uses a four-step travel demand model to estimate base year and future year traffic volumes by link. In some cases, the model estimates truck trips independent of passenger vehicle trips (i.e., independent truck trip generation and trip distribution modules). In other cases, the models estimate only passenger vehicle trips or total trips, and truck volumes are calculated as a percentage of the total volume (Step 5 below). Travel demand models use a computerized representation of the regional roadway system that includes all freeways and arterials but typically few or no local streets.
2. As required by EPA, the MPO adjusts the travel model traffic volumes based on observed traffic counts from the Highway Performance Monitoring System (HPMS), possibly supplemented with additional traffic counts. In this way, the model is calibrated to reflect base year conditions as accurately as possible.
3. The MPO estimates traffic volumes on local roads, which are not represented in a travel model. Some MPOs do this estimation themselves (e.g., the Baltimore MPO); others rely on local roadway VMT provided by the state DOT (e.g., the Detroit MPO).
4. Daily traffic volumes by link are disaggregated to hourly volumes, using observed traffic counts.

5. Model traffic volumes at the link level are allocated to major vehicle types, based on traffic count information. For example, BMC uses traffic count data provided by Maryland DOT to convert the hourly model traffic volumes into four vehicle types: motorcycles; 2-axle, 4-tire (passenger vehicles); buses; and 2-axle, 6-tire plus 3+ axles (heavy-duty trucks).
6. VMT is summed by vehicle type and facility type.
7. The MOBILE6 model requires VMT by 16 different vehicle types. The vehicle types are defined by vehicle configuration and the gross vehicle weight rating (GVWR). Most regions do not have VMT or traffic count information at this level of detail, so they rely on the MOBILE6 defaults to apportion VMT into these 16 vehicle types. In California, the EMFAC model uses only three weight classes for trucks (light-heavy duty, medium-heavy duty, and heavy-heavy-duty), each divided into gasoline catalyst, gasoline non-catalyst, and diesel engines.
8. Hourly speeds are estimated for each link. Because emission factors vary with vehicle speed, the distribution of VMT by speed can have an important effect on emissions. MPOs use equations that compare link-level volume and capacity to estimate speed. VMT is then grouped into 14 speed “bins.”
9. The distribution of VMT by speed will vary by roadway functional class. The four functional classes in MOBILE6 are freeway (excluding ramps), arterial/collector, local roadway, and freeway ramp. MOBILE6 allows users to enter a distribution of VMT by speed only for freeways and arterials/collectors. For local roadways and freeway ramps, the average speed in the model is fixed at 12.9 mph and 34.6 mph, respectively, and cannot be modified. Thus, MPOs will typically input a 24 x 14 x 2 matrix of VMT fractions (24 hours in the day, 14 speed bins, 2 facility types).
10. MOBILE6 input scripts are developed for information such as fuel Reid vapor pressure (RVP), engine tampering levels, inspection and maintenance programs, and vehicle emission standards. If emissions are being calculated for a specific day or month, MOBILE also requires input information for factors such as maximum and minimum temperature and sunrise and sunset times.
11. MOBILE6 produces emission factors and VMT weighting factors, typically for each county, urban/rural area, and roadway functional type. VMT is multiplied by the appropriate emission factors to determine emissions.

Note that the standard on-road vehicle emission inventory process using the MOBILE model, as outlined above, does not calculate emissions from long-term truck idling. A small amount of idling emissions are implicitly calculated by virtue of the standard urban driving cycle used in emission factor development (which include some stop-and-go driving patterns). The next generation EPA emissions model (MOVES) is expected to more fully capture long-term idling. In California, the EMFAC model has recently been modified to calculate some long-term idling emissions associated with each truck trip.

Summary of Results

Heavy-duty trucks account for 6.0 to 12.7 percent of total on-road VMT in the six study regions. The truck fraction is highest in the Detroit region (12.7 percent), probably due in part to the high U.S.-Canada truck volumes in the region. The Los Angeles region has the largest total heavy-duty truck VMT, but the smallest truck VMT fraction (6.0 percent). This is likely because the very large regional population and passenger vehicle activity means that trucks are responsible for a relatively small share of the on-road total.

Table 3-1 presents a comparison of heavy-duty truck emissions in the six study regions. Numbers in bold reflect the highest truck percentage among the six regions. The regions show some significant differences in terms of the relative contribution of trucks to total on-road pollutant emissions. The contribution of freight trucks to total on-road NOx emissions ranges from a high of 63 percent (Detroit) to a low of 49 percent (Los Angeles). The contribution of freight trucks to total on-road PM-10 emissions ranges from a high of 63 percent (Chicago) to a low of 31 percent (Los Angeles). (Two regions did not provide total on-road PM-10 emissions.)

Table 3-1: Comparison of Heavy-Duty Truck Emissions in the Six Study Regions, 2002

Region	NOx (tons)	as % of total on-road NOx	VOC (tons)	as % of total on-road VOC	PM-10 (tons)	as % of total on-road PM-10	CO (tons)	as % of total on-road CO
Baltimore	29,081	49.7%	1,416	5.8%	734	N/A	13,232	3.9%
Chicago	96,291	57.4%	6,500	10.9%	**2,641**	**62.6%**	58,330	6.0%
Dallas-Ft. Worth	53,718	50.4%	2,174	4.1%	884	38.3%	20,229	2.3%
Detroit	**98,195**	**62.8%**	5,374	8.8%	2,382	N/A	62,805	5.6%
Houston	64,590	54.7%	2,408	5.6%	1,256	47.7%	20,117	2.7%
Los Angeles	130,341	49.4%	**14,839**	**11.0%**	2,210	31.3%	**121,776**	**9.1%**

Source: Based primarily on data provided by state air quality agencies and MPOs; see report text for details.

A number of factors contribute to these differences. Some industry sectors are more transportation intensive than others, so differences in regional economic structure create different levels of trucking activity. Differences between Los Angeles and the other regions are caused in part by differences in the MOBILE6 and EMFAC emission factors. Some of the emissions differences may also be caused by differences in the composition of the truck fleet. For example, in the Los Angeles region, gasoline trucks account for the largest share of total truck VMT (32 percent), which means that truck VOC and CO emissions are relatively larger in Los Angeles. Because long-haul trucks tend to be larger combination vehicles, regions with more pass-through truck traffic will tend to have a larger share of Class 8b truck VMT (diesel-powered) and therefore, will have higher NOx and PM emissions.

3.3 Freight Railroad Emissions

The standard approach for calculating railroad emissions is generally the most simplistic, and potentially the least accurate, of the four major freight modes. Unlike trucks, marine vessels, and aircraft, which use publicly-owned facilities, there is typically little or no published information on private railroad activity available for a specific region. Thus, state and regional air quality agencies must rely on obtaining railroad activity data directly from the railroad companies. Even when this data is provided, it is often not reported with a high level of detail, due in part to the railroad company procedures for maintaining this data.

To determine freight rail emissions in the six study regions, we relied on data provided by state air quality agencies. In some cases, we modified or supplemented state emissions estimates; in other cases, we report the state figures as provided.[36]

Summary of Methodology

All six study regions follow a similar methodology to estimate railroad emissions. This involves estimating county-level fuel use for line-haul locomotives and, separately, for switch yard locomotives. Fuel use estimates are then used to calculate emissions. The steps in this approach are outlined below. The details of the methodology (and its accuracy) depend heavily on the nature of the locomotive activity data provided to the states by the railroads.

1. Each freight railroad that operates in a state is asked to report their gross ton-miles (GTM) by county, as well as their total fuel consumption in the state. If a railroad is able to provide this information, the statewide line-haul fuel use is apportioned to counties in direct proportion to the GTM. Sometimes the railroads perform this fuel use allocation, using their own estimate of fuel use per GTM.
2. Some railroads are not able to report GTM. For these railroads, mileage of active track is used as a proxy. If the railroad is able to report statewide line-haul fuel use, fuel use is apportioned to counties in direct proportion to the railroad's track mileage by county. If the railroad cannot report statewide fuel use, national-level fuel use (as reported by the Association of American Railroads) is apportioned to state and county based on track mileage.
3. Each freight railroad that operates in a state is asked to report the number of switch yard locomotives they operate, by county or by individual yard. Some railroads are able to provide hours of switch locomotive use by county or yard. Railroads are also asked to report the average annual fuel consumption rate (in gallons per locomotive per year) of their switch yard locomotives. If railroads cannot provide this rate, a rate is assumed based on EPA guidance or information from other railroads. Switch yard locomotive fuel use is then calculated by applying a fuel consumption rate to the number of switch yard locomotives.
4. Class II and III railroads (shortline and switching railroads) are often unable to provide the information described above. In some regions (such as Chicago), the number of Class II/III railroads in operation is considered too large to make surveys of individual companies practical. In these cases, fuel consumption can be estimated by obtaining the number of employees of the railroad by county (using a commercial employment database such as Dun & Bradstreet) and a ratio of fuel consumption per employee.
5. The fuel use estimates for each railroad are summed. The result is an estimate of total railroad fuel use by county.
6. Emission factors (in grams per gallon) are applied to the fuel use figures to estimate annual emissions.

There are a number of potential shortfalls to this methodology. Most notably, length of active track is almost certainly not an accurate proxy for fuel use. In most regions, some rail lines are used much more heavily than others. Thus, using track length to apportion fuel consumption to the county level probably results in significant inaccuracies. GTM is a much better proxy for fuel use, but there have been questions about the accuracy of county-level GTM data reported by railroads.

There have also been questions about the accuracy of the fuel consumption data reported by railroads.[37] For example, the fuel use reported by railroads for Texas' 2001 inventory (220 million gallons) is less than half the locomotive fuel sales for the state as reported by the U.S. Department of Energy (504 million gallons) for that year. Some of this discrepancy can likely be explained by the fact that railroads often purchase fuel in one state and then consume that fuel in another. Unfortunately, there are no mechanisms to verify the fuel consumption data reported by railroads.

Some states use locomotive emission factors from EPA's 1992 emission inventory guidance.[38] These emission factors are likely outdated. In cases where we were able to obtain fuel use data (Baltimore, Dallas, Houston), we calculated emissions using 2002 emission factors provided in EPA's 1998 Regulatory Support Document, which was developed to support the adoption of locomotive emission standards.[39]

Summary of Results

Table 3-2 shows the freight rail emissions totals in the six study areas. Chicago has far more freight rail emissions than any other region – approximately twice the emissions in the Los Angeles region (with the exception of CO) and more than four times (in some cases, more than 10 times) that in any of the other regions.

Table 3-2: Freight Rail Emissions in the Six Study Areas, 2002

	Emissions (annual tons)			
Region	NOx	VOC	PM-10	CO
Baltimore	2,655	136	71	289
Chicago	23,212	1,098	792	2,568
Dallas	4,157	193	113	459
Detroit	2,106	102	58	230
Houston	5,163	243	141	569
Los Angeles	12,744	641	346	2,282

Source: Based primarily on data provided by state air quality agencies; see report text for details.

The regions show significant differences in the contribution of switch yard locomotive activity to the freight rail emissions total, as shown in Table 3-3. In Baltimore, for example, switchers are estimated to be responsible for more than half of the freight rail emissions. In contrast, switcher locomotives in the Los Angeles region contribute only 10 percent of NOx and 8 percent of PM-10 from freight rail, according to the region's emission inventory. Some of these differences are likely a product of variations in the inventory development methods.

Table 3-3: Contribution of Yard Operations to Freight Rail Emissions Total

	Pollutant			
Region	NOx	VOC	PM-10	CO
Baltimore	54%	63%	52%	53%
Chicago	18%	23%	32%	17%
Dallas	27%	35%	26%	26%
Detroit	25%	32%	23%	24%
Houston	31%	38%	29%	30%
Los Angeles	10%	10%	8%	8%

Source: Based primarily on data provided by state air quality agencies; see report text for details.

3.4 Marine Freight Emissions

Marine freight sector emissions are caused by the engines used to power vessels and associated equipment and by engines in the land-based equipment that are used for handling marine cargo at ports. Marine freight includes shipping to and from U.S. coastal ports, in the Great Lakes, and in navigable inland waterways. Freight shipping vessels range from non-self-propelled barges and scows to self-propelled container ships, bulk carriers, tankers, and tugboats.

Land-based port emissions originate from three general sources: on-dock equipment, trucks, and locomotives. Emissions from on-road trucks and locomotives at ports are captured in the estimates of the emissions from the trucking and railroad sectors, respectively, so we have not included them in the marine freight sector. On-dock equipment includes the equipment used to load and unload freight from ships, service the ships, and move freight within the port area. We refer to this equipment as *cargo handling equipment* and have developed estimates of these emissions for each port. Examples of cargo handling equipment include yard tractors (or yard hostlers), top and side loaders, forklifts, and cranes.

As with all transportation sources, estimating emissions from marine freight generally involves multiplying an activity parameter by an emission factor. Activity for marine vessels is typically described in terms of *tonnage*, *calls*, or *trips* at a port in a given period, usually one year. *Tonnage* is the mass of goods loaded or unloaded at a port. A *call* is a single entrance and exit from the port boundary. A *trip* is a single movement of a vessel and can include the movement into a port, the movement out of a port, or a vessel shift within a port. Thus, vessel trips at a given port are always two or more times the number of calls. The U.S. Army Corps of Engineers' *Waterborne Commerce of the United States* series reports annual tonnage and trips for every port in the U.S. More detailed data can be obtained from individual ports.

Summary of Methodology

Development of an accurate marine vessel emission inventory also requires information on the time vessels spend in different operating modes in the port region, typically the following:

- *cruise* – operating at sea speed
- *reduced speed zone (RSZ)* – speed roughly 30 percent of cruise, typically occurring between the breakwater and the maneuvering zone
- *maneuvering* – dead slow or reverse, typically about 3-4 knots occurring within about 2 miles before the vessel reaches its dock or anchors
- *hotelling* – time spent at dock or anchorage

Several parameters for each ship type must be specified in order to properly characterize emission rates. These include the *total power* of the main engines, the *load factor* (the fraction of full power used in each operating mode), and the power of the *auxiliary engines*.

The Port of Los Angeles and Houston have recently developed marine vessel emission inventories, and we report these emissions estimates, scaling to 2002 as necessary. For the other ports in the study regions, we estimated vessel emissions using a combination of EPA guidance, methodologies and data from other studies, and published current port activity data. Our inventories for the ports of Baltimore, Chicago, and Detroit are developed primarily based on the methodologies laid out in reports for EPA by ARCADIS[40,41] and Environ[42] and use parameters developed for the most recent emissions study for the Port of Los Angeles.[43] For the Port of Long Beach, we estimated vessel emissions based on the Port of Los Angeles inventory and the ratios of cargo tonnage between the two ports.

No EPA guidance or other standardized methodology exists for developing estimates of port cargo handling equipment (CHE) emissions. For the ports of Houston, Los Angeles, and Long Beach, we used the recent CHE inventories developed by the ports.[44,45,46] For the other study ports, we developed a methodology that relies on the Los Angeles and Long Beach CHE emission inventories and scales emissions using appropriate cargo tonnage. Table 3-4 summarizes the methods used for estimating vessel and CHE emissions at the study ports.[47]

Table 3-4: Summary of Emissions Estimation Process

Port	Vessel Emissions	Cargo Handling Equipment Emissions
Port of Baltimore	Determined 1996 emissions using ARCADIS (1999a) and Environ (2002) and scaled to 2002 based on growth in trips.	Based on Port of Los Angeles and Long Beach CHE inventories and ratios of marine tonnage.
Port of Chicago	Determined 1995 emissions using ARCADIS (1999b) and Environ (2002) and scaled to 2002 based on growth in trips.	Based on Port of Los Angeles and Long Beach CHE inventories and ratios of marine tonnage.
Port of Detroit	Determined 1995 emissions using ARCADIS (1999b) and Environ (2002) and scaled to 2002 based on growth in trips.	Based on Port of Los Angeles and Long Beach CHE inventories and ratios of marine tonnage.
Port of Houston, Port of Galveston, Port of Texas City, Port of Freeport	Interpolated 2002 emissions using 1997 and 2007 values from Starcrest (2000) for each waterway section.	Houston: Based on 2001 CHE inventory and scaled to 2002 based on marine tonnage. Galveston, Texas City, Freeport: Based on Port of Los Angeles and Long Beach CHE inventories and ratios of marine tonnage.
Port of Los Angeles	Used emissions from 2001 vessel inventory and scaled to 2002 based on tonnage.	Used emissions from 2001 CHE inventory and scaled to 2002 based on tonnage.
Port of Long Beach	Scaled from 2002 Port of Los Angeles inventory using ratios of cargo tonnage.	Used values from 2002 CHE inventory.

Summary of Results

Table 3-5 shows total marine freight vessel and port CHE emissions in the study area ports. The Los Angeles region has by far the greatest marine freight emissions – more than 22,600 tons of NOx and more than 1,500 tons of PM-10 annually. The Houston metropolitan area has more than 14,000 tons of NOx and more than 900 tons of PM-10 annually from marine freight. Marine freight emissions in the other three regions are smaller – roughly 3,300 tons of NOx and 190 tons of PM-10 in Baltimore, 2,200 tons of NOx and 175 tons of PM-10 in Chicago, and 500 tons of NOx and 30 tons of PM-10 in Detroit.

The Port of Houston has the greatest marine vessel emissions of any single port, followed closely by the Ports of Long Beach and Los Angeles. Port CHE emissions are greatest at the Port of Long Beach, followed by the Port of Los Angeles. CHE emissions make up approximately 20 percent of the marine freight total at these ports. At the Port of Houston, CHE emissions are only about 10 percent of the marine freight total. This difference reflects differences in the freight handled at the ports – Houston handles a large proportion of liquid bulk freight (mostly petroleum), which requires relatively little in terms of land-side CHE, while Los Angeles and Long Beach handle large volumes of containers, which require extensive land-side activity by CHE.

Table 3-5: Total Marine Freight Vessel and Port CHE Emissions by Port

		Marine Freight Vessel Emissions		Port CHE Emissions		Port Total Freight Emissions	
Region	Port	NOx	PM-10	NOx	PM-10	NOx	PM-10
Baltimore	Port of Baltimore	2,399	141	916	50	3,315	190
Chicago	Port of Chicago	1,901	160	298	13	2,199	173
Detroit	Port of Detroit	247	18	221	9	468	27
Houston	Port of Houston	10,576	694	1,011	74	11,587	769
	Port of Galveston	403	21	179	9	582	30
	Port of Freeport	461	20	228	12	688	32
	Port of Texas City	1,294	73	200	10	1,494	84
	Sub-total	12,734	808	1,618	106	14,351	915
Los Angeles	Port of Los Angeles	8,687	614	1,892	113	10,579	728
	Port of Long Beach	9,660	647	2,371	147	12,031	794
	Sub-total	18,347	1,261	4,263	260	22,610	1,521

Source: Based on Port emission inventories and calculations by ICF Consulting; see report text for details.

Table 3-6 shows a comparison of NOx emissions by vessel type. This comparison illustrates the vast differences in vessel and cargo type between study area ports. Containerships are the largest single emissions source at the Ports of Los Angeles and Long Beach. At the Port of Houston, 40 percent of NOx emissions come from tankers, while tankers contribute relatively little at the other ports. Emissions at the Ports of Chicago and Detroit are dominated by bulk carriers. Tugs and harbor craft account for significant portions of NOx emissions at most of the ports and approximately one-third of all vessel emissions at Los Angeles and Long Beach.

Table 3-6: Comparison of Marine Freight NOx Emissions by Vessel Type

	Containerships		Tankers		Bulk Carriers		Other		Tugs and Harborcraft	
Port	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%
Port of Baltimore	614	26%	216	9%	537	22%	987	41%	46	2%
Port of Chicago	-	0%	2	0%	1,639	86%	16	1%	245	13%
Port of Detroit	-	0%	0	0%	204	83%	-	0%	43	17%
Port of Houston	541	5%	4,302	41%	924	9%	1,851	18%	2,959	28%
Port of Los Angeles	5,032	58%	468	5%	110	1%	305	4%	2,772	32%
Port of Long Beach	3,735	39%	1,254	13%	575	6%	493	5%	3,603	37%

Source: Based on Port emission inventories and calculations by ICF Consulting; see report text for details.

Table 3-7 shows a comparison of NOx emissions from hotelling by ocean-going vessels (i.e., excluding tugs and other harborcraft) at the study area ports. The contribution of hotelling to total ocean-going vessel (OGV) emissions varies significantly. It is highest at the Texas ports and at the Port of Baltimore. Hotelling accounts for roughly 30 percent of OGV emissions at Los Angeles and Long Beach. Hotelling contributes very little to OGV emissions at the Ports of Chicago and Detroit.

Table 3-7: Comparison of Marine Freight OGV Hotelling Emissions

	Hotelling NOx Emissions		Other OGV NOx Emissions	Total OGV NOx Emissions
	tons	percent	tons	tons
Port of Baltimore	1,192	51%	1,161	2,353
Port of Chicago	154	9%	1,503	1,657
Port of Detroit	12	6%	192	204
Port of Houston	3,379	44%	4,238	7,618
Port of Galveston	218	75%	72	290
Port of Freeport	301	91%	31	332
Port of Texas City	607	65%	325	932
Sub-total	4,505	49%	4,667	9,172
Port of Los Angeles	1,670	28%	4,245	5,915
Port of Long Beach	1,983	33%	4,074	6,057
Sub-total	3,653	31%	8,319	11,972

Source: Based on Port emission inventories and calculations by ICF Consulting; see report text for details.

Table 3-8 shows a comparison of the NOx emissions from port CHE for the three ports that were able to provide CHE emissions by equipment type. Yard tractors make up the largest component of port CHE emissions in all cases. This comparison shows that, while yard tractor emissions are similar at the Ports of Los Angeles and Long Beach, emissions from handlers/loaders and from cranes are significantly higher at Long Beach. Emissions from yard tractors and handlers/loaders are relatively smaller at the Port of Houston than at the San Pedro Bay ports, reflecting the relatively small share of containerized cargo at Houston.

Table 3-8: Comparison of Port CHE NOx Emissions by Port

	Port of Los Angeles		Port of Long Beach		Port of Houston	
CHE Type	NOx tons	percent	NOx tons	percent	NOx tons	percent
Yard Tractors	1,475	78%	1,409	59%	459	45%
Forklifts	92	5%	141	6%	244	24%
Handlers/Loaders	228	12%	363	15%	120	12%
Cranes	72	4%	365	15%	101	10%
Other	25	1%	93	4%	86	9%
Total	1,892	100%	2,371	100%	1,011	100%

Source: Based on Port emission inventories and calculations by ICF Consulting; see report text for details.

3.5 Air Freight Emissions

In this section, we present estimates of the emissions that are attributable to air transport of freight. Air transport is by far the smallest of the four freight modes on a tonnage or ton-mile basis. Nationally, air freight accounts for 0.4 percent of domestic freight ton-miles. Air freight is the most rapidly growing freight mode, however, with ton-miles nearly doubling since 1990.

Emissions from air freight are generated by aircraft and by airport *ground support equipment* (GSE). Aircraft include those devoted exclusively to cargo and passenger aircraft that carry freight together with passenger baggage in the cargo space (belly cargo). Airport GSE include aircraft and baggage tow tractors, ground power units, portable aircraft air conditioning units, and air start units, as well as medium and light duty trucks for such operations as refueling and de-icing. Over the past five years, many of the nation's airports have been working to electrify GSE, and as a result, GSE emissions are dropping significantly. For this study, we have estimated GSE emissions attributable to freight based on the same fractions used in determining the aircraft emissions associated with freight, as discussed below.

Summary of Methodology

Aircraft emit pollutants during flight that, due to atmospheric mixing, affect ground level pollutant concentrations. This mixing zone extends to 3,000 feet on average, and all pollution emissions in this zone are included in an airport emission inventory. The aircraft operations of interest within the mixing zone are defined as those in the landing and takeoff (LTO) cycle. Exhaust emissions are calculated for one complete LTO cycle of each aircraft type using emissions factors for the aircraft's specific engines at each power setting or mode of operation, as well as the time spent in each mode. The activity of aircraft for the inventory period can then be multiplied by emission factors to calculate the total emissions.

All regions use the FAA-sponsored Emissions and Dispersion Modeling System (EDMS) to develop emission inventories for airports. For each of the major freight airports in the six study areas, we obtained from the state or regional air quality agency an annual emission estimates from the most recent application of the EDMS model. We considered the airports of interest to be those handling at least five percent of a region's air cargo, which includes the major passenger airport in each region plus the Ontario airport in the Los Angeles region and the Alliance airport in the Dallas-Fort Worth region.

The EDMS model does not distinguish between freight movement from non-freight (passenger) movement. Therefore, we developed an approach to allocate each airport's total commercial aircraft emissions to the freight and non-freight sectors, as described previously in Section 2.1 and summarized below.[48]

We obtained commercial aircraft departure records from the BTS Air Carrier Statistics database. We assumed emissions from air cargo aircraft are attributable entirely to freight. Alliance Airport in Fort Worth (AFW) is unusual in that it handles air cargo almost exclusively. Among the other study airports, air cargo aircraft account for 0.4 to 7.0 percent of departures. For passenger aircraft departures, we estimated the weight of the aircraft's freight (belly cargo) and the weight of the aircraft's passengers and baggage and used these percentages to allocate emissions.[49] Through this process, we estimate that freight is responsible for 1.4 to 6.7 percent of passenger aircraft emissions at the study airports. In total, we estimate that the air freight share of aircraft emissions ranges from a low of 2.3 percent at Detroit to a high of 10.9 percent at LAX, among the study airports with passenger service (the exception being AFW, which is nearly 100 percent freight).

Summary of Results

Table 3-9 summarizes the emissions attributable to air freight movement for five criteria pollutants: VOC, NOx, CO, SOx, and PM-10.[50] LAX has by far the largest freight emissions among the eight study airports. Aircraft emissions of VOC, NOx, and CO in the Los Angeles region are approximately 70 percent more than the next largest region (Chicago). Emissions of SOx (and PM-10, which we calculated from the SOx emissions) are proportionally lower for the Los Angeles airports, most likely due to the use of jet aircraft fuel with lower sulfur content, as required in California.

Table 3-9: Aircraft Emissions Associated with Freight Movement, 2002

		Emissions (tons per year)				
Region	Airport	VOC	NOx	CO	SOx	PM-10
Baltimore	BWI	3.1	20.7	26.6	2.0	0.6
Chicago	ORD	47.6	439.1	281.3	27.6	8.6
Dallas-Ft Worth	DFW	13.3	66.1	75.9	6.4	2.0
	AFW	26.3	68.9	76.2	4.8	1.5
	Total	39.7	135.1	152.1	11.1	3.5
Detroit	DTW	10.5	35.4	96.7	4.3	1.3
Houston	IAH	8.1	75.0	83.9	7.0	2.2
Los Angeles	LAX	75.4	662.0	448.0	23.7	7.4
	ONT	5.0	71.4	49.5	2.4	0.8
	Total	80.4	733.5	497.4	26.2	8.1

Source: Compiled by ICF Consulting based primarily on data provided by state and regional air quality agencies; see report text for details.

Table 3-10 shows GSE emissions attributable to air freight movement for five criteria pollutants: VOC, NOx, CO, SOx, and PM-10. We obtained GSE emissions from each state or regional air quality agency and allocated a portion to freight using the same methodology and ratios as discussed above for aircraft. With the exception of Baltimore, all of the air quality agencies estimated the emissions for ground support equipment outside of the EDMS model, which likely reflects past problems with the emission factors used in the EDMS. The latest version of EDMS uses the same emission factors as the current EPA NONROAD model. GSE emissions for DTW and AFW were not available from air quality agencies. For DTW, we estimated GSE emissions by multiplying ORD GSE emissions by the ratio of air freight activity at DTW to ORD. For AFW, we estimated GSE emissions by multiplying the DFW GSE emissions by the ratio of air freight activity at AFW to DFW.

The results show that LAX has again by far the largest air freight-related emissions of NOx and PM from GSE among the eight study airports. In all airports, NOx and PM-10 emissions from GSE are generally much less than the freight aircraft emissions of those pollutants, typically less than 20 percent of the aircraft emissions. The high CO emissions reflect the use of gasoline fuel in much of the ground support equipment.

Table 3-10: Ground Support Equipment Emissions Associated with Freight Movement, 2002

		Emissions (tons per year)				
Region	Airport	VOC	NOx	CO	SOx	PM-10
Baltimore	BWI	3.8	5.0	94.4	0.4	0.2
Chicago	ORD	2.8	22.5	31.4	0.4	1.6
Dallas-Ft Worth	DFW	5.3	18.4	219.8	0.6	0.6
	AFW	0.6	2.0	23.4	0.1	0.1
	Total	5.8	20.4	243.2	0.6	0.6
Detroit	DTW	0.6	5.0	7.0	0.1	0.4
Houston	IAH	3.0	9.6	123.5	0.3	0.3
Los Angeles	LAX	17.6	122.0	218.2	0.5	5.1
	ONT	2.1	14.7	26.3	0.1	0.6
	Total	19.7	136.7	244.5	0.6	5.7

Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies; see report text for details.

3.6 Summary and Comparison

Table 3-11 shows a comparison of freight transportation NOx emissions by mode. Emissions are greatest in magnitude in Los Angeles, followed by Chicago and Detroit. NOx emissions from freight in the Los Angeles region are nearly five times those in Baltimore and nearly three times those in Dallas-Fort Worth.

Table 3-11 clearly shows the dominant role of trucking in urban freight movement and emissions. Heavy-duty trucks are responsible for more than three-quarters of freight emissions in all six regions. In Detroit and Dallas-Fort Worth, trucking accounts for virtually all freight emissions – 97 percent of the freight total in Detroit and 93 percent in Dallas-Fort Worth.

In other modes, the regions show considerable diversity in terms of freight emissions. Freight rail NOx emissions in Chicago are nearly twice that in any other region and make up almost 20 percent of Chicago’s total freight emissions. In the other five regions, freight rail accounts for less than 10 percent of the total.

Marine freight NOx emissions are greatest in the Los Angeles region, where they account for 14 percent of the freight total, and in Houston, where they account for 17 percent of the total. Air freight emissions are dwarfed by the other modes in all six regions. Air freight NOx emissions are greatest in the Los Angeles region, making up 0.5 percent of the region’s freight total.

Table 3-11: Regional NOx Emissions from Freight by Mode, 2002

	Trucking		Freight Rail		Marine Freight		Air Freight		Freight Total	
Region	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%	NOx tons	%
Baltimore	29,081	83%	2,655	8%	3,315	9%	26	0.1%	35,078	100%
Chicago	96,291	79%	23,212	19%	2,199	2%	462	0.4%	122,164	100%
Dallas-Ft. Worth	53,718	93%	4,157	7%	0	0%	155	0.3%	58,030	100%
Detroit	98,195	97%	2,106	2%	468	0%	40	0.0%	100,809	100%
Houston	64,590	77%	5,163	6%	14,351	17%	85	0.1%	84,189	100%
Los Angeles	130,341	78%	12,744	8%	22,610	14%	870	0.5%	166,564	100%

Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies, MPOs, and ports; see report text for details.

Table 3-12 shows the comparison of freight transportation PM-10 emissions across modes. Trucking is still the largest contributor, though less dominant than with NOx emissions. In particular, marine freight accounts for a major portion of freight PM-10 emissions in regions with large seaports – 40 percent of the total in Houston, 37 percent in Los Angeles, and 19 percent in Baltimore. This in part reflects the high PM emission rates of large marine vessels that burn residual fuel and have little or no emission controls.

Table 3-12: Regional PM-10 Emissions from Freight by Mode, 2002

	Trucking		Freight Rail		Marine Freight		Air Freight		Freight Total	
Region	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%	PM-10 tons	%
Baltimore	734	74%	71	7%	190	19%	1	0.1%	996	100%
Chicago	2,641	73%	792	22%	173	5%	10	0.3%	3,616	100%
Dallas-Ft. Worth	884	88%	113	11%	0	0%	4	0.4%	1,002	100%
Detroit	2,382	96%	58	2%	27	1%	2	0.1%	2,469	100%
Houston	1,256	54%	141	6%	915	40%	2	0.1%	2,314	100%
Los Angeles	2,210	54%	346	8%	1,521	37%	14	0.3%	4,091	100%

Source: Compiled and calculated by ICF Consulting, based primarily on data provided by state and regional air quality agencies, MPOs, and ports; see report text for details.

Table 3-13 compares annual freight NOx emissions with total mobile source and total emissions (mobile, area, and point sources). Freight accounts for 40 to 52 percent of all mobile source NOx emissions, and 29 to 39 percent of all NOx emissions in the study regions (total emissions data was not available for

Baltimore). This is significantly higher than the national freight share of NOx emissions (26.8 percent) presented in Table 2-9. Freight NOx emissions are highest in absolute terms and in percentage terms in the Los Angeles region, which likely reflects the large contribution from the region's ports.

Table 3-13: Regional Freight NOx Emissions Compared to Total Mobile Source and Total Emissions, 2002

	Freight Sources	All Mobile Sources		All Sources	
Region	Tons NOx	Tons NOx	Freight %	Tons NOx	Freight %
Baltimore	35,078	N/A	N/A	N/A	N/A
Chicago	122,164	241,375	51%	357,978	34%
Dallas-Ft. Worth	58,030	143,392	40%	166,088	35%
Detroit	100,809	196,756	51%	327,422	31%
Houston	84,189	161,745	52%	291,001	29%
Los Angeles	166,564	384,227	43%	425,954	39%

Source: Freight emissions from sources as described in report text. Total mobile source emissions and total emissions obtained from state air quality agencies; data in most cases reflects preliminary submittal of 2002 emission inventory data under EPA's Consolidated Emissions Reporting Rule.

Table 3-14 compares annual freight PM-10 emissions with total mobile source and total emissions (mobile, area, and point sources). Freight accounts for 22 to 47 percent of PM-10 emissions from mobile sources in the study regions. Compared to total emissions, freight accounts for 1.0 to 5.8 percent of PM-10 emissions in the study regions. Again, this is higher than the national freight share (0.8 percent) presented in Table 2-9. Freight accounts for the largest share of total PM-10 emissions in the Chicago region, which likely reflects the intensive railroad activity there. Note, however, that the vast majority of PM-10 emissions come from agricultural fields, wildfires, and fugitive dust. The total PM-10 emissions in the six regions, and the portions attributable to freight, therefore depend heavily on the amount of undeveloped land within the nonattainment boundaries. Note also that the PM emissions from freight transportation are a greater concern than the coarse particulates from sources like fugitive road dust. Current emission inventories do not provide an accurate estimate of fine particulates, so it is difficult to assess the freight sector contribution to these emissions.

Table 3-14: Regional Freight PM-10 Emissions Compared to Total Mobile Source and Total Emissions, 2002

	Freight Sources	All Mobile Sources		All Sources	
Region	Tons PM-10	Tons PM-10	Freight %	Tons PM-10	Freight %
Baltimore	996	N/A	N/A	N/A	N/A
Chicago	3,616	9,053	40%	62,273	5.8%
Dallas-Ft. Worth	1,002	4,485	22%	105,326	1.0%
Detroit	2,469	5,947	42%	114,313	2.2%
Houston	2,314	4,906	47%	132,387	1.7%
Los Angeles	4,091	15,196	27%	232,476	1.8%

Source: Freight emissions from sources as described in report text. Total mobile source emissions and total emissions obtained from state air quality agencies; data in most cases reflects preliminary submittal of 2002 emission inventory data under EPA’s Consolidated Emissions Reporting Rule.

4 Emission Mitigation Strategies

As illustrated in the previous section, there is a need to significantly reduce freight transportation emissions in major metropolitan areas. This section describes strategies to reduce emissions from freight transportation. These strategies can be grouped in two major categories:

- *Technological strategies*, which modify a piece of equipment or its fuel to reduce emissions.
- *Operational strategies*, which change the way a piece of equipment is used, resulting in lower emissions.

This section reviews technological and operational emission reduction strategies that apply to one or more of the major freight emissions sources: trucking, railroads, marine vessels, port cargo handling equipment, aircraft, and airport ground support equipment. Selection of any particular strategy depends greatly on the cost effectiveness of the strategy, a complex issue that is not discussed here.

4.1 Technological Strategies

Technological strategies focused on pollutant emission reductions are often summarized as the "Five Rs" – Retrofit, Repower, Refuel (with alternative fuels), Repair/Rebuild, and Replace.

Retrofit

A retrofit typically involves the addition of an after-treatment device to remove emissions from the engine exhaust. Retrofits can be very effective at reducing emissions – eliminating up to 90 percent of pollutants in some cases. Many of the effective after-treatment devices require use of ultra-low sulfur diesel (ULSD). Some examples of after-treatment devices used for diesel retrofits are summarized in the box to the right.

Repower

Repowering involves replacing an existing engine with a new engine. This strategy is most effective for use in equipment with a useful life longer than that of the engine. Repowering provides an opportunity to install a new engine that meets much lower emission standards than the original engine, often in conjunction with fuel economy benefits and lower maintenance costs. Repowering can also include converting diesel-powered equipment (such as port cranes) to electrical power.

Examples of Retrofit Technologies

Diesel oxidation catalysts *use a chemical process to break down pollutants into less harmful components. They have been used for over 20 years and are perhaps the most proven after-treatment device. Diesel oxidation catalysts can reduce emissions of PM by 20 to 50 percent, but do not affect NOx emissions. They work best when combined with ULSD.*

Diesel particulate filters *collect particulate matter in the exhaust stream. The high temperature of the exhaust heats the ceramic structure and allows the particles inside to break down into less harmful components. These filters can be installed on both new and used vehicles, but they must be used in conjunction with low sulfur diesel. Diesel particulate filters can reduce PM emissions by 50 to 90 percent, but do not affect NOx emissions.*

NOx catalysts *employ a chemical process to reduce NOx emissions, although these devices have not been tested extensively in off-road applications. Lean NOx catalysts have been shown to reduce NOx emissions by 10 to 20 percent. NOx adsorbers can eliminate more than 70 percent of NOx, but require the use of ULSD.*

Selective catalytic reduction *(SCR) technology is currently employed at many power plants to chemically reduce NOx emissions to nitrogen and water, but has only recently been adapted to vehicles and other mobile sources. SCR requires a reducing agent (ammonia or urea) to be injected into the exhaust stream. SCR has been shown to reduce NOx emissions by 75 to 90 percent and PM emissions by 20 to 30 percent. An SCR system can be used in conjunction with a diesel particulate filter to achieve much greater particulate reduction.*

Alternative Fuels

A variety of alternative fuels can be used in freight vehicles and equipment. Some require little or no modification to the engine (such as emulsified diesel or biodiesel) while others (such as natural gas) require engine conversion or replacement. The alternative fuels summarized in the box to the right can reduce emissions from many types of diesel engines, although some come at a price of lower fuel efficiency or power.

In addition to these fuels, ULSD can help to reduce diesel emissions. As described in Section 2.3, ULSD has less than 15 ppm sulfur, compared to 500 ppm typically used in today's on-road diesel and 3,000 ppm in today's off-road diesel. The primary purpose of ULSD is to enable or improve the performance of after-treatment technologies, such as a particulate filter. Use of ULSD alone (without after-treatment) can reduce PM emissions by 15 to 20 percent compared to higher sulfur diesel.

Hybrid-electric power may soon offer fuel savings and emission reductions in a number of freight applications. For example, many freight railroads are currently experimenting with hybrid switcher locomotives, such as the "Green Goat" manufactured by RailPower Technologies Corporation. The Green Goat relies on battery power to run electric traction motors on the axles. The lead acid batteries are charged by a small onboard diesel-powered generator and microturbine. The reduced reliance on diesel fuel allows for a 30 percent reduction in fuel use and up to a 90 reduction in NOx emissions, compared to a conventional switcher locomotive.

Replacement

Selectively replacing older freight equipment can sometimes be the most cost-effective way to reduce the emissions of a fleet. In this way, older, higher polluting equipment is retired from service before it would otherwise be retired. Newer equipment that meets more stringent emission standards is purchased to replace the retired equipment, sometimes in conjunction with retrofit devices or alternative fuels. These programs are sometimes called "scrappage" or "fleet renewal" programs. Such programs often include procedures to ensure that the retired equipment is

Examples of Alternative Fuels

Emulsified diesel *is a blended mixture of diesel fuel, water, and other additives that reduces emissions of PM and NOx. Emulsified diesel can be used in any diesel engine, but the addition of water reduces the energy content of the fuel, so some reduction in power and fuel economy can be expected. Emulsified diesel has been certified by both EPA and CARB for emission reductions. Expected NOx reductions are in the range of 17 to 20 percent; PM emission reductions range from 17 to 50 percent. Emulsified diesel typically increases VOC emissions.*

Biodiesel *is a renewable fuel that can be manufactured from new and used vegetable oils and animal fats. Biodiesel is safe and biodegradable and reduces emissions of PM, CO, HC, and air toxics. However, emissions of NOx increase with the concentration of biodiesel in the fuel. Biodiesel is often used as a blend, typically 80 percent petroleum diesel and 20 percent biodiesel (B20).*

Natural gas*, in the form of compressed natural gas (CNG) or liquefied natural gas (LNG), can be used to power off-road engines. Existing diesel engines can sometimes be converted to run on natural gas, or the existing engine can be replaced with a natural gas engine. There is often a fuel penalty incurred when migrating from traditional diesel fuel. In addition, the use of natural gas raises some challenges with respect to storage and safe handling of the fuel. Because of its fossil fuel base, natural gas is not an effective strategy for reducing GHG emissions.*

Propane *can also be used to power diesel engines in some applications. Commercial kits are available for retrofitting diesel engines to operate on liquid propane gas (LPG). A number of diesel yard tractors at southern California ports were recently converted to LPG. Compared to unregulated (Tier 0) yard tractors, LPG can reduce NOx and PM emissions by approximately 80 percent. Because of its fossil fuel base, propane is not an effective strategy for reducing GHG emissions.*

Ethanol *can be blended with diesel to reduce some emissions. Sometimes known as "E-diesel" or "oxydiesel", these blends typically have 10 percent ethanol. Ethanol-diesel blends have not been widely used.*

destroyed in order to prevent re-sale and continued use. Fleet owners often benefit from improved fuel economy and performance, as well as lower maintenance costs.

Repair/Rebuild

All freight equipment requires periodic maintenance. Routine maintenance and repairs help to ensure that engines operate at maximum performance and emission rates do not exceed the designed standard. Major maintenance intervals provides an opportunity to have the engine rebuilt using more modern, cleaner equipment that provides an immediate emission reduction benefit.

Improving Fuel Efficiency

In addition to the “Five Rs” strategies described above, technological strategies that improve fuel economy typically have the added benefit of reducing emissions. Generally, a reduction in fuel use leads to a commensurate reduction in pollutant emissions. Table 4-1 lists some examples of technological options for improving the fuel efficiency of trucks, locomotives, ships, and aircraft.

Table 4-1: Technological Strategies for Improving Freight Fuel Efficiency

Trucking	Rail	Marine	Air
Fuel efficient lubricants	Tare weight reduction	Larger vessels	Aerodynamic improvements
Tare weight reduction	Low-friction bearings	Improved hull design	Lighter weight materials
Aerodynamic improvements	Steerable rail car trucks		More efficient engines
Reduced tire rolling resistance	Improved track lubricants		

4.2 Operational Strategies

Operational strategies change the way that trucks, locomotives, ships, and aircraft operate, resulting in fewer pollutant emissions. Many of these strategies, though not all, reduce fuel use and result in lower operating costs for the equipment owner. Table 4-2 summarizes some operational strategies that can reduce emissions from freight transportation.

Table 4-2: Operational Strategies for Reducing Freight Fuel Use and Emissions

Trucking	Rail	Marine	Air
Reduced overnight idling	Reduced switchyard idling	Cold ironing (electrification)	Increased load factors
Reduced pick-up/drop-off idling	Reduced line haul speeds	Reduced port equipment idling	Reduced vertical separation minimums
Port access improvements	Reduced empty mileage	Reduced hotelling time	Reduced use of aircraft APUs
Reduced highway speeds	Double tracking	Reduced vessel speeds	Improved runway efficiency
Arterial signal synchronization	Train clearance improvement	Use of larger ships	Use of continuous descent approach
Grade crossing separation	Elimination of circuitous routings	Hull cleaning	Electrification of ground support equipment
Driver training			
Reduced empty mileage			

Trucking Operational Strategies

One of the most effective opportunities to reduce truck emissions is to reduce unnecessary idling. Idling is most extensive when trucks are parked at truck stops or other roadside rest areas, often to allow the driver to sleep. Drivers idle for extended periods in order to heat or cool the cab, to run electrical appliances, to keep the engine warm, or simply out of habit. Using a heavy-duty truck engine to provide temperature control or electricity is grossly inefficient and causes unnecessary fuel consumption and pollutant emissions.

A variety of technologies are available that provide cab heating, cooling, and/or electrical supply while consuming far less energy. These include:

- An *auxiliary power unit* (APU) mounted externally on the truck cab.
- *Automatic engine idle systems* start and stop the truck engine automatically to maintain a specified cab temperature or to maintain minimum battery voltage.
- *Truck Stop "Shore Power" Electrification*, which allows drivers to plug trucks into power outlets to run cab amenities.
- *Advanced Truck Stop Electrification*, which provide heating, cooling, and other amenities via a console through the cab window.

Many large truck stops are located on the edge of metropolitan areas, often within the boundaries of an ozone nonattainment area. Thus, idling at these truck stops can contribute significantly to a region's air quality problems. While the amount that trucks idle per night is not well understood, several studies have estimated that long-haul trucks idle approximately six hours per night.[51,52] We estimate that reducing all overnight idling by 50 percent would reduce NOx emissions by 156 tons per year in the Dallas-Fort Worth area and 524 tons per year in the Houston area. There reductions represent 0.3 and 0.8 percent of the on-road heavy-duty vehicle emission inventories in these regions, respectively.

Truck drivers also idle for extended periods when waiting to pick up or drop off a shipment. While a portion of driver wait time may be attributable to carriers building buffers into their schedules to ensure on-time pickup and delivery, the biggest contributing factor appears to be delay caused by shippers and receivers. Shippers can improve scheduling with enhanced communications or logistics software. They can also provide climate-controlled comfort stations at docking facilities and, possibly, couple this with a no-idling policy.

Roadway congestion causes truck delay, idling, and excess emissions. While trucks experience roadway congestion in every urban area, some of the most obvious congested locations are international borders, toll facilities, grade crossings, and port terminal gates. At borders, lengthy immigration and security procedures can contribute to long delays for trucks. The Detroit border crossings, for example, handle more than 5 million commercial trucks per year. Backup times for trucks averaged almost 30 minutes in 2002 and exceeded one hour at busy times on many days.[53] Greater use of electronic pre-clearance can help to streamline border operations and reduce congestion. Physical capacity expansion may also be needed at some border crossings.

It is important to also note that the effects of congestion on emissions are sometimes unclear. Generally, congested roadway conditions increase emissions because they cause idling and more frequent short bursts of acceleration, when per-mile emission rates are higher than at free flow speeds. However, at steady state speeds over 20 mph, emission rates tend to increase with speed. Per mile emissions of NOx, for example, are almost twice as high at 65 mph than at 20 mph. Many trucking companies have adopted a maximum speed policy for their drivers as a way to save fuel expenses and to promote safety. State and local agencies have also considered highway speed reductions as a way to reduce emissions. For example, the Tennessee Department of Transportation recently agreed to reduce the truck speed limit in Shelby County to 55 miles per hour as a way to help the region attain ozone standards.[54]

Driving practices can have a large impact on fuel economy. In addition to limiting speed and idling time, drivers can improve fuel economy through their acceleration practices, shifting technique, route choice, use of accessories, and number of stops. Driver training can be provided in-house (at large fleets), through vocational schools, or by outside consultants affiliated with training organizations. An effective program also includes monitoring of driver performance after training and incentives for drivers who reduce fuel consumption. Data from electronic engine monitors can be used by trainers to review detailed operating patterns with drivers and benchmark performance over time. If properly designed and implemented, incentive programs have been found to be very effective at changing driver behavior.

Trucks can also improve efficiency and reduce emissions by reducing empty mileage. When motor carriers cannot arrange for a return shipment, drivers may be forced to pull empty trailers. It is not uncommon to find that empty driving accounts for 20 percent of all mileage for long-haul trucks. Particularly for smaller trucking companies and regional operations, there are opportunities to reduce empty mileage through improved freight logistics. Minimizing empty mileage, as well as other inefficient practices, results in greater fuel productivity (more ton-miles per gallon), which reduces emissions and, at the same time, increases profits for trucking companies.

Rail Operational Strategies

As with trucks, an effective operational strategy to reduce locomotive emissions is to reduce idling. Locomotives may idle for as long as eight hours while cars are switched or while the train waits on a siding for other trains to pass. Idling may also be needed to keep the engine warm in cold weather and to keep accessories from freezing. However, locomotives are often kept idling even when there are no operational reasons to do so. EPA estimates that idling accounts for 60 percent of switch yard locomotive operating time and 12.5 percent of line-haul locomotive operating time.[55]

In order to reduce idling time, fuel consumption, and pollutant emissions, an APU can be used to provide power when a locomotive is idling. The CSX Corporation has developed an APU that automatically shuts down the main locomotive engine while maintaining all vital main engine systems, such as climate control and heating engine fluids in cold weather. The device is powered by a small diesel engine, and parallels all circulation systems on the locomotive. CSX and International Road and Rail, based in Canada, have formed a joint venture company called EcoTrans Technologies to manufacture and sell the system. EcoTrans estimates that the APU can eliminate 90 percent of switcher idling time. We estimate that retrofitting 50 percent of the switcher locomotives in the Baltimore and Houston regions with APUs, and reducing idling to the extent possible with these devices, would reduce annual NOx emissions by 231 tons and 277 tons respectively. These reductions represent 10 percent and 6 percent of the total annual freight railroad emissions in these regions, respectively.

Locomotives can also be installed with automatic shut-down devices. These devices monitor the locomotive temperature and restart it as necessary to maintain minimum temperatures. Newer locomotives are also equipped with a low idle setting that reduces fuel use and emissions during extended idle periods. Replacing older switch yard locomotives with these newer units can help to reduce the emissions associated with idling.[56]

Trains can improve fuel efficiency and reduce emissions by operating at lower maximum line-haul speeds. Railroads sometimes take this step on one or more lines in an effort to cope with higher fuel prices. For example, in 2001 BNSF experimented with operating eastbound intermodal trains between New Mexico and Chicago at a maximum speed of 60 miles per hour rather than 70.[57] Of course, if railroads lower train speeds to the point where service is inadequate to shippers, they risk diverting traffic to trucks.

Freight rail emissions also can be reduced by improving line-haul efficiency and reducing rail system congestion. However, the interconnected nature of the rail system means that it is much harder to identify and remove the causes of congestion. Rail system congestion can quickly ripple throughout the nation. If one location becomes clogged, locomotives are delayed and unable to meet their next assignments, crews exhaust their Federally-mandated on-duty hours and need to be replaced, and rail cars miss their connections.[58] Thus, rail congestion in Arizona or New Mexico can increase emissions in Los Angeles. In this way, the freight rail system has far more in common with the air travel system than with roads, although the nature of the network inefficiencies is different.

There is widespread agreement that the nation’s freight rail system is operating at levels of utilization that produce substantial congestion in many places and risk near-gridlock in the future.[59] While there are no comprehensive analyses of the national rail system congestion, its effects are evident in a number of ways. For example, Union Pacific has recently been turning away traffic (both bulk and intermodal) and canceling some existing customers’ trains in an effort to keep its system fluid.[60] The current media are full of accounts of various rail system breakdowns.[61] Rail system congestion is also evident in a drop in average train speeds since 1992.[62] While speed itself is largely unrelated to locomotive emissions, slower average train speeds generally indicate more idling and starts and stops en-route, which leads to higher emissions.[63] The solutions to rail system congestion problems are complex, but clearly the railroad companies’ lack of investment capacity has contributed to a decline in net capital stock.

Marine Operational Strategies

Ships can reduce emissions by minimizing the use of diesel-powered auxiliary engines while in port. Ships typically run their auxiliary engines while docked (termed “hotelling”) in order to provide electrical power to the ship for climate control, lighting, cargo refrigeration, on-board cargo handling equipment, and other uses. Hotelling emissions can make up a major portion of total port emissions. For example, hotelling emissions account for 32 percent of all marine vessel NOx emissions at the Port of Houston and nearly 20 percent at the Port of Los Angeles.[64,65]

Cold ironing involves retrofitting ocean going vessels to allow them to receive shore power to meet their energy needs while docked at the port, thus allowing them to shut off their auxiliary engines. This strategy is most effective for ports and vessels that have long hotelling times, multiple annual vessel calls, and high auxiliary power needs. The China Shipping terminal at the Port of Los Angeles docked its first commercial container ship using cold ironing in June 2004, and the Port of Seattle plans to implement cold ironing for cruise ships in 2005.[66]

We estimate that using cold ironing to reduce hotelling emissions for 50 percent of the vessels calling on the ports of Baltimore and Los Angeles would reduce annual NOx emissions at these ports by 567 tons and 808 tons respectively. These values represent 17 and 4 percent of the total annual marine vessel NOx emissions in the Baltimore and Los Angeles regions, respectively.

Reducing ship speed typically reduces emissions. Ships calling on a port travel at cruise speed in open water before entering a port's "reduced speed zone," as described in Section 3.4. Vessel speed reductions can be promoted by expanding the reduced speed zone further into the cruise region or lowering the specified reduced speed. For example, the Ports of Los Angeles and Long Beach have established a Voluntary Commercial Ship Speed Reduction Program, which urges vessels to travel at or below 12 knots within 20 miles of the coast.

Aircraft Operational Strategies

A number of operational strategies are being explored to improve air traffic management, many of which will result in lower fuel use and emissions. These strategies are commonly referred to as CNS/ATM (communication, navigation, surveillance/air traffic management). They will allow more accurate aircraft approach routes, increase runway efficiency, and reduce aircraft arrival spacing. One example is Reduced Vertical Separation Minimums (RVSM). This involves reducing the vertical separation between aircraft at cruise altitude from 2000 feet to 1000 feet. The effect is an increase in airspace capacity, particularly for long-distance and fuel efficient flights, which allows for greater aircraft scheduling and routing flexibility.[67] RVSM became standard in the U.S. in January 2005.

Another operational strategy involves providing electricity and air conditioning to aircraft directly at the gates, which reduces the need for aircraft APUs and decreases emissions. Many large and medium size aircraft use APUs when the main engine is shut down at the airport gate. A report for EPA estimates that, while APU emissions cannot be completely eliminated due to their use during engine startup, APU emissions can be reduced by up to 90 percent.[68] While these electrified gates are available at airports across the U.S., some air carriers choose not to use these gates because the time it takes to hook the aircraft up to the system reduces the efficiency of their established operations while cleaning and preparing the aircraft for the next flight.[69]

A longer term operational strategies for reducing aircraft emissions is the use of continuous descent approach (CDA). In a standard approach to an airport, an airplane is brought down in stages – descending and leveling off several times before landing – with the final level flight segment only 1,000 feet above the airport. Each time an aircraft descends from an intermediate altitude and levels off, thrust must be applied to maintain level flight, which increases emissions relative to a continuous gradual descent. Gradual and continuous descent approach, in which wing flaps and engine thrust are employed differently with the engine operating in idle, or near idle, is not only more fuel-efficient but also quieter. CDA is being implemented at a number of airports in Europe. In the United States, CDA has been successfully tested at Louisville International Airport in partnership with United Parcel Service in October 2002. These tests suggest that up to 500 pounds of fuel could be saved on each flight using CDA.[70]

5 Conclusions and Recommendations

Demand for freight transportation has been rising steadily, and forecasts show continued growth over at least the next several decades. This growing demand is straining portions of the nation's freight system, including some intercity corridors and critical intermodal connections. In an economy where many goods are needed in tightly scheduled manufacturing and distribution systems, deterioration in the reliability of freight travel times can have serious economic repercussions. In response to these challenges, many public agencies are considering freight system investments, including both capacity additions and operational improvements.

As freight becomes more integrated into the transportation planning and programming process, there is a need to consider more comprehensively the effects of freight movement on emissions and air quality. At the same time, increasing concerns about the health effects of diesel exhaust, coupled with the implementation of new air quality standards for ozone and fine particulates, will require many regions across the country to find new ways to control NOx and PM emissions from freight transportation sources. This report attempts to fill a void in the current understanding of the air quality impacts of freight transportation.

Summary of Freight Transportation Emissions

This study shows that freight is a major source of national and regional NOx emissions. At the national level, freight transportation accounts for half of mobile source NOx emissions and 27 percent of NOx emissions from all sources. At the regional level, freight accounts for a similar portion of mobile source NOx emissions (40 to 52 percent in the six study regions) and a larger share of total NOx emissions (29 to 39 percent in the six study regions).

Trucking is the major source of freight NOx emissions, accounting for 67 percent of freight emissions nationally and 77 to 97 percent of the freight emissions total in the six regions. In regions with major seaports (Los Angeles, Houston, and Baltimore), commercial marine freight contributes significantly to NOx emissions, accounting for 9 to 17 percent of the freight emissions total. In Chicago, rail freight accounts for 19 percent of the freight NOx total; in other regions, rail freight accounts for less than 10 percent of NOx emissions from freight. Air freight is responsible for no more than 0.5 percent of total freight NOx emissions in the six study regions and less than 0.1 percent at the national scale.

Freight is also a major source of PM-10 emissions. Freight transportation accounts for 36 percent of mobile source PM-10 emissions nationally, and 22 to 47 percent in the six study regions. Total PM-10 emissions nationally and regionally are dominated by area sources such as agricultural fields, wildfires, and fugitive dust, so freight accounts for only a small portion of total PM-10 emissions (0.8 percent nationally and 1.0 to 5.8 percent at the regional level). Freight contributes a larger share of total fine particulate (PM-2.5) emissions, but emission inventory data does not allow for an accurate assessment of the freight share of these emissions.

The strict new EPA emission standards for heavy-duty trucks and off-road equipment (such as port cargo handling equipment) will dramatically reduce NOx and PM emissions from these sources starting in 2007. Similar strict standards are expected to be adopted for locomotives and U.S.-flagged commercial marine vessels, but slow fleet turnover means that the full impact of these standards will not be felt for several decades. As a result of the EPA standards, emissions from freight transportation are generally expected to decline over the next several decades, although emissions from some modes will decline more rapidly than others. By 2020, the commercial marine and rail sectors will account for a much larger share of freight NOx and PM-10 emissions than they do currently.

Recommendations for Further Research

In order to more comprehensively consider the emissions effects of freight transportation in the planning and project development process, additional research is needed in a number of areas. This study highlights in particular the need for improvements to the standard processes for developing emission inventories for non-road freight modes and the need for a better understanding of the effects of freight operational improvements on emissions.

Improved Emission Inventory Processes

There are a number of shortcomings in the current practices for estimating regional freight emissions:

- The process for estimating regional truck emissions typically ignores long-term truck idling. Most state and regional agencies do not have adequate data to properly estimate the extent of truck idling. There is also some uncertainty surrounding the emission factors for extended truck idling and the effects of new emission standards on truck idle emission rates.
- Regional truck activity is usually estimated through a process that does not fully account for differences between passenger vehicle and truck behavior. For example, truck speeds are assumed to be the same as passenger vehicle speeds. Forecasts of truck activity are often based on passenger vehicle forecasts. There is a need to improve the modeling of regional truck activity in a way that supports the emissions estimation process. One option would be to undertake this effort as part of FHWA’s Freight Model Improvement Program (FMIP).
- The standard approach for calculating freight railroad emissions is simplistic and potentially subject to significant errors. Because there is little publicly available data on the operation of private railroads, state and regional air quality agencies must rely on data provided by the railroads themselves. These data can vary widely in their completeness, level of detail, and accuracy. The fuel consumption and emission rates used to estimate locomotive emissions are often outdated or do not reflect local conditions. As a result, estimates of freight railroad emissions are potentially subject to a large degree of error, even though this source can account for nearly 20 percent of total freight NOx emissions in urban areas such as Chicago.
- The process for estimating marine vessel emissions varies from sophisticated (in the case of major seaports like Los Angeles, Long Beach, and Houston) to very simplistic and subject to error (in the case of most other ports). Even the sophisticated inventories suffer from marine engine emission factors that are based on limited and outdated data.
- Only a handful of regions or ports have developed emission inventories for port cargo handling equipment. In other regions, these sources are lumped together with all off-road equipment for emission inventory purposes, which prevents an accurate assessment of the benefits of mitigation strategies focused on cargo handling equipment.
- The process for estimating airport emissions (including aircraft and ground support equipment) is relatively advanced due to the development of the EDMS model and requirements for its use. The model does not distinguish between freight and non-freight activity, but there would typically be no reason to make such a distinction. One significant shortcoming for airport emissions analysis is the lack of sufficient PM emissions data to characterize the current aircraft fleet. FAA is currently working to collect data on aircraft engine PM emissions, which will allow enhancement of the EDMS model to estimate aircraft PM emissions.
- The emission factors and methodologies for estimating emissions of fine particulates (PM-2.5) and toxic air contaminants are less robust than for other criteria pollutants. While this study

focused almost exclusively on NOx and PM-10 emissions, there are growing concerns about health effects of toxic air emissions and PM-2.5 emissions from diesel engines. There is a need to improve the emission factors for these sources.

Improved Understanding of the Effects of Operational Strategies

The other major area for improvement is the understanding of the effects of operational strategies on emissions. Nearly all technology-oriented strategies to reduce emissions have been the subject of at least some research, and some have been studied extensively. Many technology-oriented strategies are relatively easy to assess because one can analyze the impact on a single vehicle or piece of equipment and then apply this impact to the entire affected population of vehicles/equipment. Assessing the effect of operational strategies on emissions, however, can be more difficult because it often requires modeling the performance of an integrated transportation system. A more complete understanding of these effects is needed to support public agencies that are considering investments to improve freight operating efficiency in the name of reducing emissions. Some specific areas for research include:

- The effects of changes in roadway congestion on emissions are sometimes unclear or are not properly captured in the tools for estimating emissions. Generally, congested roadway conditions increase emissions because they cause idling and more frequent short bursts of acceleration, when per-mile emission rates are higher than at free flow speeds. However, at steady state speeds over 20 mph, emission rates tend to increase with speed. Per mile emissions of NOx, for example, are almost twice as high at 65 mph than at 20 mph. The MOBILE model uses an average speed for each roadway link. Thus, congestion can sometimes result in lower modeled emissions on certain roadway segments because the average speed of the roadway has been reduced. There is a need to better understand how highway improvements that reduce congestion affect emissions.
- In freight systems that are highly integrated, such as railroads or aviation, the emissions effects of congestion are often difficult to assess. Congestion in one location can cause delays to ripple throughout the system, so an increase in emissions might occur far from the bottleneck that triggered it. Research is needed to better understand how changes in freight congestion affect emissions in these conditions.
- Significant opportunities exist to reduce freight-related emissions by reducing unnecessary idling. Control strategies include the use of truck stop electrification, APUs for locomotives, cold ironing for ships, and electrified gate equipment for aircraft. Yet there is often a poor understanding of the extent of idling, particularly the extent of idling that can be eliminated through control strategies. More research is needed to assess how operational and technology-oriented strategies can be applied most effectively to reduce idling associated with freight movement.
- Better logistics practices can improve the productivity of freight movement, resulting in less fuel consumption and emissions per ton-mile. Freight carriers can achieve better productivity by, for example, reducing empty mileage, increasing load factors, or eliminating circuitous routing. These strategies offer “win-win” solutions in that they increase carrier profitability while minimizing environmental impacts. There is little information on the effects of these types of strategies on emissions.

The growth in freight transportation demand and limited system capacity will create tremendous challenges for transportation planners and decision makers in the coming years. As a result of increases in freight movement, slow fleet turnover, and challenges associated with controlling freight emissions, freight will continue to account for a significant portion of pollutant emissions for many years, both nationally and regionally. Freight has historically been an afterthought in the transportation and air quality planning processes. Public agencies must continue to better integrate freight into these processes and improve their understanding of the linkages between freight transportation and air quality. Through a more integrated approach to planning and better knowledge about freight emissions impacts, agencies can help to ensure the continued efficiency and reliability of the freight system while, at the same time, supporting societal goals related to public health and the environment.

Appendix A – EPA Emission Standards

Table A-1: Heavy-Duty Diesel Vehicle Emission Standards

	Emission Standards (grams/brake horsepower-hour)			
Model Year	Hydrocarbons (HC)	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Particulate Matter (PM)
1974-78 [a]	-	40	-	-
1979-83 [b]	1.5	25	-	-
1984-87	1.3	15.5	10.7	-
1988-89	1.3	15.5	10.7	0.6
1990	1.3	15.5	6	0.6
1991-93	1.3	15.5	5	0.25
1994-97	1.3	15.5	5	0.1
1998-2003	1.3	15.5	4	0.1
2004-2006 [c,d]	0.5	15.5	2	0.1
2007+	0.14	15.5	0.2	0.01

Note a: Combined HC+NOx standard of 16 g/bhp-hr
Note b: Combined HC+NOx standard of 10 g/bhp-hr
Note c: Under a consent decree with U.S. EPA, engine makers implemented the 2004 standards in October 2002
Note d: Standards allow the option of 2.4 g/bhp-hr NMHC+NOx, or 2.5 g/bhp-hr NMHC+NOx and 0.5 NMHC
Source: http://www.dieselnet.com/standards/us/hd.html

Table A-2: U.S. Emission Baseline and Standards for Locomotives

	Emissions (g/bhp-hr)	
	NOx	PM-10
Est. 1990 Baseline Levels (unregulated)		
Line-haul duty-cycle	13.0	0.32
Switch duty-cycle	17.4	0.44
Tier 0 (1973 – 2001 model years)		
Line-haul duty-cycle	9.5	0.60
Switch duty-cycle	14.0	0.72
Tier 1 (2002 – 2004 model years)		
Line-haul duty-cycle	7.4	0.45
Switch duty-cycle	11.0	0.54
Tier 2 (2005 and later model years)		
Line-haul duty-cycle	5.5	0.20
Switch duty-cycle	8.1	0.24

Source: U.S. EPA, *Locomotive Emission Standards, Regulatory Support Document*, April 1998.

Table A-3: Marine Vessel Emission Standards

				Emission Standards (g/kW-hr)		
Engine Category	Power	Displacement	Year	HC+NOx	PM	CO
Category 1	kW ≥ 37	L/cy < 0.9	2005+	7.5	0.4	5.0
		0.9 ≤ L/cy < 1.2	2004+	7.2	0.3	5.0
		1.2 ≤ L/cy < 2.5	2004+	7.2	0.2	5.0
		2.5 ≤ L/cy < 5.0	2007+	7.2	0.2	5.0
Category 2		All Cat. 2	2004-06	IMO stds	-	-
		5.0 ≤ L/cy < 15	2007+	7.8	0.27	5.0
	kW < 3300	15 ≤ L/cy < 20	2007+	8.7	0.5	5.0
	kW ≥ 3300	15 ≤ L/cy < 20	2007+	9.8	0.5	5.0
		20 ≤ L/cy < 25	2007+	9.8	0.5	5.0
		25 ≤ L/cy < 30	2007+	11.0	0.5	5.0
Category 3		L/cy ≥ 30	2004+	IMO stds	-	-

Note: IMO standards are defined as follows:
if rpm ≥ 2000 NOx = 9.8 g/kW-hr
if 130 ≤ rpm < 2000 NOx = 45 x rpm^(-0.2) g/kW-hr
if rpm < 130 NOx = 17 g/kW-hr

Source: “Marine Diesel Engine Emission Control Programs,” presentation by Jean Marie Revelt, U.S. EPA, January 29, 2004.

Table A-4: Aircraft Emissions Standards (gas turbine engines)

		Applicability		
Pollutant	Standard	Rated Pressure Ratio	Rated Output	Year of Manuf.
CO	118 g/kN (rated output)	All	All	All
NOx	(40 + 2(rated pressure ratio))g/kN(rated output)	All	All	1997-1999
NOx	(32 +1.6(rated pressure ratio))g/kN(rated output)	All	All	2000-2003
NOx	(37.572 + 1.6(rated pressure ratio) – 0.2087(rated output))g/kN (rated output)	30 or less	26.7 - 89 kN	2004+
NOx	(19 + 1.6(rated pressure ratio)) g/kN(rated output)	30 or less	> 89 kN	2004+
NOx	(42.71 + 1.4286(rated pressure ratio) - 0.4013(rated output) + 0.00642(rated pressure ratio -rated output)) g/kN(rated output)	30 - 62.5	26.7 - 89 kN	2004+
NOx	(7 + 2(rated pressure ratio) g/kN (rated output)	30 - 62.5	> 89 kN	2004+
NOx	32 + 1.6(rated pressure ratio) g/kN (rated output)	greater than 62.5	All	2004+

Note: Table does not reflect the latest NOx emissions standard as agreed at the sixth meeting of ICAO Committee on Aviation Environmental Protection (CAEP) in February 2004, which have not been promulgated by U.S. EPA regulations.
Source: U.S. EPA and the International Civil Aviation Organization.

Table A-5: EPA Non-Road Diesel Equipment Emission Standards

Engine Power	Tier	Starting Model Year	Emission Standards (g/bhp-hr)			
			NMHC+NOx	NOx	CO	PM
hp < 11	1	2000	7.8		6.0	0.75
	2	2005	5.6		6.0	0.60
11 ≤ hp < 25	1	2000	7.1		4.9	0.60
	2	2005	5.6		4.9	0.60
hp < 25	4	2008	5.6			0.3
25 ≤ hp < 50	1	1999	7.1		4.1	0.60
	2	2004	5.6		4.1	0.45
25 ≤ hp < 75	4	2013	3.5			0.02
50 ≤ hp < 100	2	2004	5.6		3.7	0.30
	3	2008	3.5		3.7	0.30
100 ≤ hp < 175	2	2003	4.9		3.7	0.22
	3	2007	3.0		3.7	0.22
75 ≤ hp < 175	4	2012		0.3		0.01
175 ≤ hp < 300	2	2003	4.9		2.6	0.15
	3	2006	3.0		2.6	0.15
300 ≤ hp < 600	2	2001	4.8		2.6	0.15
	3	2006	3.0		2.6	0.15
600 ≤ hp < 750	2	2002	4.8		2.6	0.15
	3	2006	3.0		2.6	0.15
175 ≤ hp < 750	4	2011		0.3		0.01
hp > 750	2	2006	4.8		2.6	0.15
	4	2011 (gensets>1200 hp)		0.5		0.075
	4	2011 (all others)		2.6		0.075
	4	2015 (all gensets)		0.5		0.02
	4	2015 (all others)		2.6		0.03

Source: U.S. EPA, *Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*, June 29, 2004.

Appendix B – Estimation of Future Truck Emissions

To estimate future trucking emissions, we first estimated current (2002) truck VMT by truck type and facility type. Table B-1 shows the distribution of truck VMT by these categories. This information is derived from the VM1 and VM2 tables in *Highway Statistics*. We distributed truck VMT across the four MOBILE6 roadway types, assuming the same distribution for each truck/fuel type. VMT for single-unit vehicles was split between gas and diesel based on the distribution in the 1997 Vehicle Inventory and Use Survey (VIUS).

Table B-1: Truck VMT by Functional Class and Vehicle Type, 2002 (millions)

	Gasoline Single-Unit Trucks	Diesel Single-Unit Trucks	Diesel Comb. Trucks	Total Freight Trucks	
Facility Type	VMT	VMT	VMT	VMT	Percent
Local	2,261	7,605	18,024	27,074	13%
Minor Arterial / Collector	6,087	20,474	48,525	75,667	35%
Urban Freeway	5,217	17,549	41,593	63,933	30%
Rural Freeway	3,826	12,869	30,501	47,856	22%
Total	17,391	58,496	138,643	214,530	100%

We estimated future trucking VMT by applying the estimated annual growth in trucking ton-miles (2.5 percent, as presented in Table 2-5) to current trucking VMT figures (by truck type and facility type). We assume that growth is uniform across all truck and facility types. We then developed truck emission factors using MOBILE6.2. We developed emission factors for single-unit heavy-duty gasoline trucks, single-unit heavy-duty diesel trucks, and combination diesel trucks. Emission factors differ by the four facility types in MOBILE6 (local streets, arterial/collector, urban freeway, and rural freeway). These emission factors are presented in Tables B-2 through B-5.

Table B-2: Local Road Truck Emission Factors

		Local Road Emission Factors (grams/mile)				
	Year	VOC	CO	NOx	PM-10	PM-10 (Exhaust only)
Single-Unit Gasoline Truck	2002	7.06	144.07	5.94	0.13	0.11
	2010	1.87	34.32	4.09	0.09	0.07
	2020	0.63	21.71	1.58	0.05	0.03
Single-Unit Diesel Truck	2002	1.18	6.86	14.95	0.42	0.38
	2010	0.74	3.39	7.27	0.17	0.13
	2020	0.52	0.71	1.27	0.07	0.03
Combination Diesel Truck	2002	1.22	7.64	16.07	0.41	0.37
	2010	0.78	3.52	7.45	0.17	0.13
	2020	0.56	0.78	1.29	0.07	0.03

Table B-3: Arterial Truck Emission Factors

		Arterial Emission Factors (grams/mile)				
	Year	VOC	CO	NOx	PM-10	PM-10 (Exhaust only)
Single-Unit Gasoline Truck	2002	2.29	59.87	7.18	0.13	0.11
	2010	0.61	14.24	4.95	0.09	0.07
	2020	0.21	9.00	1.92	0.05	0.03
Single-Unit Diesel Truck	2002	0.59	2.86	15.34	0.42	0.38
	2010	0.37	1.41	6.18	0.17	0.13
	2020	0.26	0.30	1.01	0.07	0.03
Combination Diesel Truck	2002	0.61	3.18	17.02	0.41	0.37
	2010	0.39	1.47	6.38	0.17	0.13
	2020	0.28	0.33	1.03	0.07	0.03

Table B-4: Urban Freeway Truck Emission Factors

		Urban Freeway Emission Factors (grams/mile)				
	Year	VOC	CO	NOx	PM-10 (total)	PM-10 (exhaust only)
Single-Unit Gasoline Truck	2002	1.31	51.39	8.12	0.13	0.11
	2010	0.35	12.24	5.60	0.09	0.07
	2020	0.12	7.74	2.17	0.047	0.025
Single-Unit Diesel Truck	2002	0.42	2.21	22.69	0.42	0.38
	2010	0.28	1.10	8.06	0.17	0.13
	2020	0.27	0.28	1.24	0.071	0.032
Combination Diesel Truck	2002	0.43	2.48	25.65	0.41	0.37
	2010	0.28	1.14	8.38	0.17	0.13
	2020	0.20	0.25	1.28	0.073	0.034

Table B-5: Rural Freeway Truck Emission Factors

		Rural Freeway Emission Factors (grams/mile)				
	Year	VOC	CO	NOx	PM-10	PM-10 (Exhaust only)
Single-Unit Gasoline Truck	2002	1.31	75.87	8.84	0.13	0.11
	2010	0.35	18.07	6.09	0.09	0.07
	2020	0.12	11.43	2.36	0.05	0.03
Single-Unit Diesel Truck	2002	0.41	2.80	30.39	0.42	0.38
	2010	0.30	1.41	11.95	0.17	0.13
	2020	0.29	0.35	1.92	0.07	0.03
Combination Diesel Truck	2002	0.41	3.13	33.96	0.41	0.37
	2010	0.27	1.44	12.39	0.17	0.13
	2020	0.19	0.32	1.97	0.07	0.03

Applying the emission factors to the VMT forecasts, we estimate national truck emissions in 2002, 2010, and 2020, shown in Table B-6. These results show truck emissions are expected to drop steeply over the next two decades, despite more than 50 percent growth in VMT. Total NOx emissions from freight trucks in 2020 will be one-tenth the level in 2002. PM-10 emissions in 2020 will be one-quarter current levels.

Note that our 2002 estimate of truck emissions is significantly different than the EPA National Emission Inventory (NEI) heavy-duty truck emissions for 2002 (presented in Table 2-9). Our estimate is 33 percent higher in the case of NOx and 23 percent lower in the case of PM-10. There are likely a variety reasons for this discrepancy. The NEI is developed in part using data submitted by state and regional air quality agencies, and these agencies use local VMT estimates that most likely do not sum to the national total reported in *Highway Statistics*. EPA, state, and local emissions estimates may also have disaggregated VMT into more vehicle classes than we did, since MOBILE6 allows up to 16 vehicle classes. Finally, the NEI reflects some local differences in vehicle speeds, whereas our estimate uses a single average speed by facility type.

Our future year estimates of truck emissions are also different than the estimates reported in EPA's regulatory impact analysis documents for the 2007/10 heavy-duty truck emission standards. Our 2010 NOx estimate is 2 percent higher than EPA's estimate for that year, and our 2020 NOx estimate is 26 percent lower than EPA's estimate. Again, a variety of factors probably contribute to this discrepancy. For example, our analysis used MOBILE6.2 while the EPA analysis used MOBILE5 (although EPA made adjustments to account for the changes to the MOBILE model). Our analysis uses a 2.5 percent annual growth rate for all VMT. EPA's estimate is based on the VMT forecasts inherent in the MOBILE model, which are determined from the forecast growth in the heavy-duty truck population and assumptions about vehicle mileage accumulation rates. And, as described above, our emissions forecasts are calculated using different values for the base year (2002) emissions.

Table B-6: Estimated Current and Future National Truck Emissions

		Emissions (tons/year)			
	Year	VOC	CO	NOx	PM-10
Single-Unit Gasoline Truck	2002	46,048	1,376,529	146,991	2,536
	2010	14,870	399,338	123,432	2,032
	2020	6,440	323,270	61,141	1,393
Single-Unit Diesel Truck	2002	37,025	204,715	1,341,873	27,115
	2010	29,745	123,704	640,704	13,386
	2020	30,633	35,794	132,017	7,096
Combination Diesel Truck	2002	90,749	541,082	3,548,023	62,807
	2010	70,832	303,489	1,571,932	31,161
	2020	65,447	86,514	320,878	17,371
All Freight Trucks	2002	173,822	2,122,325	5,036,887	92,457
	2010	115,447	826,532	2,336,068	46,579
	2020	102,520	445,579	514,036	25,860

Appendix C – Regional Freight Transportation Profiles

This appendix presents profiles of freight transportation systems and activity levels in the six selected regions. The profile of each region begins with some general socio-economic statistics and an overview of the economic base that drives much of the freight activity in the region. Each profile then discusses the four major freight modes – trucking, rail, marine, and air – providing a snapshot of the freight system and current freight activity, including an identification of major freight facilities and analysis of commodity flow data by mode. These freight profiles help to explain some of the regional differences in freight transportation emissions, as discussed in Section 3.

Los Angeles Freight Transportation Profile

The Southern California Association of Governments is the metropolitan planning organization (MPO) for the Los Angeles metropolitan area. The region includes the five counties of Los Angeles, Orange, Riverside, San Bernardino, and Ventura.[71] The 2002 population estimate for the five-county Los Angeles region is 17.0 million, an increase of 17 percent since 1990.[72] Total employment in the region is 9.4 million.[73] The Los Angeles region is designated as an air quality nonattainment area for ozone (1-hour and 8-hour standard), PM-10, and CO.

The Los Angeles region has a large and diverse economic base, driven by large manufacturing, trade, and transportation sectors.[74] The region has a particularly high concentration of wholesale trade employment, as well as high concentrations of manufacturing and transportation & warehousing employment. Nearly 60,000 are employed in the truck transportation sub-sector alone. Within the manufacturing sector, the Los Angeles region has a very high concentration of employment in apparel manufacturing, particularly in Los Angeles County, and in related industries such as textile product mills and leather product manufacturing. The region is a major center for computer and electronics manufacturing, with more than 124,000 employees in this sub-sector. Other manufacturing industries concentrated in the region include furniture-making and fabricated metal products. The region has relatively low concentrations of many traditional heavy industries such as machinery, primary metals manufacturing, and chemicals manufacturing.

Table C-1 shows commodity flows into and out of the five-county Los Angeles region in 2003 by mode.[75] Trucking carries 64 percent of interregional freight tonnage, marine vessels carry 21 percent, and railroads carry 14 percent. Among the six study regions, the Los Angeles region is second to Houston in total intercity freight tonnage and tied with Chicago for the greatest volume of intercity truck freight.

Table C-1: Commodity Flows Into and Out of the Los Angeles Region, 2003

Mode	Tonnage	Percent
Trucking	378,995,000	64%
Railroad	82,013,000	14%
Marine Vessel	124,791,000	21%
Aircraft	2,234,000	0.4%
Total	588,033,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Trucking

The Los Angeles area has one of the most extensive networks of highways and arterial streets in the U.S., including 903 miles of Interstates and other highways plus 2,932 miles of principal arterial roads.[76] Four major Interstate highway corridors link the region to the rest of the U.S.:

- I-5, a north-south route linking the West Coast, Canada, and Mexico
- I-15, a north-south route connecting Los Angeles to Las Vegas and Salt Lake City
- I-40, an east-west route running from Barstow to Okalahoma, Tennessee, and North Carolina
- I-10, an east-west route connecting Los Angeles to Arizona, Texas, and the Southeast

Other major truck routes include Interstates 210, 710, and 215, as well as State Routes 60, 91, 55, and 57.

Table C-2 shows annual VMT in the Los Angeles region (South Coast and Ventura nonattainment areas) by vehicle type for 2002. Heavy-duty trucks (defined as truck with a gross vehicle weight rating over 8,500 lbs) account for 6 percent of the region's total VMT, including 2 percent from gasoline trucks and 4 percent from diesel trucks.

Table C-2: Los Angeles Region Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
122,478	94%	2,525	2%	5,292	4%	130,295

Source: California Air Resources Board; data for South Coast and Ventura County Air Basins.

Rail Freight

Both the Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) railroads have extensive operations in the Los Angeles region. There are also four short-line railroads that shuttle cars and equipment in and between the marine ports and rail intermodal yards. In 2002, UP and BNSF were handling close to 60 freight trains per day along their most heavily used line segments.[77] In addition to on-dock rail terminals at the ports, there are six major rail/truck intermodal transshipment yards in the region. Three inland rail yards serve primarily the ports of Los Angeles and Long Beach:

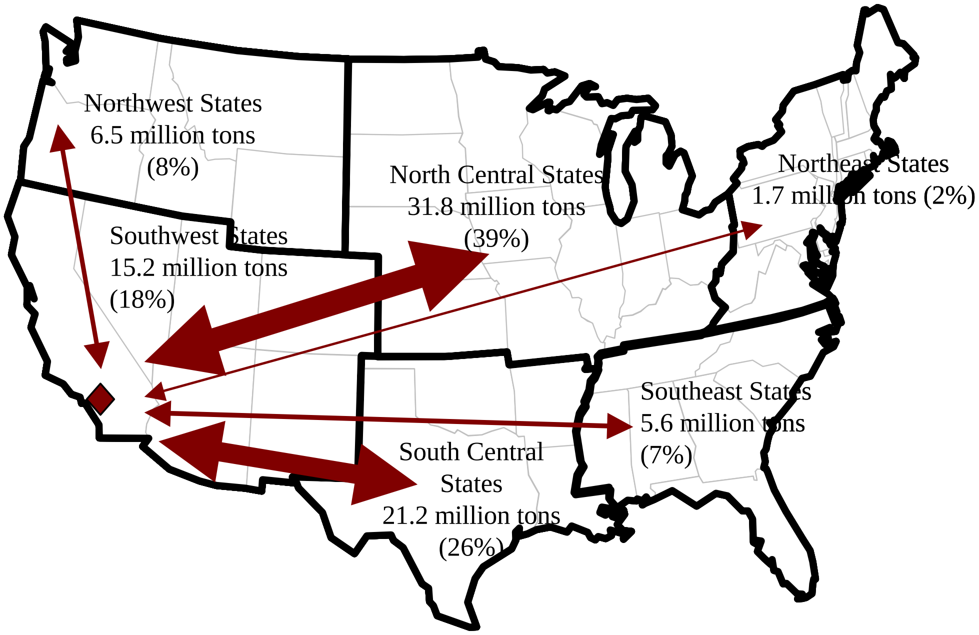
- The Intermodal Container Transfer Facility (UP) five miles inland from the ports of Los Angeles and Long Beach. The ICTF facilitates the relay of marine cargo containers between the ports and major rail yards near downtown Los Angeles.
- East Los Angeles facility (UP) near downtown Los Angeles
- Hobart Intermodal Facility (BNSF), also near downtown Los Angeles

These facilities are connected to the ports by the Alameda Corridor, a 20-mile freight rail expressway that currently handles an average of 35 train movements per day but has capacity to handle up to 150 daily trains. There are also three additional rail intermodal centers in the region:[78]

- LATC (UP) near downtown Los Angeles
- City of Industry facility (UP) approximately 15 miles east of Los Angeles
- San Bernardino facility (BNSF) approximately 50 miles east of Los Angeles

Figure C-1 illustrates domestic commodity flows by rail between Los Angeles and the rest of the U.S. Only 18 percent of the flow of rail tonnage remains within California and surrounding southwestern states. Nearly 40 percent of the flow of rail freight moves to and from the north central states, largely reflecting the flow of freight from the ports of Long Beach and Los Angeles to Chicago and other Midwestern cities. Just over a quarter of the rail tonnage moves to and from Texas and other south central states.

Figure C-1: Rail Commodity Flows To and From Los Angeles, 2003



Source: FHWA, Freight Analysis Framework.

Marine Freight

The Los Angeles area is served by the seaports of Los Angeles, Long Beach, and Hueneme. The ports of Long Beach and Los Angeles form a combined port facility commonly referred to as the San Pedro Bay ports, which presently handle 80 percent of California’s and 30 percent of the nation’s maritime trade shipments in value terms.[79] Table C-3 shows trade tonnage at the three ports in 2001. More than 80 percent of total tonnage is foreign imports or exports.

Table C-3: Waterborne Commerce at Los Angeles Area Ports, 2001

	Port of Los Angeles		Port of Long Beach		Port of Hueneme		Total	
	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
Foreign Imports	30,302,000	59%	37,729,000	56%	956,000	85%	68,987,000	57%
Foreign Exports	14,636,000	28%	13,819,000	20%	109,000	10%	28,564,000	24%
Coastwise	5,170,000	10%	15,077,000	22%	64,000	6%	20,311,000	17%
Internal and Local	1,257,000	2%	1,004,000	1%	0	0%	2,261,000	2%
Total	51,365,000	100%	67,629,000	100%	1,129,000	100%	120,123,000	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States* database.

The Port of Los Angeles has 29 major cargo terminals, including eight container facilities and terminals dedicated to the handling of automobiles, break-bulk, dry bulk, and liquid bulk cargoes. In 2002, the Port of Los Angeles was the top containership port in the U.S., handling a total of 6.1 million TEUs (twenty-foot equivalent units) and was ranked 13th among U.S. ports in terms of tonnage.[80]

The Port of Long Beach, located just east of the Port of Los Angeles, has eight major container facilities that operate 44 cranes. Five of the terminals have on-dock rail facilities to handle double-stack intermodal shipments. Other terminal facilities at the port specialize in break-bulk, dry bulk, and liquid bulk shipments. In 2002, the Port of Long Beach ranked second after Los Angeles among the nation's containership ports, handling 4.5 million TEUs and was ranked ninth among U.S. ports in terms of total tonnage.[81]

Air Freight

The Los Angeles area handles nearly twice as much air cargo tonnage as any of the other five study areas. The region has five cargo-capable commercial airports: Los Angeles International (LAX), Ontario International, Burbank, Long Beach, and John Wayne/Santa Ana. LAX ranks fifth nationally in terms of the landed weight of all-cargo aircraft.[82] Table C-4 shows air freight tonnage (cargo and passenger aircraft) at the region's five airports.

Table C-4: Los Angeles Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	Inbound	Outbound	Total
Los Angeles International (LAX)	899,658	734,625	1,634,282
Ontario International (ONT)	240,881	254,298	495,179
Burbank (BUR)	15,037	22,542	37,580
Long Beach (LGB)	23,431	29,145	52,576
John Wayne/ Santa Ana (SNA)	1,954	12,380	14,334
Total	1,180,961	1,052,990	2,233,951

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Dallas-Fort Worth Freight Transportation Profile

The North Central Texas Council of Governments (NCTCOG) is the MPO for the Dallas-Fort Worth metropolitan area. The region includes all of Collin, Dallas, Denton, Rockwall, and Tarrant Counties, and contiguous portions of Ellis, Johnson, Kaufman, and Parker Counties.[83] Other major cities in the region include Arlington, Garland, Irving, and Plano. The 2002 population of the Dallas-Fort Worth region is estimated at 5.3 million, an increase of 37 percent since 1990.[84] Total 2002 employment in this region was 3.4 million.[85] The Dallas-Fort Worth region is designated as a nonattainment area for ozone (1-hour and 8-hour standard).

The regional economy of the Dallas-Fort Worth area is driven by the service sector and by trade and transportation industries. [86] Wholesale trade is heavily concentrated in the region, particularly in Dallas, as is the transportation & warehousing sector. Although they are the largest two industry sectors in the region, the manufacturing and retail sector employment shares in Dallas-Fort Worth are lower than the national average. The region has high concentration of certain manufacturing sub-sectors. Computer & electronic product manufacturing is heavily concentrated in the region, particularly in Dallas. Transportation equipment manufacturing is heavily concentrated in Fort Worth. The region also has relatively high concentrations in the printing industry, beverage products, and nonmetallic mineral product manufacturing.

Table C-5 shows commodity flows into and out of the Dallas-Fort Worth region by mode. Trucking dominates intercity freight flows in Dallas-Fort Worth more than the other five study regions, carrying 87 percent of all freight tonnage into and out of the region. The Dallas-Fort Worth region has no significant waterborne freight flows.

Table C-5: Commodity Flows Into and Out of the Dallas-Fort Worth Region, 2003

Mode	Tonnage	Percent
Trucking	237,442,000	87%
Railroad	33,454,000	12%
Marine Vessel	0	0%
Aircraft	840,000	0.3%
Total	271,735,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air).

Trucking

In the Dallas-Fort Worth area, trucking moves over a network of greater than 556 miles of Interstate and other highways and 1,026 miles of other principal arterial roads.[87] Interstates linking the Dallas area to the rest of the U.S. include:

- I-35, which runs north-south from Lake Superior in northern Minnesota to the Texas-Mexico border (the “NAFTA Superhighway”)
- I-20, which runs east-west from South Carolina to western Texas
- I-45 from Houston
- I-30 to Little Rock

According to the 1997 Commodity Flow Survey, 65 percent of freight tonnage shipped by truck in the Dallas-Fort Worth CMSA moves less than 50 miles. This suggests that 35 percent of truck freight shipments originating in the region (on a tonnage basis) leaves the region, the highest percentage of the six study areas.

Table C-6 shows the annual VMT by vehicle type in the four-county core of the Dallas-Fort Worth region (Collin, Dallas, Denton, and Tarrant Counties). Heavy-duty trucks account for 9 percent of total VMT, 2 percent from gasoline trucks and 7 from diesel trucks.

Table C-6: Dallas-Fort Worth Area Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
43,232	91%	744	2%	3,279	7%	47,256

Source: North Central Texas Council of Governments.

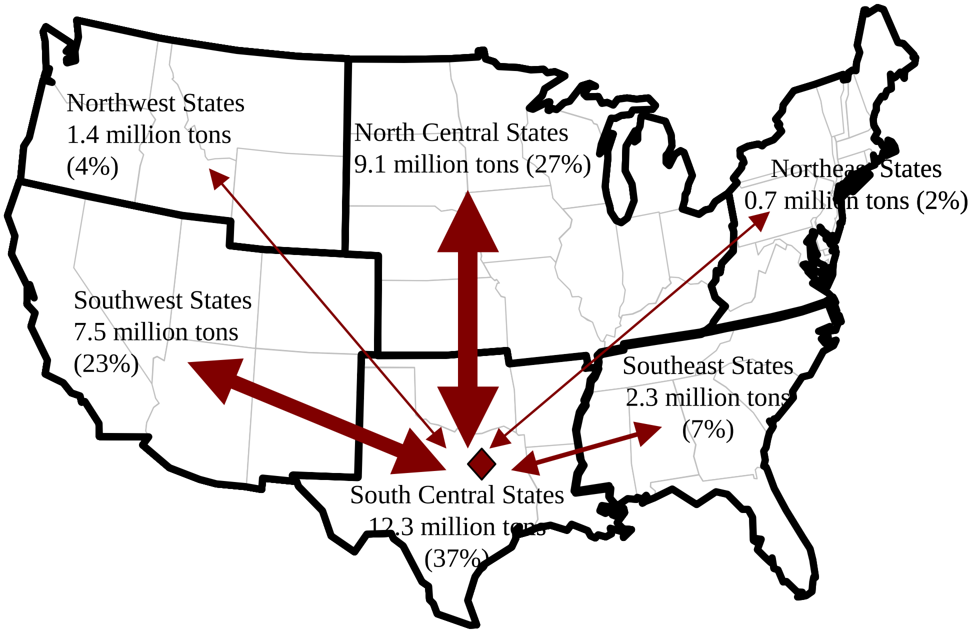
Rail Freight

Three Class I railroads operate in the Dallas-Fort Worth region: UP, BNSF, and Kansas City Southern. Fort Worth is one of UP's three operations hubs in Texas, and the city is also the home to Centennial Yard, one of the railroad's largest freight classification facilities. Fort Worth is the location of Tower 55, one of the busiest railroad intersections in the United States, where several railroads share the crossing with UP.[88] UP operates intermodal truck-rail facilities in Dallas and Mesquite.[89]

BNSF operates the Intermodal and Carload Transportation Center at the Alliance Airport near Fort Worth, one of the largest facilities of its kind in the country. Kansas City Southern provides rail service throughout the south central states and also to Mexico through its subsidiaries, including the Texas Mexican Railway (Tex Mex) and the Mexican Grupo Transportacion Ferroviaria Mexicana, S.A. de C.V. (TFM). Kansas City Southern operates an intermodal terminal in Garland, near Dallas.

Figure C-2 shows rail freight flows between Dallas-Fort Worth and six regions of the U.S. Heavy rail freight flows occur between Dallas-Fort Worth and the north central states (27 percent of total rail flows) and between Dallas-Fort Worth and the southwestern states (23 percent of total rail flows).

Figure C-2: Rail Commodity Flows To and From Dallas-Fort Worth, 2003



Source: FHWA, Freight Analysis Framework.

Air Freight

The Dallas-Fort Worth region has two major air cargo airports: Dallas/Fort Worth International (DFW) and Fort Worth Alliance. DFW is the region's largest air freight facility, handling 660,000 tons of air cargo annually. The airport ranks 11th among the nation's airports in terms of landed weight of cargo carriers. The Alliance Airport north of Fort Worth is the largest commercial/industrial airport in the country, providing airfreight service for manufacturing, warehousing, and distribution firms throughout the region. Federal Express operates from the Alliance Airport. Table C-7 shows annual inbound and outbound air freight tonnage (cargo and passenger carriers) at the two airports.

Table C-7: Dallas-Fort Worth Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	Inbound	Outbound	Total
Dallas-Fort Worth International (DFW)	350,570	308,642	659,213
Alliance Fort Worth (ATW)	67,176	75,173	142,350
Total	417,747	383,816	801,562

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Houston Freight Transportation Profile

The Houston-Galveston Area Council (HGAC) is the MPO for the Houston metropolitan area. The region includes Harris County, which contains the City of Houston, and seven surrounding counties (Brazoria, Chambers, Fort Bend, Galveston, Liberty, Montgomery, and Waller). The 2002 population estimate for the eight-county Houston region is 4.9 million, an increase of 32.4 percent since 1990.[90] The 2002 estimate for employment in the region was 2.9 million.[91] The Houston-Galveston-Brazoria region is designated as a nonattainment area for ozone (1-hour and 8-hour standard).

Freight transportation in the Houston region is heavily influenced by the region's concentration of petrochemical industries. Houston has the highest concentration of transportation & warehousing employment among the six study areas and also a high concentration of construction and wholesale trade employment.[92] The manufacturing employment share in the Houston region is lower than the national average. But the region has very high employment concentrations in petroleum products and chemicals manufacturing. This is due in part to the large number of petrochemical refineries in the southeastern portion of the Houston region and also the presence of major petrochemical company headquarters in downtown Houston. The region also has high concentrations of fabricated metal product manufacturing and machinery manufacturing. Light industries such as apparel, computer & electronics products, and food manufacturing have a relatively small presence in the region.

Table C-8 shows commodity flows into and out of the Houston region in 2003 by mode. The total commodity flow tonnage is the largest among the six study regions, primarily because of large marine freight component (39 percent of total freight flows). Because Houston area ports handle large volumes of petrochemicals and other bulk commodities, the total marine vessel freight tonnage at the Houston ports is more than the total marine tonnage in the other five study regions combined. Trucking carries approximately half of intercity freight flows, and railroads carry another 12 percent.

Table C-8: Commodity Flows Into and Out of the Houston Region, 2003

Mode	Tonnage	Percent
Trucking	340,435,000	49%
Railroad	84,375,000	12%
Marine Vessel	269,307,000	39%
Aircraft	352,000	0.1%
Total	694,468,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Trucking

In the Houston urbanized area, trucking moves on a network of 456 miles of Interstate and other highways, plus 858 miles of other principal arterials.[93] The region is traversed by I-10 (running from California to Florida) and I-45 (running from Galveston to Dallas), and U.S. 59 (running from Laredo to Shreveport). The I-610 loop encircles the region.

Table C-9 shows annual VMT in the eight-county Houston region by vehicle type and county. Three-quarters of the region's VMT occurs in Harris County. Total VMT in the region is similar to the Dallas-Fort Worth area, as is the composition of VMT by vehicle type: heavy-duty trucks make up 9 percent of total VMT, with 2 percent gasoline trucks and 7 percent diesel trucks.

Table C-9: Houston Area Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
40,949	91%	744	2%	3,141	7%	44,834

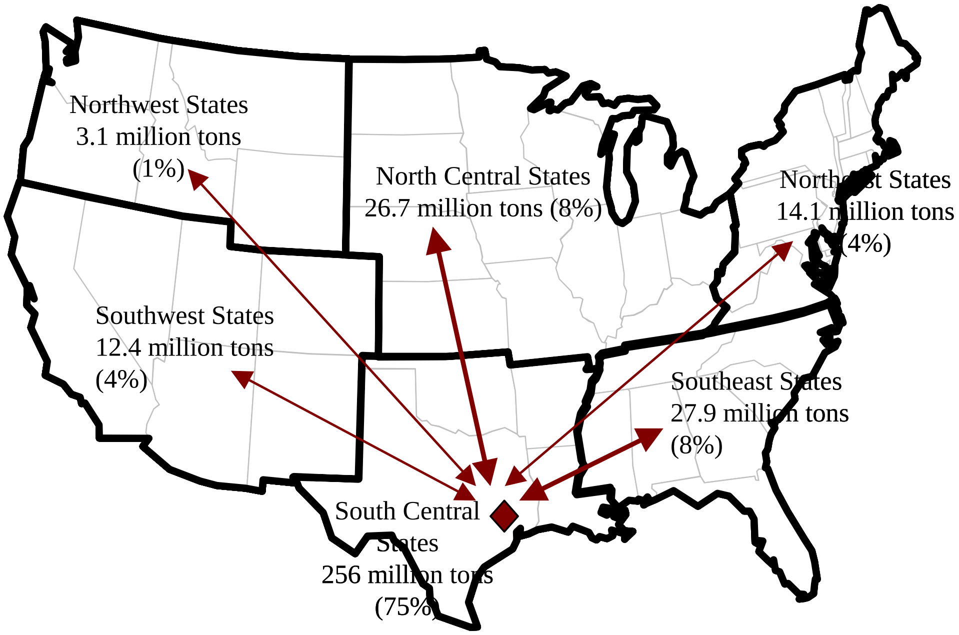
Source: Texas Commission on Environmental Quality.

Rail Freight

The Houston-Galveston region serves a major rail hub for the region and has five freight rail yards. The rail network in Houston is dominated by UP and BNSF, with UP rail lines transporting the majority of the tonnage on the system.[94] The railroad's Settegast and Englewood railyards in Houston are major classification yards for the southern part of Texas and serve the petrochemical industry along the Texas Gulf Coast.[95] UP also has an intermodal facility at the Port of Houston. BNSF has two intermodal facilities in the Houston area, one near Hobby airport and another at the Port of Houston. BNSF also serves the ports of Galveston and Texas City.

Figure C-3 shows rail freight flows to and from the Houston region. The bulk of rail freight (75 percent) remains within the south central states. Chemicals represent almost 64 percent of all rail commodities originating in the Gulf Coast port districts and are the largest rail commodity originating in the Houston area.[96]

Figure C-3: Rail Commodity Flows To and From Houston, 2003



Source: FHWA, Freight Analysis Framework.

Marine Freight

The Houston region is served by the Port of Houston, the Port of Texas City, and two smaller ports at Freeport and Galveston. Crude oil and chemical products, which are handled in large quantities at the ports in the region, are frequently processed at or in close proximity to the ports. The resulting product is then shipped out again or transported via oil pipeline to destinations such as Oklahoma. In 2002, the Port of Houston ranked 11th among U.S. containership ports, handling 1.2 million TEUs, and ranked second in the nation in terms of tonnage.[97] The Port of Texas City is a privately owned, for-profit port that almost exclusively handles bulk liquid products, such as chemical and crude oil products. Table C-10 shows annual marine freight tonnage at the region's four ports. Nearly two-thirds of total tonnage is foreign imports or exports.

Table C-10: Waterborne Commerce at Houston Area Ports, 2001

	Port of Houston		Port of Texas City		Port of Galveston		Port of Freeport		Total	
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
Foreign Imports	84,877,000	46%	40,304,000	65%	1,360,000	12%	22,646,000	75%	126,541,000	49%
Foreign Exports	34,874,000	19%	3,827,000	6%	4,822,000	43%	2,247,000	7%	43,523,000	17%
Coastwise	11,531,000	6%	5,853,000	9%	2,249,000	20%	605,000	2%	19,633,000	8%
Internal and Local	52,929,000	29%	12,288,000	20%	2,843,000	25%	4,646,000	15%	68,060,000	26%
Total	184,211,000	100%	62,272,000	100%	11,274,000	100%	30,144,000	100%	257,757,000	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States* database.

Air Freight

The Houston-Galveston region has three major airports: George Bush Intercontinental Airport/Houston (IAH), William P. Hobby Airport (HOU), and Ellington Field (EFD). IAH handles the vast majority of air cargo for the Houston Airport System – 336,000 tons in 2003, as shown in Table C-11. IAH ranks 30th among the nation's cargo-service airports in terms of landed weight.

Table C-11: Houston Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	Inbound	Outbound	Total
George W. Bush International (IAH)	172,651	163,729	336,380
William P. Hobby Airport (HOU)	7,041	8,121	15,162
Total	179,692	171,850	351,542

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Chicago Freight Transportation Profile

The Chicago metropolitan area is the nation's third most populous area. The Chicago Area Transportation Study (CATS) is the MPO for the region, covering Cook, Dupage, Kane, Lake, McHenry, and Will counties and a portion of Kendall County, all in Illinois. In 2002, the population of the seven-county Chicago area was 8.3 million, a 14 percent increase since 1990.[98] Total employment in the region is approximately 5.0 million.[99] The Chicago region is designated nonattainment for ozone (1-hour and 8-hour standard).

The Chicago region has a large and diverse economy, anchored by service industries, manufacturing, trade, and transportation. The region has a relatively high concentration of wholesale trade employment and transportation & warehousing employment.[100] Chicago has traditionally been a center for food processing (especially bakeries, slaughterhouses, and sugar product manufacturing), and food continues to be a major manufacturing sub-sector in the region, particularly in Cook County. The region has a high concentration of employment in fabricated metal product manufacturing. Printing is also intensive in the region, as is paper manufacturing. Finally, the Chicago region has a large concentration of electrical equipment & appliance manufacturing establishments.

Chicago is a major freight crossroads. Two transnational Interstates and all six major North American Class I railroads meet in the region. Chicago also boasts two major airports, a seaport on Lake Michigan, and canal access to the Mississippi River. Table C-12 shows domestic commodity flows into and out of the seven-county Chicago region by mode. Trucking carries 60 percent of these flows, and rail carries another 36 percent. Rail freight flows in the Chicago region are more than double the rail freight in any of the other five study regions.

Table C-12: Commodity Flows Into and Out of the Chicago Region, 2003

Mode	Tonnage	Percent
Trucking	379,532,000	60%
Railroad	223,837,000	36%
Marine Vessel	22,924,000	4%
Aircraft	1,155,000	0.2%
Total	627,448,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Trucking

Trucking moves in the Chicago region on a network of 478 miles of Interstate and other highways plus 1,608 miles of other principle arterials.[101] Interstates I-80, I-90, and I-94 connect Chicago to cities to the east, north, and west; Interstates I-55, I-57, and I-65 connect Chicago to cities to the south.

Table C-13 shows annual on-road VMT by vehicle type in the Chicago region (that portion of the ozone nonattainment area contained in Illinois). Eleven percent of VMT results from heavy-duty trucks, 3 percent from gasoline trucks and 8 percent from diesel trucks.

Table C-13: Chicago Area Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
51,452	89%	1,893	3%	4,532	8%	57,876

Source: Illinois Environmental Protection Agency.

Rail Freight

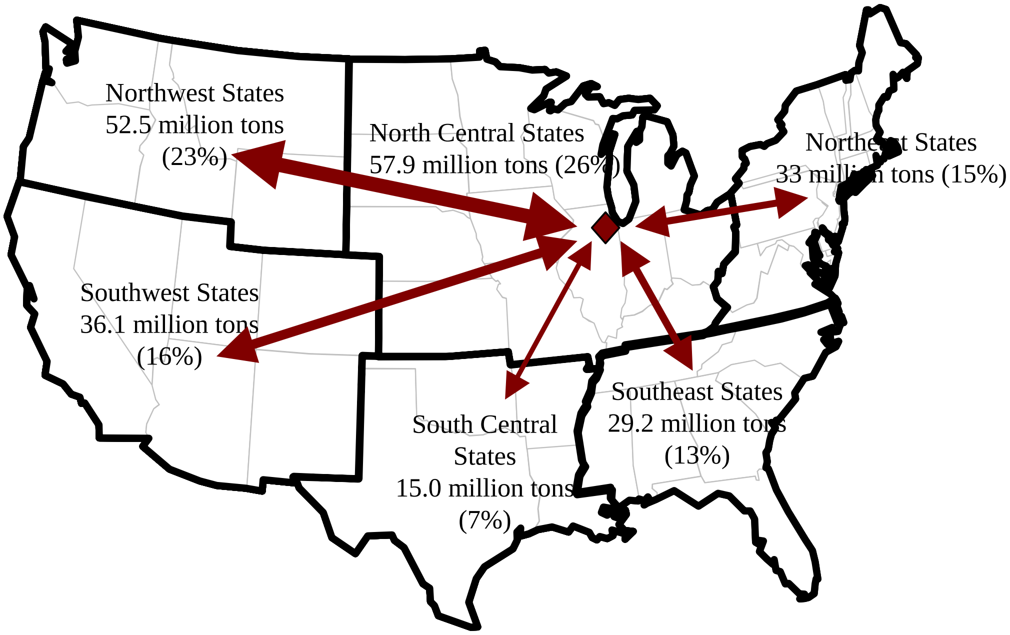
Chicago is the only city where all six major U.S. and Canadian Class I railroads come together to interchange freight. This includes the two major western U.S. railroads, BNSF and UP, the two major eastern U.S. railroads, CSX and Norfolk Southern, and the two major Canadian railroads, Canadian National (CN) and Canadian Pacific (CP). At least six other private railroads operate in the Chicago region, although the vast majority of the region's rail infrastructure is owned and maintained by the Class I carriers.

It has been estimated that Chicago-area railroads operate 1,200 daily trains and generate more than 3,200 daily truck trips to transfer cargo from yard to yard.[102] Freight railroads in Chicago own 74 marshalling yards, including 17 for rail-truck intermodal traffic.

- *BNSF* has four intermodal facilities in the Chicago area: Cicero and Corwith in the city of Chicago, Willow Springs in Hodgkins, and the Logistics Park-Chicago in Elwood (about 40 miles southwest of Chicago).
- *UP* serves Chicago via Springfield from St. Louis and over BNSF trackage from Kansas City. UP has several intermodal facilities, including Yard Center, Global I, Global II, Canal Street, Markham, and Chicago IMX.
- *CSX* maintains intermodal facilities at 59th Street and Bedford Park.
- *Norfolk Southern* has four intermodal facilities in the Chicago area: 47th Street, 63rd Street, Landers Yard, and Calumet (port).
- CN has an intermodal facility in Harvey, just south of Chicago.
- CP has intermodal facilities in Franklin Park and in Schiller Park (both northwest of downtown Chicago, near O'Hare Airport). CP has also automotive and transload facilities in Chicago.

Figure C-4 illustrates domestic commodity flows by rail between Chicago and the rest of the U.S. Due to its position as the nation's most important rail crossroads, major rail flows move between Chicago and all regions of the U.S. Nearly one-quarter of Chicago's rail tonnage moves to and from the northwest states. This includes large volumes of freight imported from Asia through the ports of Seattle and Portland.

Figure C-4: Rail Commodity Flows To and From Chicago, 2003



Source: FHWA, Freight Analysis Framework.

In June 2003, the city of Chicago, the state of Illinois, and the six Class I railroads announced a plan to significantly improve railroad infrastructure in the Chicago area. The plan, known as the Chicago Region Environmental and Transportation Efficiency (CREATE) project, calls for more than $1.5 billion in infrastructure improvements throughout the region. The plan includes creation of five rail corridors, 25 new grade separations, and the opening for commercial development of a key corridor in downtown Chicago.

Marine Freight

Positioned on Lake Michigan, Chicago is a major port in the north central states, although its total waterborne freight tonnage is significantly less than the major seaport regions like Houston and Los Angeles. From Chicago, deep-draft commercial ships can reach the Atlantic Ocean through the St. Lawrence Seaway, and barge traffic can reach the Gulf of Mexico through the Illinois and Mississippi Rivers. In 2002, the Port of Chicago ranked 36th among U.S. ports in terms of tonnage.[103] As shown in Table C-14, approximately 12 percent of waterborne freight tonnage is foreign trade.[104]

Table C-14: Waterborne Commerce at the Port of Chicago, 2001

	Port of Chicago	
	Tons	**Percent**
Foreign Imports	2,054,000	9%
Foreign Exports	568,000	3%
Lakewise	4,010,000	18%
Internal and Local	15,345,000	70%
Total	21,977,000	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States* database.

Air Freight

The two major Chicago airports are O'Hare International (ORD) and Midway International (MDW). O'Hare is Chicago's primary air freight facility, located 17 miles northwest of downtown Chicago and serviced by I-190 and I-294. O'Hare ranks eighth among the nation's cargo service airports in terms of landed weight of all cargo carriers and handles over 1.1 million tons of freight annually, as shown in Table C-15.[105] O'Hare airport hosts operations of 24 all-cargo airlines.[106] Midway Airport, located 10 miles southwest of downtown Chicago, handles over 21,000 tons of freight annually, or two percent of the region's total air freight.[107]

Table C-15: Chicago Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	Inbound	Outbound	Total
O'Hare International (ORD)	639,907	493,207	1,133,114
Midway International (MDW)	11,391	10,158	21,549
Total	651,299	503,364	1,154,663

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Detroit Freight Transportation Profile

The Southeast Michigan Council of Governments (SEMCOG) is the MPO for the Detroit metropolitan area. The region includes the seven Michigan counties of Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne. In 2002, the population of the Detroit transportation planning area was estimated at 4.9 million, an increase of 6 percent since 1990.[108] The 2002 estimate for total employment in the region was 2.8 million.[109] The Detroit region is designated an ozone nonattainment area under the 8-hour ozone standard.

The Detroit regional economy is dominated by automobile manufacturing and business services. The region has the highest concentration of manufacturing among the six study regions, primarily as a result of the automakers and related businesses.[110] The transportation equipment manufacturing sub-sector supports more than two out of every five manufacturing jobs in the region. Other metals-based heavy industries are also heavily concentrated in Detroit, including fabricated metal product manufacturing, machinery manufacturing, and primary metal manufacturing. Most other manufacturing sub-sectors (such as food products, printing, chemicals, computers, and electronics) have a relatively small presence in the region. Compared to other large metro areas, the region also has relatively low concentrations of employment in the wholesale trade and transportation & warehousing sectors.

The Detroit region serves as an international crossroads for freight movement and is an important gateway to Canada and to Chicago and the Midwest. Approximately 19 million tons of surface freight are imported through the Detroit region annually, including 14.5 million tons of truck freight and 4.2 million tons of rail freight, more tonnage than at any other U.S. border crossing. Ships using the Detroit ports connect with other cities on the Great Lakes and, via the Saint Lawrence Seaway, with ports worldwide. Table C-16 shows commodity flows into and out of the Detroit region by mode. Trucking carries 75 percent of interregional freight tonnage, followed by rail (17 percent) and marine vessels (8 percent).

Table C-16: Commodity Flows Into and Out of the Detroit Region, 2003

Mode	Tonnage	Percent
Trucking	166,037,000	75%
Railroad	37,793,000	17%
Marine Vessel	17,449,000	8%
Aircraft	206,000	0.1%
Total	221,485,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Trucking

The Detroit urbanized area has 280 miles of Interstates and other highways plus 1,026 miles of other principal arterial routes.[111] The region is traversed by Interstates 69, 75, 275, 94, and 96. Detroit also has the busiest commercial vehicle border crossing in North America. There were more than 5.2 million truck crossings between southeast Michigan and Canada in 2000, including 3.5 million trucks on the Ambassador Bridge, 1.6 million trucks on the Blue Water Bridge, and almost 200,000 trucks through the Detroit-Windsor Tunnel.[112] Approximately one-quarter of all truck shipments between the Detroit region and Canada are automobiles and related parts, though there are also large flows of steel, wood, paper products, and machinery.[113]

Table C-17 shows annual on-road VMT in the Detroit region by vehicle type. Heavy-duty trucks account for 13 percent of total VMT in the region, the highest of the six study areas. This high portion of truck traffic is likely a reflection of the large volumes of U.S.-Canada truck traffic, including freight trips originating and terminating in the Detroit region and international trips passing through the region

Table C-17: Detroit Area Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
40,604	87%	1,807	4%	4,117	9%	46,528

Source: Southeast Michigan Council of Governments.

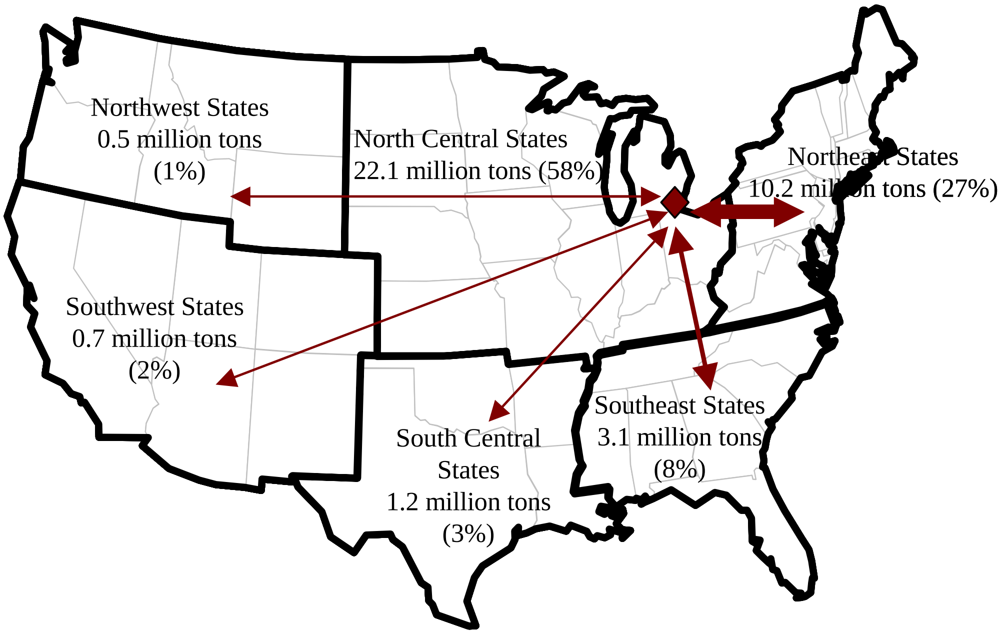
Rail Freight

Four Class I railroads are active in the Detroit area: Norfolk Southern, CSX, CN, and CP. Based on commodity flow data, an estimated 300,000 loaded rail cars cross between Canada and southeast Michigan annually, or more than 800 loaded rail cars per day. CP operates the Detroit-Windsor rail tunnel while CN operates the St. Clair River Tunnel north of Detroit between Port Huron and Sarnia. The St. Clair River Tunnel is a new facility handling modern double-stack cars and RoadRailer service. Norfolk Southern and CSX provide service between Detroit and points west.

Trucks and rail-truck intermodal transfer facilities are critical to the automobile industry's just-in-time inventory process. There are eight rail-truck transfer facilities in the Detroit area. Norfolk Southern operates four of these facilities – the Triple Crown, Delray, and Oakwood facilities in Wayne County and the Thoroughbred Bulk Transfer Facility in Washtenaw County. CN operates an intermodal facility in Oakland County (CN North America) and CP operates a facility in Wayne County (Oak Yard). Two other intermodal facilities are the New Boston Auto Ramp and the Detroit Junction/Livernois Intermodal Terminal, both in Wayne County.[114]

Figure C-5 illustrates *domesti*c commodity flows by rail between Detroit and the rest of the U.S. Over half (58 percent) of Detroit's rail tonnage remains in the north central states and 27 percent moves to and from the northeast states. International rail flows are significant in the Detroit region and are not represented in Figure C-5.

Figure C-5: Rail Commodity Flows (domestic) To and From Detroit, 2003



Source: FHWA, Freight Analysis Framework.

Marine Freight

The largest port in the region is the Port of Detroit, which has seven privately owned terminals located on the Detroit and Rouge Rivers. The region also has port facilities along the St. Clair River. The port handles approximately 17 million tons annually, 28 percent of it foreign, and ranks 40th among the nation's water ports as measured by tonnage. [115]Most Port of Detroit freight (71 percent) remains within the Great Lakes, as shown in Table C-18.

Table C-18: Waterborne Commerce at the Port of Detroit, 2001

	Port of Detroit	
	Tons	**Percent**
Foreign Imports	4,465,000	26%
Foreign Exports	261,000	2%
Lakewise	12,028,000	71%
Internal and Local	237,000	1%
Total	16,991,000	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States* database.

Air Freight

The Detroit region has two major airports that handle freight: Detroit Metropolitan Wayne County (DTW) and Willow Run (YIP). DTW is the region's primary air cargo facility, handling 200,000 tons annually, as shown in Table C-19. DTW ranks 41st among the nation's cargo service airports in terms of landed weight of all cargo carriers. The Willow Run airport, located approximately tens miles west of DTW along the Detroit-Ann Arbor high technology and manufacturing corridor, handles approximately 3 percent of the region's air cargo.

Table C-19: Detroit Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	Inbound	Outbound	Total
Detroit Wayne County (DTW)	109,361	91,097	200,459
Willow Run (YIP)	2,089	3,186	5,274
Total	111,450	94,283	205,733

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Baltimore Freight Transportation Profile

The Baltimore Metropolitan Council (BMC) is the metropolitan planning organization for the Baltimore metropolitan area. The region includes the cities of Baltimore and Annapolis and the five Maryland counties of Anne Arundel, Baltimore, Carroll, Harford, and Howard. The population of the Baltimore region was 2.6 million in 2002, an increase of 9 percent since 1990.[116] The 2002 total employment in the region was 1.5 million.[117] The Baltimore region is designated nonattainment for ozone (1-hour and 8-hour standard).

The private sector economy in the Baltimore region is led by the service sector. With the exception of construction, Baltimore has a relatively low concentration of industries that traditionally generate heavy freight activity, as compared to the other study regions.[118] Manufacturing has a particularly low concentration in Baltimore. The largest manufacturing sectors in Baltimore are chemicals and computers & electronic products. High technology and biotechnology firms have reportedly grown rapidly in the region.[119]

Table C-20 shows domestic commodity flows into and out of the Baltimore region by mode. The region is considerably smaller than the other five study areas in population and employment, and consequently, total freight flows to and from the region are the smallest of six study areas. Trucking carries 59 percent of Baltimore area interregional freight and marine vessels transport another 34 percent.

Table C-20: Commodity Flows Into and Out of the Baltimore Region, 2003

Mode	Tonnage	Percent
Trucking	76,821,000	59%
Railroad	8,537,000	7%
Marine Vessel	44,052,000	34%
Aircraft	146,000	0.1%
Total	129,556,000	100%

Source: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine).

Trucking

Trucking moves in the Baltimore urbanized area on a network of 288 miles of Interstate and other highways plus 374 miles of principal arterial roads.[120] Major highways linking the region include I-95 (which runs from Florida to Maine), I-83 (which runs from Baltimore to Harrisburg, Pennsylvania), and I-70 (which runs from Baltimore to the Pennsylvania Turnpike in southwestern Pennsylvania). The I-695 loop encircles the city of Baltimore.

Table C-21 shows annual VMT in the Baltimore ozone nonattainment area by vehicle type for 2002. Heavy-duty trucks account for 7 percent of the region's total VMT, including 2 percent from gasoline trucks and 5 percent from diesel trucks.

Table C-21: Baltimore Area Annual VMT by Vehicle Type, 2002 (millions)

Light Duty Vehicles		Heavy-Duty Gasoline Trucks		Heavy-Duty Diesel Trucks		
VMT	Percent	VMT	Percent	VMT	Percent	Total VMT
21,449	92%	547	2%	1,271	5%	23,267

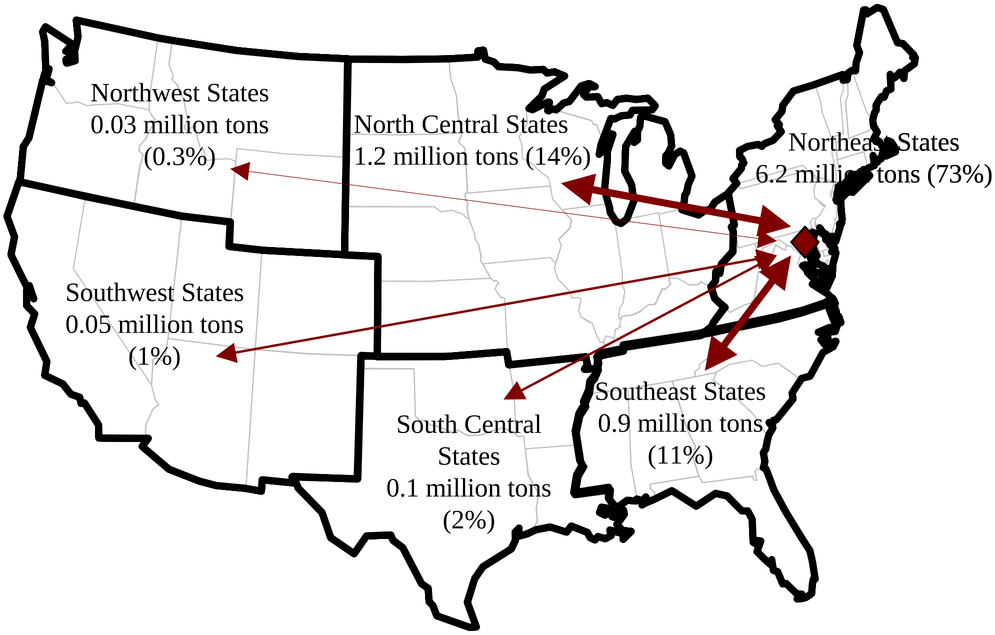
Source: Annual VMT estimated by ICF Consulting based on 2002 average summer weekday VMT data provided by Baltimore Metropolitan Council.

Rail Freight

Two Class I railroads (CSX and Norfolk Southern) and several smaller railroads operate in the Baltimore region. The region also hosts two switching and terminal rail companies, Canton Railroad and Patapsco & Back Rivers Railroad. CSX owns and operates several rail facilities in the Baltimore region, including rail switching yards and rail-to-truck and auto distribution centers (Annapolis, Curtis Bay, Fairfield, and Point Breeze). It also operates the publicly owned Intermodal Container Transfer Facility at the Baltimore port.[121] Norfolk Southern owns a rail/truck intermodal facility and the Bayview Intermodal Container Transfer Facility and switching yard in the city of Baltimore.

Figure C-6 shows railroad commodity flows to and from the Baltimore region. Most rail freight (73 percent) remains within the northeastern states. Another 14 percent of rail freight moves between Baltimore and the north central states, and 11 percent moves to and from the Southeast.

Figure C-6: Rail Commodity Flows To and From Baltimore, 2003



Source: FHWA, Freight Analysis Framework.

Marine Freight

The Port of Baltimore is the region's major maritime facility. Located near the northern end of the Chesapeake Bay, the port is accessible from the Atlantic Ocean through either the south end of the bay or through the Chesapeake and Delaware Canal. Because of the port's inland location, it provides access to more than 30 percent of the nation's population overnight by truck or within two days by rail.[122] In 2002, the Port of Baltimore ranked 15th among the nation's containership ports, with a total of 508,000 TEUs, and ranked 21st nationally in terms of tonnage.[123] Sixty percent of tonnage at the Port of Baltimore is foreign imports or exports, as shown in Table C-22.[124]

Table C-22: Waterborne Commerce at the Port of Baltimore, 2001

	Port of Baltimore	
	Tons	Percent
Foreign Imports	18,262,000	43%
Foreign Exports	7,076,000	17%
Coastwise	5,511,000	13%
Internal and Local	11,212,000	27%
Total	42,061,000	100%

Source: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States* database.

Air Freight

The Baltimore area's major air freight facility is the Baltimore-Washington International Airport (BWI). The airport handles 146,000 tons of freight, as shown in Table C-23. Several all-cargo airlines serve BWI, including FedEx, Airborne Express, UPS, AirNet, Emery Forwarding, and Kitty Hawk.[125]

Table C-23: Baltimore Area Air Cargo Flows, 2003

	Air Cargo (tons)		
Airport	**Inbound**	**Outbound**	**Total**
Baltimore-Washington International (BWI)	79,717	66,420	146,137

Source: Bureau of Transportation Statistics, Air Carrier Statistics T-100 database.

Trucks drive nightly from BWI to New York's John F. Kennedy Airport to meet the next day's international flight departures. These trucks gather freight at the Philadelphia and Newark airports along the way and deliver local destination freight. On the reverse trip, these trucks pick up freight for distribution along the route.[126]

Endnotes

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[1] Federal Highway Administration, *Highway Statistics*, various years.

[2] American Association of Railroads, *Railroad Facts*, 2004

[3] American Association of State Highway and Transportation Officials (AASHTO), *Freight-Rail Bottom Line Report*, undated.

[4] U.S. Army Corps of Engineers, *Waterborne Commerce of the United States*.

[5] According to the Port of Los Angeles, total TEUs handled (loaded and empty) increased 92 percent between 1999 and 2004.

[6] U.S. Department of Transportation Maritime Administration, *Intermodal Access to U. S. Ports; Report on Survey Findings*, August 2002.

[7] Bureau of Transportation Statistics, *National Transportation Statistics 2004*.

[8] Bureau of Transportation Statistics, Airline On-Time Statistics and Delay Causes.

[9] Between 1982 and 2002, truck energy use per vehicle mile declined 3.6 percent, freight railroad energy use per ton-mile declined 37.6 percent, and domestic waterborne commerce energy use per ton-mile increased 51.9 percent. Source: U.S. Department of Energy, Oak Ridge National Laboratory, Transportation Energy Data Book, 24th Edition. Truck freight energy intensity improvements are likely to be greater because of improvements in utilization (ton-miles per vehicle mile). No data available for foreign waterborne commerce or air freight, although gains in aviation fuel efficiency and utilization are widely recognized.

[10] U.S. EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines*, EPA420-R-00-010, July 2000. ; U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998.; U.S. EPA, *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel En*gines, EPA420-R-99-026, November 1999; Federal Aviation Administration, *Aviation & Emissions, A Primer*, 2005.

[11] U.S. EPA, National Emission Inventory.

[12] According to EPA's National Emission Inventory, light duty vehicle NOx emissions declined 55 percent between 1982 and 2002. Emissions from electric utility fuel combustion declined 31 percent over this period.

[13] U.S. EPA, National Emission Inventory.

[14] Bureau of Transportation Statistics, *National Transportation Statistics 2004*.

[15] Class I railroads are defined as line haul freight railroads with operating revenue greater than $277.7 million.

[16] U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998.

[17] We assume an average weight per passenger of 240 lbs, based on a FAA sponsored weight survey (March 21, 2003) of more than 6,000 passengers. The weight includes an average adult passenger weight of 196 lbs, 16 lbs of carry-on items, and 29 lbs of checked baggage.

[18] Bureau of Transportation Statistics, *The Changing Face of Transportation*, BTS00-007, Washington, DC, 2000.

[19] Forecasts for rail ton-miles are based on 1990 through 1998 BTS data, using damped trend exponential smoothing. Forecasts for truck ton-miles are based on two forecast models: linear trend based on 1990 through 1997 data and double (Brown) exponential smoothing based on 1960 through 1995 data in five year increments; the two forecasts are combined with equal weights. Forecasts for air ton-miles are based on two forecasting methodologies: linear trend based on 1990 through 1998 data and damped trend exponential smoothing based on 1960 through 1995 data in five year increments; the two forecasts are combined with equal weights.

[20] American Association of State Highway and Transportation Officials, *Freight-Rail Bottom Line Report*, undated.

[21] American Trucking Associations, *Freight Transportation Forecasts to 2014*, 2004.

[22] ICF Consulting, *2010 and Beyond: A Vision of America's Transportation Future*, 21st Century Freight Mobility, NCHRP Project 20-24(33) A, Final Report, August 2004.

[23] For references to this literature, see Natural Resources Defense Council, *Harboring Pollution: Strategies to Clean Up U.S. Ports*, August 2004.

[24] Federal Aviation Administration, *Aviation & Emissions, A Primer*, 2005.

[25] In addition to emission standards, reduction in PM-10 emissions in this figure reflects the effects of non-road ULSD by locomotives and Category 1 and 2 commercial marine engines. PM-10 emissions are estimated to be 12.1% lower in 2010 and 15.3% lower in 2020, based on U.S. EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*, EPA420-R-04-007, May 2004. Category 1 and 2 commercial marine emissions estimated to be 40% of total commercial marine emissions, based on EPA regulatory support documents.

[26] U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998.

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[27] U.S. EPA, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, EPA420-R-00-026, December 2000.

[28] U.S. EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines*, EPA420-R-00-010, July 2000.

[29] U.S. EPA, *Locomotive Emissions Standards, Regulatory Support Document*, April 1998.

[30] U.S. EPA, *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel En*gines, EPA420-R-99-026, November 1999.

[31] U.S. EPA, *Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*, EPA420-R-03-004, January 2003.

[32] U.S. EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*, EPA420-R-04-007, May 2004.

[33] In addition to emission standards, these figures reflect the PM-10 reductions achieved by the use of ULSD in locomotives and most Category 1 and 2 marine engines in 2010 and 2020.

[34] The vast majority of GHG emissions from transportation sources are CO2. Transportation sources also emit small amounts of other GHG emissions, such as methane (CH4) and nitrous oxide (N2O). Emissions of non-CO2 GHGs are weighted by their respective global warming potential to determine total GHG emissions in terms of CO2 equivalents.

[35] For a detailed description of the emission estimation methodology, see Task 4 Technical Memorandum prepared for FHWA by ICF Consulting dated October 15, 2004.

[36] For a detailed description of the emission estimation methodology, see Task 4 Technical Memorandum prepared for FHWA by ICF Consulting dated October 15, 2004.

[37] Texas Natural Resources Conservation Commission (now the Texas Commission on Environmental Quality), "Locomotive Emission Inventory: Update and Discussion," Memo from Sam Wells, Starcrest Consulting Group and Rick Baker, ERG, Inc., August 30, 2002.

[38] U.S. EPA, "Procedures for Emission Inventory Preparation. Volume VI Mobile Sources," 1992.

[39] U.S. EPA, *Locomotive Emission Standards, Regulatory Support Document*, April 1998.

[40] ARCADIS Geraghty & Miller (1999a), *Commercial Marine Activity for Deep Sea Ports in the United States*, Prepared for U.S. EPA, 1999.

[41] ARCADIS Geraghty & Miller (1999b), *Commercial Marine Activity for Great Lake and Inland River Ports in the United States*, Prepared for U.S. EPA, 1999.

[42] Environ International Corporation, *Commercial Marine Emission Inventory Development*, Prepared for U.S. EPA, 2002.

[43] Starcrest Consulting Group, *Port-Wide Baseline Air Emissions Inventory*, Prepared for the Port of Los Angeles, 2004.

[44] Starcrest Consulting Group, *2001 Cargo Handling Equipment Emissions Inventory: Methodology Comparison*, Prepared for the Port of Houston Authority, 2004.

[45] Starcrest Consulting Group, *Port-Wide Baseline Air Emissions Inventory*, Prepared for the Port of Los Angeles, 2004.

[46] Starcrest Consulting Group, 2002 *Baseline Emissions Inventory: Cargo Handling Equipment, Rail Locomotives, and Heavy-Duty Vehicles*, Prepared for the Port of Long Beach, 2004.

[47] For a detailed description of the emission estimation methodology, see Task 4 Technical Memorandum prepared for FHWA by ICF Consulting dated October 15, 2004.

[48] For a detailed description of the emission estimation methodology, see Task 4 Technical Memorandum prepared for FHWA by ICF Consulting dated October 15, 2004.

[49] An average weight per passenger of 240 lbs was used based on a FAA sponsored weight survey (March 21, 2003) of more than 6,000 passengers. The weight includes an average adult passenger weight of 196 lbs, 16 lbs of carry-on items, and 29 lbs of checked baggage.

[50] The EDMS model does not currently estimate PM emissions for aircraft and therefore most airports and air agencies do not report aircraft PM emissions. In order to facilitate comparison across modes, we developed a rough estimate of aircraft PM emissions using the ratio of PM to SOx emissions from a California Air Resources Board research study. This study, called the Southern California Ozone Study (SCOS97), estimated PM emissions from jet aircraft at Southern California airports using fuel use data obtained from airports; emissions of other pollutants were estimated using EDMS. Using the results of this study, we calculated the average PM and SOx emissions for all study days and airports, and used these averages to estimate a ratio of 0.311 tons of aircraft PM emissions per ton of

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aircraft SOx emissions. We applied this ratio to the SOx emissions reported for each of the study airports to estimate PM emissions.

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[52] Lutsey, Nicholas, Christie-Joy Broderick, Daniel Sperling, Carollyn Oglesby, "Heavy-Duty Truck Idling Characteristics – Results from a Nationwide Truck Survey," paper submitted for the 2004 Annual Meeting of the Transportation Research Board, 2004.

[53] Taylor, Dr. John C. et al. "The U.S.-Canada Border: Cost Impacts, Causes, and Short to Long Term Management Options." May, 2003, p.14. Available at http://www.fhwa.dot.gov/uscanada/studies/taylor/costrpt_2003.pdf.

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[55] U.S. EPA, *Locomotive Emission Standards, Regulatory Support Document*, April 1998.

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[60] "Union Pacific turning away some freight traffic; giant fights congestion at 'key terminals,' mainly in West and Southwest," *Trains*, October 2004.

[61] In addition to the longer Union Pacific example given, see, for just two examples: "Rail congestion diverts coal to trucks," *Toledo Blade*, August 10, 2004; Suzanne Marta, "Rail shippers struggle with congestion woes", *Dallas Morning News*, August 27, 2004.

[62] TRB Committee for the Study of Freight Capacity for the Next Century, *Freight Capacity for the 21st Century*, Special Report 271, Transportation Research Board, 2003.

[63] As long as they are not idling, locomotive emissions are largely independent of train speed; as diesel-electrics, the speed of the diesel engine is independent of the speed of the electric motors that actually power the wheels. The operating mode, efficiency, and emissions of the diesel engine itself (called the "prime mover") are largely determined by the load on the locomotive, and not its speed.

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[67] Federal Aviation Administration, *Aviation & Emissions, A Primer*, 2005.

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[71] Imperial County is also officially part of the SCAG region but was excluded from this analysis because it is distant and distinct from the greater Los Angeles metropolitan area.

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[73] U.S. Bureau of Economic Analysis, Regional Economic Accounts (county-level data)

[74] U.S. Census Bureau, County Business Patterns.

[75] Commodity flow data summary tables for each region developed from: FHWA Freight Analysis Framework (trucking and rail); Bureau of Transportation Statistics, Air Carrier Statistics T-100 database (air); U.S. Army Corps of Engineers, Waterborne Commerce of the United States database (marine) (2003 marine freight estimated using

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[79] Southern California Association of Governments, *Goods Movement Program White Paper*, January 2002.

[80] Data from the American Association of Port Authorities.

[81] Data from the American Association of Port Authorities.

[82] Federal Aviation Administration, CY 2003 Passenger Boarding and All-Cargo Data.

[83] For the analyses of commodity flow data, entire counties must be used. For that reason, all of Ellis and Johnson counties were included in the analyses and Parker and Kaufman counties were excluded.

[84] U.S. Census Bureau (data for all 9 counties that lie wholly or partially in the region).

[85] U.S. Bureau of Economic Analysis, Regional Economic Accounts (data for all 9 counties that lie wholly or partially in the region).

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[91] U.S. Bureau of Economic Analysis, Regional Economic Accounts (county-level data).

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[94] Houston Galveston Area Council, *Draft 2025 Regional Transportation Plan, Freight Appendix*.

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[97] American Association of Port Authorities.

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