Controlling Airport-Related Air Pollution

June 2003

Center for Clean Air Policy

NESCAUM
Northeast States for Coordinated Air Use Management

Controlling Airport-Related Air Pollution

Prepared by

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Table of Contents

List of Tables

List of Figures

Executive Summary

This report was undertaken by the Northeast States for Coordinated Air Use Management (NESCAUM) and the Center for Clean Air Policy (CCAP) as part of an effort to assist policymakers at the national, state, and local levels in better understanding the contribution of the aviation sector to air pollution problems and in developing control options for reducing airport-related emissions.

Airport-related activities result in the emission of a host of air pollutants that adversely affect public health and the environment, including nitrogen oxides (NOx), hydrocarbons (HC), particulate (PM), carbon monoxide (CO), and toxics. NOx and HC are precursor emissions of ground-level ozone, which causes lung irritation and aggravates diseases such as asthma, chronic bronchitis, and emphysema. Particulates have adverse cardiopulmonary effects and contribute to regional environmental problems such as haze and acid rain. Toxics such as benzene and formaldehyde are known or probable human carcinogens. Nationally, the number of aircraft operations (defined as one takeoff *or* one landing) has grown substantially from around 15 million in 1976 to almost 30 million in 2000, a cumulative growth of about 105 percent. While emissions from most source sectors are declining due to the implementation of more stringent control programs, the growth in air travel[1] and the continued lack of federal control programs for aircraft engines is resulting in increased pollution from airports. States in non-attainment of criteria pollutant National Ambient Air Quality Standards (NAAQS) are required by federal law to reduce ambient levels of these pollutants. Given the existence of stringent control programs for other industry sectors, reductions in airport-related air pollution are necessary in order for states to lower emissions to meet air quality and public health goals. Absent control measures to reduce airport-related emissions, further emissions reductions from other sectors will be needed in order for states to attain air quality requirements.

The study involved: (1) quantifying airport-related emissions for three Northeast airports; (2) assessing control options; (3) outlining various policy options for achieving cost-effective reductions; and (4) outlining and assessing legal opportunities and barriers to actions by states. This report contains six chapters. Chapter I introduces the issue and describes the study. Chapter II presents the results of the emission inventory assessment for several airports in the Northeast and explains the methodology NESCAUM used. The inventory includes non-military aircraft, auxiliary power units (APU), and ground service equipment (GSE). Stationary source emissions were not estimated. Chapter III is an assessment of technological and operational control options for various sources of emissions at airports. Chapter IV highlights policy options available to reduce airport-related emissions and provides case studies of approaches currently in place or proposed in the U.S. and abroad. Chapter V evaluates and summarizes statutory and regulatory options and constraints with regard to controlling airport-related pollution. Chapter VI summarizes the findings and recommendations of the study.

[1] FAA's revised Terminal Air Forecast shows that national aircraft operations will increase by about 1 percent per year from 2000 to 2020. Recent analysis by ICAO's Forecasting and Economic Analysis Support Group (FESG) predicts worldwide growth of 4.3 percent per year between 2000 and 2020 (FESG, *Report of the FESG/CAEP/6 Traffic and Fleet Forecast*, 2003).

A. Emissions Inventories for Three Selected Airports

- In aggregate, aircraft at Logan International Airport (Boston, MA), Bradley International Airport (Windsor Locks, CT), and Manchester Airport (Manchester, NH) emitted 3,538 tons of NOx, 4,461 tons of CO, and 700 tons of HC in 1999. Combined aircraft-related emissions of benzene totaled 20 tons at Logan, Bradley, and Manchester in 1999. For comparison, aggregate benzene emissions from the largest stationary sources in Massachusetts, Connecticut, and New Hampshire combined totaled six tons in 1996.[2]

- At the three airports studied, 85 percent of airport NOx emissions are from aircraft. Of aircraft emissions, air carriers contribute the majority of the NOx. In 1999, air taxi operations contributed one-third of aircraft-related HC emissions and air carrier operations contributed two-thirds.[3]

- Auxiliary power units and ground service equipment combined account for approximately 15 percent of aviation-related NOx emissions at the three airports studied.

- Significant increases in airport operations are predicted over the next decade at airports in the Northeast region. Aircraft operations are projected to grow by 8 percent at Logan, 30 percent at Bradley, and 14 percent at Manchester over the next ten years.[4]

- Regionalization, or the shift in traffic from larger to smaller airports, will cause rapid expansion at smaller airports over the next decade in the Northeast.

B. Control Options

- In the long term, cost effective options to reduce fuel consumption and criteria pollutants from aircraft engines are technically feasible; an example of such options is aerodynamic aircraft bodies.

- Aircraft operational changes such as single engine taxi and reduced use of reverse thrust (used at the pilot's discretion) cost little or nothing to implement and provide fuel-use savings and emissions reductions.

- Electrification of ground support equipment provides reductions in all pollutants, and can save the airport operators and air carriers money over the long term due to the increased efficiency of electric motors compared to gasoline and diesel engines.

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[2] EPA Office of Air Quality Planning and Standards, http://www.epa.gov/air/data/ Geographic Area Report from NTI's Facilities Emissions Data, February 15, 2001.

[3] Aircraft are generally grouped into four categories: air carriers, air taxis, general aviation, and military. These denominations are based on the operator of the aircraft, not on the aircraft themselves. Air carriers own and operate at least one aircraft that seats at least 60 passengers or has a payload of at least 18,000 pounds. Air carriers may also own smaller aircraft, but their landings and takeoffs (LTOs) are reported with those of the larger aircraft. Air taxis operate smaller certified aircraft as defined in 14 CFR Part 298. Air taxis usually fly short routes and are considered regional or shuttle carriers. General aviation includes small planes that are usually privately owned or belong to corporations.

[4] Aircraft activity after September 11, 2001 decreased dramatically. However, Federal Aviation Administration (FAA) forecasts for growth in the number of landings and takeoffs have not changed and thus aircraft activity is expected to return to pre-9/11 rates within a few years.

- Gate electrification is one of the most cost-effective options examined in this study. Gate electrification in some cases provides a cost benefit within two years of installation.

- Operation of factory-built, dedicated compressed natural gas (CNG) and liquid propane gas (LPG) ground service equipment reduce emissions of NOx, HC, CO, and PM relative to gasoline and diesel-powered equipment. Conversions from diesel or gasoline to CNG/LPG provide NOx and PM reductions but can sometimes increase HC and CO emissions.

- A federal program called the Federal Aviation Administration's Inherently Low-Emission Airport Vehicle Pilot Program (ILEAV) provides financial incentives for airports to reduce emissions by introducing clean alternative fuel ground service and ground access vehicles into fleets. A total of ten airports have been selected to receive funding.

C. Policy Options

- A variety of regulatory and policy options exist for states, localities, and airport operators to control airport-related emissions. Innovative programs have been initiated at many airports around the world.

- While emission standards are in place for aircraft engines, most engines currently in production emit NOx at levels below the national standards. Efforts at the national and international levels to increase the stringency of engine emission standards could play a role in reducing air pollution from aviation and in driving technology development.

- "Cap-and-trade" or airport "bubble" approaches have the potential to limit airport-related emissions, provide flexibility in achieving reductions, and encourage the use and development of cleaner technologies. The operators of Logan Airport (Massport) have established a cap on airport emissions; any emissions increases that result from airport activity must be offset by on-airport emission reductions, reductions near the airport, or by purchasing emission credits.

- Fee-based strategies, such as increased or variable landing fees, are another potentially useful tool that officials at the state, local, and airport level can use to reduce emissions. Variable aircraft landing fees are have been implemented at Zurich and Geneva Airports in Switzerland, and at nineteen airports in Sweden. The fees are emissions-based and result in a greater charge being levied on higher polluting aircraft entering those airports.

- Regulatory approaches such as 1) promoting or requiring the purchase of cleaner alternatives when fleet vehicles or equipment are replaced or added; and 2) developing a declining fleet emissions target can be utilized to achieve emissions reductions from ground service equipment and ground access vehicles.

- Emission reductions can also be achieved through voluntary agreements. Currently, states, the airline industry, the US EPA, the FAA, environmental groups and others are discussing a voluntary national program to reduce airport-related emissions.

- Voluntary agreements at the local level are also possible to reduce emissions from aircraft ground activities (taxi and gate operation), ground service equipment, ground access vehicles, and stationary sources. A voluntary agreement has been reached at airports in the Dallas-Forth Worth and Houston areas of Texas, where the airlines have agreed to reduce NO_X emissions from ground service equipment. A similar program is being developed for airports in southern California.

D. Regulatory Context

- The International Civil Aviation Organization (ICAO) and its Committee on Aviation and Environmental Protection (CAEP) seek to coordinate the development of consistent international standards for aircraft engines.

- US EPA is required by Section 231 of the Clean Air Act Amendments of 1990 to regulate aircraft engine emissions and has generally adopted the standards recommended by ICAO as the applicable federal standards in the U.S.

- The Clean Air Act provides states with some authority to require emissions reductions at airports, although legal barriers constrain this authority.

- States (within narrow confines) could impose controls on ground operation of aircraft. Regulations that do not impact safety and the movement of aircraft are most likely to avoid preemption.

- States may petition EPA to control aircraft engine emissions to more stringent standards. The Administrative Procedure Act provides that "interested person[s]" have the right to petition an Agency to amend or repeal a rule.[5] Since the EPA sets standards for aircraft engine emissions as part of its rulemaking capacity, any interested person may petition the Agency to revise the rule.

- Emissions controls for ground service equipment could be implemented through "in-use limits" on their operation, provided that fleet operators have options available that do not require modifications to the equipment.

- States that are proprietors of airports can impose requirements on fleets operating within the airport. A fleet emission requirement could be established, provided that the fleet operator had options available to meet the requirement without modifying the fleet engines.

- States acting as proprietors of airports may be able to impose landing fees on airplanes, provided that the fees are "reasonable" and used wholly for "airport or aeronautical purposes."

- States may be permitted, as a condition of modifying or expanding an airport, to set a limit on airport emissions under the "indirect source review" provisions of the Clean Air Act.

[5] 5 U.S.C., section 553(e).

E. Conclusions

- Airport-related emissions are increasing while emissions from nearly all other major source sectors are decreasing.

- There are a host of technical and operational control options for reducing airport-related emissions.

- Establishing an airport emissions cap can serve to encourage the introduction of control technologies such as gate electrification, less polluting aircraft engines, and alternative fuel ground service equipment and ground access vehicles.

- National and international agreements to encourage the development of less polluting, more efficient aircraft engines and more aerodynamic aircraft bodies can result in aircraft that pollute substantially less, are quieter, and burn less fuel than today's airplanes.

- States have some authority under the Clean Air Act to require emissions reductions from airport sources.

- Without technology forcing emission standards that provide incentives for reductions in criteria pollutants and more efficient engines, NOx emissions from aircraft engines will likely increase for the foreseeable future.

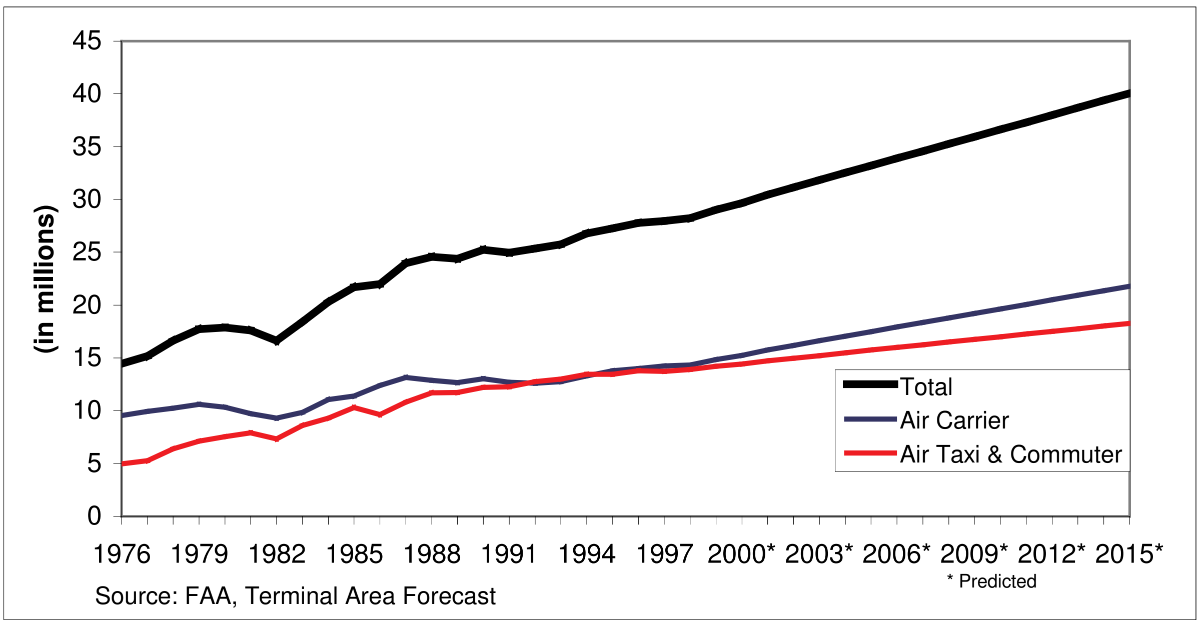
I. Introduction

A. Overview

Airport-related activities result in the emission of a host of air pollutants that adversely affect public health and the environment. While emissions from most source sectors are declining due to the implementation of various national, state, and local control programs, the rapid growth in air travel and the lack of technology-forcing federal or international control programs is resulting in increased pollution from airports.

The number of aircraft operations (defined as one aircraft takeoff *or* landing) in the U.S. has grown substantially, from around 15 million in 1976 to almost 30 million in 2000, a cumulative growth of about 105 percent. Figure I-1 illustrates the growth in aircraft operations over the past 25 years and projects growth rates for the next 15 years.[6]

Figure I-1: Historical and Projected Air Carrier Operations



As the relative importance of this source sector grows, so has the number and variety of local airport pollution reduction initiatives across the country. Interest in and concern about this trend toward more and diverse local initiatives prompted the Federal Aviation Administration (FAA) and the U.S. Environmental Protection Agency (EPA) in 1998 to convene a multi-stakeholder forum (henceforth "Stakeholder Process") to consider a voluntary national program for controlling nitrogen oxides (NOx) emissions from aircraft and airports. An appropriate national strategy could maximize emission reductions, improve the cost-effectiveness of these reductions, and provide planning certainty to the affected parties. Absent a viable and effective national strategy, and potentially to

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[6] In March of 2003, FAA revised its forecast for growth in the number of landings and takeoffs as a result of the September 11, 2001 attacks. The revised forecast has not been used in the estimation of aircraft activity for the purposes of this report.

Table I-1: Airports in One-Hour Ozone Nonattainment and Maintenance Areas, by State

State	**Number of Airports**[a]		
	Nonattainment	***Maintenance***[b]	***Total***
Alabama	1	-	1
Arizona	2	-	2
California	22	3	25
Colorado	-	1	1
Connecticut	3	-	3
Florida	-	6	6
Georgia	1	-	1
Illinois	3	-	3
Indiana	-	3	3
Kentucky	-	3	3
Louisiana	1	3	4
Massachusetts	8	-	8
Maryland	1	-	1
Maine	2	1	3
Michigan	-	7	7
Missouri	2	1	3
North Carolina	-	3	3
New Hampshire	1	-	1
New Jersey	4	-	4
New York	6	-	6
Nevada	1	-	1
Ohio	-	6	6
Oregon	-	1	1
Pennsylvania	8	2	10
Rhode Island	3	-	3
Tennessee	-	2	2
Texas	8	1	9
Utah	-	1	1
Virginia	2	3	5
Washington	-	3	3
West Virginia	-	3	3
Total	***79***	***53***	***132***
a) Airports with more than 10,000 aircraft operations in 1999.			
b) Includes Section 185A and Incomplete Data Areas.			

Source: See Appendix A.

complement a national strategy, state and local governments across the country will pursue programs to reduce airport-related emissions in their jurisdictions.

State and local governments have cause for concern. Many major hub airports in the U.S. are located in large metropolitan areas where air pollution levels exceed national health-based standards. Twenty-two of the largest 31 airports in the U.S. are located in ozone nonattainment areas. An additional number of airports are located in areas that could potentially be listed as nonattainment for the new, more protective eight-hour ozone standard.[7] Tables I-1 and I-2 show airports across the country located in nonattainment areas for the one-hour and eight-hour standards.

Table I-2: Airports Located in Potential Eight-Hour Ozone Nonattainment Areas, by State[8]

State[a]	Number of Airports[b]	State[a]	Number of Airports[b]
Alabama	4	*North Carolina*	6
Arizona	2	*New Hampshire*	1
California	19	*New Jersey*	3
Connecticut	3	*New York*	7
Florida	2	*Nevada*	3
Georgia	5	*Ohio*	7
Illinois	3	*Oklahoma*	2
Indiana	4	*Pennsylvania*	12
Kentucky	5	*Rhode Island*	3
Louisiana	4	*Tennessee*	5
Massachusetts	6	*Texas*	10
Maryland	1	*Virginia*	4
Maine	2	*West Virginia*	3
Michigan	7	*Wisconsin*	1
Missouri	3	***Total***	***137***

a) Counties where the 8-hr standard was exceeded in ambient monitoring over a two-year period. The number of airports included could be broader as states delegate the breadth of areas for 8-hr ozone classification. Includes counties that have a "potential to violate".

b) Airports with more than 10,000 aircraft operations in 1999.

Source: See Appendix A.

The situation is especially important in the Northeast and Mid-Atlantic regions, where airports are located in counties where pollution levels exceed federal health-based standards. Tables I-3 and I-4 show airports in the Ozone Transport Region (OTR) located in nonattainment areas for the one-hour and eight-hour ozone standards.

While many airport initiatives to date have focused primarily on NOx emissions, other pollutants such as hydrocarbons (HC), particulate matter (PM) and air toxics from airport-related activities are also of concern to state and local air quality agencies. A concerted effort must be undertaken at international, national, state, local, and airport levels to ensure those new, cleaner technologies and operational measures are introduced to ensure that airport-related emissions decrease over time.

[7] The one-hour ozone standard is 120 ppb and the eight-hour ozone standard is 80 ppb.
[8] The potential nonattainment areas are based on three years of data between 1997 and 1999.

Table I-3: OTR Airports Located in 1-Hour Ozone Nonattainment and Maintenance Areas

Airport[a]	State	Airport Code	County	Ozone Classification
Bradley Intl	CT	BDL	Hartford	Serious Nonattainment
Groton-New London	CT	GON	New London	Serious Nonattainment
Tweed-New Haven	CT	HVN	New Haven	Serious Nonattainment
Logan Intl	MA	BOS	Middlesex	Serious Nonattainment
Laurence G. Hanscom Field	MA	BED	Middlesex	Serious Nonattainment
Nantucket Memorial	MA	ACK	Nantucket	Serious Nonattainment
Provincetown Municipal	MA	PVC	Barnstable	Serious Nonattainment
Barnstable Muni-Boardman/Polan	MA	HYA	Barnstable	Serious Nonattainment
Marthas Vineyard	MA	MVY	Dukes	Serious Nonattainment
New Bedford Regional	MA	EWB	Bristol	Serious Nonattainment
Worcester Regional	MA	ORH	Worcester	Serious Nonattainment
Baltimore/Washington Intl	MD	BWI	Anne Arundel	Severe-15 Nonattainment
Portland Intl Jetport	ME	PWM	Knox	Moderate Nonattainment
Knox County Regional	ME	RKD	Cumberland	Moderate* Nonattainment
Hancock County-Bar Harbor	ME	BHB	Hancock	Marginal Maintenance
Manchester	NH	MHT	Hillsborough	Marginal Nonattainment
Newark Intl	NJ	EWR	Essex	Severe-17 Nonattainment
Teterboro	NJ	TEB	Bergen	Severe-17 Nonattainment
Trenton Mercer	NJ	TTN	Mercer	Severe-15 Nonattainment
Atlantic City Intl	NJ	ACY	Atlantic	Moderate Nonattainment
La Guardia	NY	LGA	Queens	Severe-17 Nonattainment
JFK Intl	NY	JFK	Queens	Severe-17 Nonattainment
Stewart Intl	NY	SWF	Suffolk	Moderate Nonattainment
Buffalo Niagara Intl	NY	BUF	Orange	Marginal Nonattainment
Albany Intl	NY	ALB	Erie	Marginal Nonattainment
Long Island Mac Arthur	NY	ISP	Albany	Severe-17 Nonattainment
Philadelphia Intl	PA	PHL	Delaware	Severe-15 Nonattainment
Pittsburgh Intl	PA	PIT	Allegheny	Moderate Maintenance
Lehigh Valley Intl	PA	ABE	Westmoreland	Marginal Nonattainment
Lancaster	PA	LNS	Lehigh	Marginal Nonattainment
Wilkes-Barre/Scranton Intl	PA	AVP	Lancaster	Marginal Nonattainment
Harrisburg Intl	PA	MDT	Luzerne	Marginal Nonattainment
Erie Intl	PA	ERI	Dauphin	Marginal Nonattainment
Arnold Palmer Regional	PA	LBE	Erie	Moderate Maintenance
Johnstown-Cambria County	PA	JST	Cambria	Marginal Nonattainment
Altoona-Blair County	PA	AOO	Blair	Marginal Nonattainment
Theodore Francis Green State	RI	PVD	Kent	Serious Nonattainment
Block Island State	RI	BID	Washington	Serious Nonattainment
Westerly State	RI	WST	Washington	Serious Nonattainment
Washington Dulles Intl	VA	IAD	Loudoun	Serious Nonattainment
Ronald Reagan Washington Natl	VA	DCA	Arlington	Serious Nonattainment
Newport News/Williamsburg Intl	VA	PHF	Henrico	Marginal Maintenance
Norfolk Intl	VA	ORF	Newport News	Marginal Maintenance
Richmond Intl	VA	RIC	Norfolk	Moderate Maintenance

a) Airports with more than 10,000 aircraft operations in 1999.

Sources: Ozone nonattainment areas from U.S. EPA, Greenbook, as of November 4, 2002: <www.epa.gov/oar/oaqps/greenbk/oindex.html#List1>. Locations from G.C.R. & Associates Inc.: <http://www.gcr1.com/5010WEB/default.htm>.

Table I-4: Airports Located in Potential 8-Hour Ozone Nonattainment Areas, in the OTR

Airport[a)]	State	Airport Code	County
Bradley Intl	CT	BDL	Hartford
Groton-New London	CT	GON	New London
Tweed-New Haven	CT	HVN	New Haven
Logan Intl	MA	BOS	Middlesex
Laurence G. Hanscom Field	MA	BED	Middlesex
Provincetown Municipal	MA	PVC	Barnstable
Barnstable Muni-Boardman/Polan	MA	HYA	Barnstable
New Bedford Regional	MA	EWB	Bristol
Worcester Regional	MA	ORH	Worcester
Baltimore/Washington Intl	MD	BWI	Anne Arundel
Portland Intl Jetport	ME	PWM	Cumberland
Hancock County-Bar Harbor	ME	BHB	Hancock
Manchester	NH	MHT	Hillsborough
Newark Intl	NJ	EWR	Essex
Trenton Mercer	NJ	TTN	Mercer
Atlantic City Intl	NJ	ACY	Atlantic
La Guardia*	NY	LGA	Queens
John F Kennedy Intl*	NY	JFK	Queens
Westchester County	NY	HPN	Westchester
Stewart Intl	NY	SWF	Orange
Buffalo Niagara Intl	NY	BUF	Erie
Long Island Mac Arthur	NY	ISP	Suffolk
Chautauqua County/Jamestown	NY	JHW	Chautauqua
Philadelphia Intl	PA	PHL	Delaware
Pittsburgh Intl	PA	PIT	Allegheny
Lehigh Valley Intl	PA	ABE	Lehigh
Reading Regional/Carl A Spaatz	PA	RDG	Berks
Lancaster	PA	LNS	Lancaster
Wilkes-Barre/Scranton Intl	PA	AVP	Luzerne
Harrisburg Intl	PA	MDT	Dauphin
University Park	PA	UNV	Centre
Erie Intl	PA	ERI	Erie
Arnold Palmer Regional	PA	LBE	Westmoreland
Johnstown-Cambria County	PA	JST	Cambria
Altoona-Blair county	PA	AOO	Blair
Theodore Francis Green State	RI	PVD	Kent
Block Island State	RI	BID	Washington
Westerly State	RI	WST	Washington
Washington Dulles Intl	VA	IAD	Loudoun
Ronald Reagan Washington	VA	DCA	Arlington
Richmond Intl	VA	RIC	Henrico
Roanoke Regional/Woodrum Field	VA	ROA	Roanoke

a) Airports with more than 10,000 aircraft operations in 1999.

Sources: Ozone data from *U.S. EPA 1997-1999 8-Hour Ozone County Design Values* at <www.epa.gov/ttn/rto/areas/state/aq/aq99cnty.htm>. Airport locations from G.C.R. & Associates Inc. at <http://www.gcr1.com/5010WEB/default.htm>.

B. Study Design and Goals

The Northeast States for Coordinated Air Use Management (NESCAUM) and the Center for Clean Air Policy (CCAP) undertook this analysis to quantify aviation emissions, assess technical and operational options, and outline and evaluate policy approaches to controlling air pollution related to airport operations. This study quantified airport-related pollutants of regional concern in the Northeast, including NOx, HC, PM, and air toxics. Where possible, an inventory for all four categories of pollutants was developed. In some cases insufficient information prevented us from calculating an inventory for all pollutants. The study is intended as a policy-relevant analysis to inform and guide state and local air pollution officials as they grapple with the issue of airport emissions in their own jurisdictions, at the national level, and through the FAA/EPA Stakeholder Process. Based on this analysis, we highlight potential policy approaches to implementing effective and consistent airport emission control programs. The information generated through this study can be useful for crafting a meaningful national program and/or state and regional programs, and can serve as a resource for state and local governments, airport operators, and industry to develop and implement effective emission reduction measures should the Stakeholder Process fail to deliver the control initiative needed to adequately protect public health and the environment. In the event that the Stakeholder Process proves successful, this study can serve as a resource for state/local governments, airport operators, and industry to develop and implement effective emission reduction measures in accord with the national agreement or to attain additional reductions.

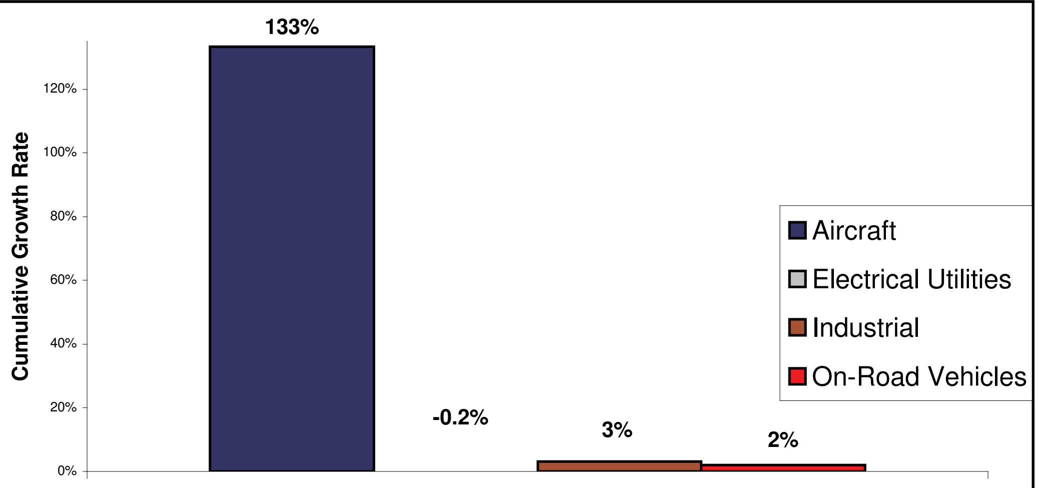
The study involved: (1) quantifying airport-related emissions at three Northeast airports; (2) assessing control options; (3) outlining various policy options for achieving cost-effective reductions; and (4) outlining and assessing legal opportunities and barriers to actions by state and local governments. This report contains six chapters. Chapter I introduces the issue and describes the study. Chapter II presents the results of the emission inventory assessment for several airports in the Northeast and explains the methodology NESCAUM used. The inventory includes non-military aircraft, auxiliary power units (APU), and ground service equipment (GSE). Stationary source and ground access vehicle (GAV) emissions were not estimated. Chapter III is an assessment of technological and operational control options for various sources of emissions at airports. Chapter IV highlights policy options available to reduce airport-related emissions and provides case studies of approaches currently in place or proposed in the U.S. and abroad. Chapter V evaluates and summarizes statutory and regulatory options and constraints with regard to controlling airport-related pollution. Chapter VI summarizes the findings and recommendations of the study.

C. Impact of Airport-Related Emissions on Public Health and the Environment

C.1 Sources, Levels and Trends in Airport Emissions

Emissions from aircraft, GSE, GAV, stationary sources and private vehicles contribute to the total air pollution burden associated with airport operations. Currently, aircraft NOx and VOC emissions at major airports are comparable to those from large stationary sources in their respective metropolitan areas. Aircraft NOx emissions are growing more quickly than NOx emissions from other sources. As more stringent controls are mandated for large stationary sources and air travel continues to grow, the relative importance of aircraft emissions will increase, absent additional controls on this sector. In Massachusetts, for example, aircraft from Logan International Airport currently emit approximately 20 percent as much NOx as the largest power plant in the state. By 2010, aircraft NOx emissions at Logan are expected to exceed those of any single power plant in the state, without further regulation. In Connecticut, aircraft operations at Bradley International Airport result in similar levels of HC emissions as a metal painting company (10^{th} largest HC source in the nonattainment area) and a large petroleum storage facility (11^{th} largest source). Figure I-2 compares national aircraft, electric utilities, industrial, and on-road vehicle NOx emissions growth rates between 1970 and 1998.

Figure I-2: National NOx Emission Growth Rates: 1970-1998



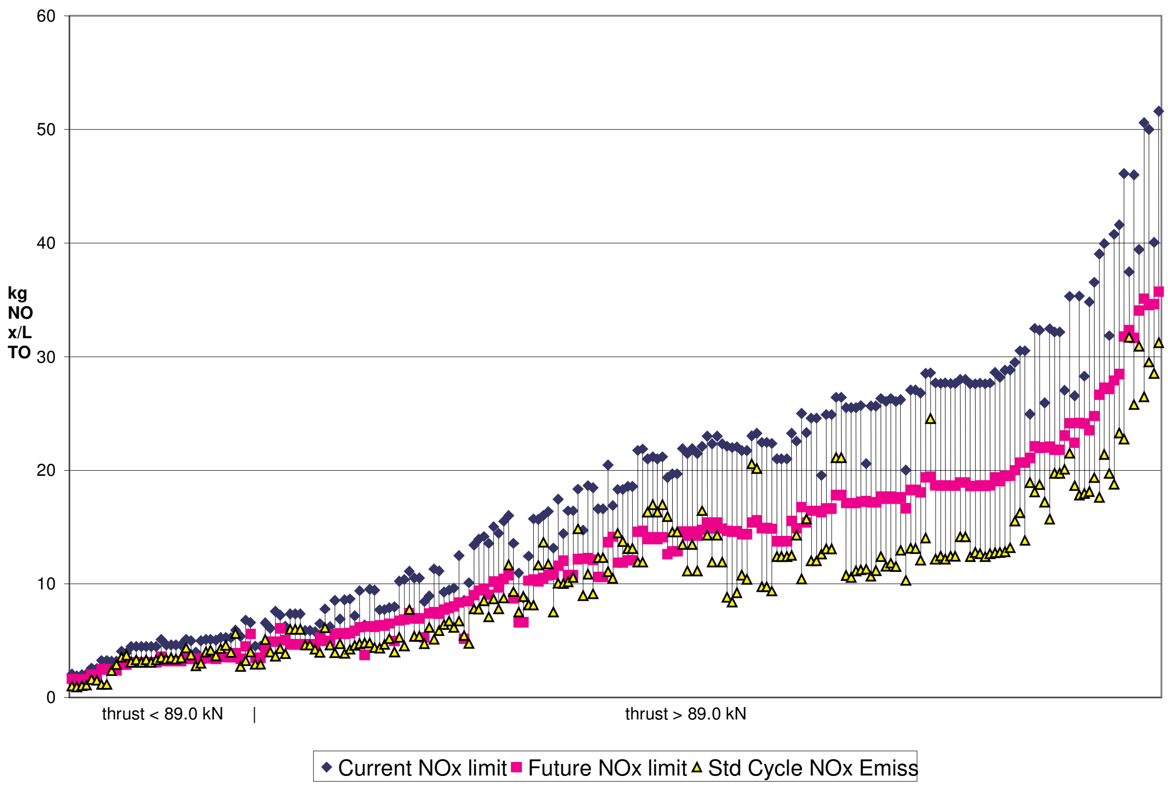
Source: Author's calculation; EPA, National Air Pollutant Emission Trends: 1900-1998, 2000

The effect of stringent state and federal emission control programs on electric utilities, industrial, and automobile NOx emission growth rates are reflected in this graph. For example, while the number of registered automobiles in the U.S. has grown from 90 million to approximately 200 million from 1970 to 1998,[9] NOx emissions have remained close to 1970 levels. EPA estimates that automobile emissions standards have resulted in a greater than 99 percent reduction in emissions per mile during this period. In contrast, aircraft engine NOx emissions have grown substantially in the same time frame. Under the current international process through the International Civil Aviation Organization (ICAO), the introduction of new aircraft engine emission standards holds little promise to reduce overall aircraft NOx emissions. To date, the standards, developed internationally, have not been "technology forcing" in that they have been based upon currently available aircraft engines. Figure I-3 shows ICAO standards for different types of engines. Existing and future ICAO standards will not reduce NOx emissions from most aircraft engines. The U.S. has elected to conform its aircraft engine emissions standards to those developed by ICAO. Although EPA has the authority to promulgate emission standards for aircraft engines, that authority is limited.[10]

[9] Ward, "Motor Vehicle Facts and Figures," 2001.
[10] See Chapter V for greater detail.

Emission standards for other airport sources are largely under the control of the federal government. Diesel GSE emissions have been regulated since 1996 by EPA.[11] However, to date these standards have had little impact, given that the durability of diesel engines results in slow fleet turnover. In addition, the standards are not nearly as stringent as highway diesel standards: nonroad diesel engines emit twice as much NOx and PM as similar sized engines used in highway applications. Even with the rule in place, PM emissions from nonroad diesel engines are projected to increase while NOx emissions will decline 40 percent from uncontrolled levels with the full phase in of the rule, 20 years from now. Gasoline GSE engine emissions remain unregulated at this time, although EPA recently finalized standards for gasoline powered GSE that are comparable to those established by the California Air Resources Board.[12] The requirements of the rule will be phased-in between 2004 and 2007. When implemented, these standards will require the installation of three-way catalysts similar to those used in automobile engines. Given slow fleet turnover, the benefits of the new rule will not be realized for many years.

Figure I-3: Current and Future ICAO NOx Standards Relative to Current Engine Emissions[13]



The blue line indicates the current NOx limit for aircraft engines, the red line indicates the adopted ICAO aircraft engine standards and the yellow line indicates existing engine NOx emissions.[14]

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[11] EPA, Control of Emissions of Air Pollution From Nonroad Diesel Engines, October, 1998.
[12] EPA Control of Emissions From Nonroad Large Spark-Ignition Engines, and Recreational Engines (Marine and Land-Based) " November, 2002.
[13] Sources: the ICAO Engine Exhaust Emissions Data Bank, http://www.qinetiq.com/aviation_emissions_databank/index.asp and ICAO "Annex 16 to the Convention on International Civil Aviation, Volume II: Aircraft Engine Emissions" (including Amendment 4).

Aircraft tend to dominate airport emissions; however, GSE and GAV are significant contributors to overall airport emissions. Table I-5 shows the contribution of various sources to NOx and VOC emissions at Logan International Airport as reported by the airport authority (Massport) in 1999.[15]

Table I-5: Massport Inventory of 1999 Emissions at Logan International Airport

Source Categories	NOx Emissions		VOC Emissions	
	1999 emissions (kilograms per day)	**% of total**	**1999 emissions (kilograms per day)**	**% of total**
Aircraft Sources				
Air carriers	4,699	77%	510	30%
Commuter aircraft	139	2%	133	8%
Cargo aircraft	277	5%	42	3%
General aviation	27	<1%	50	3%
Total aircraft sources	**5,142**	**85%**	**714**	**42%**
Ground Service Equipment	**329**	**5%**	**151**	**9%**
Airport-Related Motor Vehicles				
Ted Williams Tunnel through-traffic	22	<1%	15	<1%
Parking/curbside	38	<1%	124	7%
On-airport vehicles	369	6%	260	15%
Total motor vehicle sources	**429**	**7%**	**399**	**24%**
Other Sources				
Fuel storage and handling	0	0%	418	25%
Miscellaneous sources	174	3%	2	<1%
Total other sources	**174**	**3%**	**420**	**25%**
TOTAL AIRPORT SOURCES	***6,074***	***100%***	***1,684***	***100%***

As shown in Table I-5, Massport estimates that in 1999, aircraft are the largest contributors to NOx and VOC emissions at Logan, contributing 85 percent of all NOx and 42 percent of all VOC emissions. Large commercial aircraft dominate aircraft emissions, accounting for 77 percent of total NOx and 30 percent of total VOC emitted at the airport.

[14] Future standards applies to engines for which the date of manufacture of the first production model is after December 31, 2003.

[15] Emissions estimates from "1999 Environmental Status & Planning Report," Massport 2002. These estimates are presented to show relative contributions to total emissions from all source categories, as defined by Massport. The estimates differ from those in Chapter II because of different data collection and modeling methods, as described in Chapter II. The present study did not estimate emissions from Airport-Related Motor Vehicles or from the Other Sources.

Commuter aircraft are a significant source of VOCs (8 percent of the airport total) but a relatively minor source of NOx (2 percent of the airport total). Cargo planes emit about 9 percent of airport-related NOx and 3 percent of all VOCs. GSE emit about 5 percent of total NOx and 9 percent of total VOC. Fuel storage accounts for 25 percent of total VOCs, but is not a source of NOx.

C.2 Public Health Impacts

Air regulators are concerned with NOx emissions because they are precursors of ozone and secondary fine particles. Ozone is a highly irritating gas that produces acute effects including coughing, shortness of breath, and impaired lung function. Because of the adverse effects of ozone, EPA established a daily maximum one-hour average standard of 120 ppb in 1979. However, current data show impaired lung function at levels below this standard. The effects range from reversible damage to potentially irreversible lung damage.

Studies show that there is a progressive increase in the severity of lung damage from ozone exposure. Exposures of one to three hours during heavy exercise lead to increasingly severe pulmonary effects as the concentration of ozone increases from 120 to 200 ppb. In addition, equally severe damage occurs from exposures of six to eight hours to ozone concentrations as low as 80 ppb during moderate exercise. Thus, low ozone exposures of six to eight hours duration produce similar effects as those found at ozone exposures of short duration. Based on the health effects associated with longer-term exposure to ozone, EPA finalized a new ozone primary standard of 80 ppb in 1997 based on an eight-hour averaging time.

Hydrocarbons are also ozone precursors, and some constituents of total hydrocarbon are known or probable carcinogens, including aldehydes (formaldehyde, acetaldehye, and acrolein), benzene, toluene, polycyclic aromatic hydrocarbons, and 1,3 butadiene. Elevated ambient levels of these compounds have been measured in all counties of the Northeast and throughout the country.

Particulate pollution is a region-wide concern as well. Recent health effects studies have shown an association between existing levels of fine particles and health effects such as increased respiratory illness, cardio-pulmonary morbidity, and premature mortality.[16] For example, a link between air pollution and mortality was demonstrated in two studies using data collected by the American Cancer Society.[17] The study tracked over 500,000 adults in 51 cities over an 8-year period. The adjusted risk of mortality in cities with the highest levels of fine particulate pollution was approximately 15 to 25 percent higher than in cities with the lowest particulate levels. A follow-up analysis determined that each 10 microgram elevation in fine particulate air pollution was associated with an increase of approximately 8 percent in lung cancer mortality and a 6 percent increase in cardiopulmonary mortality.

A number of studies have examined the relationship between airport-related pollution and public health impacts. A study conducted for the Health Council of the Netherlands concluded that

[16] Douglas W. Dockery, et al. "An Association Between Air Pollution and Mortality in Six U.S. Cities," *New England Journal of Medicine*, Volume 329:1753-1759, December 9, 1993.
[17] Pope CA III, et al. "Particulate air pollution as a predictor of mortality in a prospective study of US adults." *American Journal of Respiratory Critical Care Medicine*, 151:669-674, 1995, and Pope CA III, et al "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution." *Journal of the American Medical Association* Vol. 287 No. 9, March, 2002.

"there is sufficient evidence that episodes of air pollution with levels observed within an airport operations system can cause short-term effects like an increased mortality rate and an increased frequency of hospital admissions due to acute respiratory and cardiovascular morbitity."[18] A study summarized in the report showed that male workers at Birmingham International Airport demonstrated a statistically significant association between high exposure to aviation fuel or jet stream and a cough with phlegm. The report concluded that exposure to airport-related air pollution appears to cause similar health effects as does exposure to urban air. The study authors also noted that more work needs to be done to determine the health impacts of airport-related air pollution given the relatively small number of studies available.

C.3 Environmental Impacts

After more than a quarter century of concerted effort, large areas of the NESCAUM region continue to experience unhealthful air that exceeds the federal ozone standard. Ozone is not directly emitted; NOx and VOC are the primary precursor emissions that result in the formation of ozone. A series of aggressive HC and NOx control initiatives have helped to improve air quality in the region; however, these strategies have fallen short of the reductions needed to bring all areas of the region into compliance with the federal ozone standard. Monitoring and modeling data suggest that, on a regional basis, NOx controls provide greater ozone reduction benefits than comparable levels of HC reductions. NOx is also a significant contributor to acid deposition, estuary eutrophication, fine particulate matter formation and regional haze. EPA has established a secondary ozone standard to protect vegetation. Since the response of vegetation to ambient ozone is cumulative in nature, a secondary standard based on some cumulative, perhaps seasonal, form is thought to better reflect biologically relevant measures of exposure than a short-term average concentration form.

Particulate matter represents a direct threat to public health and contributes to visibility degradation. In light of the compelling epidemiological evidence linking levels of ambient particulate concentrations to increase mortality and morbidity, in 1997, EPA established a new NAAQS for fine particulates less than or equal to 2.5 micron in size ($PM_{2.5}$). The 24-hour standard for $PM_{2.5}$ is 65 $\mu g/m^3$; the annual $PM_{2.5}$ standard is 15 $\mu g/m^3$. A revised NAAQS based on a $PM_{2.5}$ indicator may dramatically alter the current nonattainment situation in the Northeast. The transition to the $PM_{2.5}$ standard will shift the focus to fine particulates resulting from combustion, which constitutes a substantially larger fraction of overall particulate levels in the East.

An important regulatory complexity is introduced by the fact that the fine particulate problem in the Northeast is likely to have two dimensions: microscale or "hot spot" areas of high PM concentrations, in which local sources play a critical role, and a macroscale or regional problem in which long-range transported pollution plays a key role. Particulate can be transported thousands of miles which increases the complexity of crafting effective control strategies. States are currently embarking on efforts to develop long-term strategies to reduce fine PM and regional haze. Efforts to reduce direct fine PM emissions, as well as species that form fine PM such as nitrates and sulfates, will be critical to improving visibility in the Northeast. NESCAUM's analysis of preliminary fine PM data indicates that many areas of the NESCAUM region have ambient levels of fine PM that hover near the annual standard of 15 $\mu g/m^3$. Early reductions in fine PM emissions may allow some areas to meet the federal standard before nonattainment designations are made.

[18] Health Council of the Netherlands "Public Health Impacts of Large Airports," September, 1999.

In addition to emissions of NOx, HC, CO, and PM, carbon dioxide (CO_2) emissions are becoming increasingly important to air quality officials due to its impact on global climate change. In addition, aircraft NOx emissions are of special concern for global climate change since NOx from aircraft are emitted at high altitudes and can have an impact on the climate system.[19]

[19] Royal Aeronautical Society, The Society of British Aerospace Companies “Air Travel - Greener by Design, the Technology Challenge,” 2000.

II. Emission Inventories for Three Northeast Airports

A. Overview

This chapter presents the results of an emissions inventory analysis for three Northeast airports: The General Edward Lawrence Logan International Airport in Boston, MA; Bradley International Airport in Windsor Locks, CT; and Manchester Airport in Manchester, NH. While a detailed emissions inventory for all airports in the Northeast region was beyond the scope of this study, the three selected airports represent a range of airport types, including a large established airport, a medium-sized airport, and a small, rapidly growing airport. Beginning in the mid-1990s, growth shifted from the overcrowded Logan Airport to smaller airports in the region, such as Bradley and Manchester Airports.

In designing control programs, it is helpful to understand the relative contribution of different sources to the overall air quality problem. The purpose of this effort is to provide a relative sense of: (1) the contribution of airports to the total emission burden in a given area and (2) the contribution of emissions from various airport sources to the overall airport inventory. Hydrocarbons (HC), nitrogen oxides (NOx), and toxic emissions from different sources were quantified to the extent data existed to support such estimates. Sources within the inventory were classified into the following primary sectors: aircraft, auxiliary power units (APU), and ground service equipment (GSE). It was the intent of the report organizers to include ground access vehicles and airport-related stationary sources in the study; however, resource limitations required a focus on the lesser-understood areas of aircraft and GSE emissions. It is generally accepted that state inventories account for ground access vehicle emissions using traditional mobile source modeling tools (US EPA's Mobile model), and for stationary source emissions using AP-42 emission factors. Emissions estimates were developed for a base year (1999) and a projection year (2010).[20]

In conducting the inventory analysis, NESCAUM used the best available emission factors, activity rates, and numerical estimates of aircraft, GSE, and APUs. Although the Federal Aviation Administration's (FAA's) Emissions and Dispersion Model System (EDMS) is the federally approved model for estimating emissions from these sources, new models were required to incorporate more detailed input data. NESCAUM contracted Energy and Environmental Analysis (EEA) to design new emissions models that incorporated a world aircraft inventory,[21] and incorporated airport-specific GSE information, and allowed the modeler to easily change the defaults for aircraft and GSE used in EDMS. The resulting aircraft/APU model utilizes 1999 landing and takeoff (LTO) data from FAA to generate estimates of aircraft and APU emissions at any U.S. airport. The model allows the user to easily include airport-specific mixing heights and taxi times, as available. An additional version of the model was produced to estimate emissions for the 2010 projection year. The resulting GSE model used information from the U.S. Environmental

[20] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

[21] The world aircraft inventory reports aircraft/engine combinations and populations for aircraft owned by airlines and governments worldwide.

Protection Agency's (EPA's) Draft NONROAD model, and the California Air Resources Board (CARB)[22] OFFROAD model.

Because the EPA and CARB models are populated with data primarily obtained from surveys of GSE in southern California and other southern U.S. airport, NESCAUM contacted the airlines, fixed base operators (FBOs), and the airports of study to obtain information about GSE population and usage. This effort was necessary to obtain complete GSE estimates for the Northeast airports since the South Coast has no winter-related equipment such as snowplows and deicers, and this equipment is used infrequently at the Dallas/Ft. Worth airports.

A.1 Characteristics of the Airports of Study

The three airports selected for this study represent a range of airport sizes with varying projections of growth. In addition, these airports are located near major and small cities in ozone nonattainment areas. The airports are described below.

Logan International Airport, Boston, MA

Logan is a large airport, serving about 27 million passengers and shipping almost one billion pounds of cargo in 1999. In 1995, Logan projected passenger levels of 37.5 million in 2010, but economic changes, the introduction of the Acela high-speed train between Boston and Washington, DC, and a push toward the increased utilization of regional airports such as Manchester International in Manchester, NH and T.F. Greene in Providence, RI have slowed growth. In 2000, Logan officials revised their growth projections to 37.5 million passengers in 2015.

Because of its northeastern location, Logan is not a hub for any major airline, nor is it expected to become one. There is no dominant carrier at Logan. Large commercial air carriers run the majority of flights from Logan, but air taxi (regional shuttle) traffic accounted for almost 200,000 operations (40% of total operations) in 1999. Logan has very little general aviation (private) or military aircraft traffic. Located in Boston Harbor, Logan is just 2.25 miles from Boston's downtown and its runways are as close as a quarter mile to residential areas. With such proximity to the city, Logan's noise and pollutant emissions have a direct impact on Boston and the surrounding communities.

Bradley International Airport, Windsor Locks, CT

As recently as 1999, Bradley International Airport was a medium-sized airport, serving 6.3 million passengers annually. However, in 2000, Bradley broke into the large airport category, with a passenger increase of 15.8 percent to 7.3 million. By 2010, Bradley is projected to serve as many as 10 million passengers annually.

Bradley airport serves western Massachusetts, Connecticut, and southern Vermont, and is located 15 minutes from Hartford, CT. Bradley has almost as many shuttle (air taxi) flights as flights by larger carriers. Bradley also has a significant number of landings and takeoffs by general aviation aircraft, and has the largest number of military flights of the airports studied for this report.

[22] CARB is the air pollution control division within the California Environmental Protection Agency. CARB develops its own mobile source emissions models and does not use federal models for SIP inventory development.

Manchester Airport, Manchester, NH

Manchester Airport is the smallest of the airports included in this survey. Manchester served 2.8 million passengers in 1999 and is technically a medium-sized airport. However, this level of service represented rapid expansion since 1997, when the airport served just 1.1 million passengers. The growth at Manchester can be attributed to two main factors. First, in an effort to ease congestion at Boston's airport, Logan has worked to encourage travelers (especially those residing outside the immediate Boston area) to fly from "regional" airports in Providence, RI; Manchester, NH; and Worcester, MA. Trips from these airports reduce the demand for flights from Logan and in some cases decrease miles traveled by passengers to reach the airport. Second, the introduction of service by Southwest Airlines was an important factor in increasing traffic at Manchester. By offering low fares, which were in turn matched by other airlines serving Manchester, Southwest helped to make Manchester and other smaller airports competitive with Logan. Fares from Manchester are often much lower than fares from Boston to the same destination. Continued growth is expected to bring 5.3 million passengers to Manchester Airport in 2010.

Manchester Airport is located a short distance from Manchester, NH in the southern portion of the state. This facility supports commercial and air taxi flights, but has almost as many operations by general aviation aircraft as these categories combined. As air carrier and air taxi traffic increase, general aviation activity will fall at Manchester.

The number of landings and takeoffs by different types of aircraft at each airport are shown for 1999 and 2010 in Figure II-1 and Table II-1. The figure and table show that landings and takeoffs by commercial airlines at the three airports studied in this report will grow 10 to 40 percent over the next 10 years.[23] Air taxi[24] activity growth will be more modest at Manchester and Logan than at Bradley, where growth of up to 35 percent will occur over the next ten years. General aviation growth will be highest at Bradley. Manchester is forecast to see a decrease in general aviation LTOs, mainly from "touch and go" (T&G) operations. T&Gs are takeoff and landing exercises for general aviation aircraft, usually with a very short ground time. It is expected that the exceptional 40 percent increase in commercial aviation operations at Manchester will decrease the time and runway availability previously used by general aviation aircraft for T&G operations. Military flights are, by default, forecast to be constant as a matter of national security. If changes are made in military operations, they generally reflect FAA knowledge of change in military activity. Small changes in military operations at the three airports are incorporated and reflect historic changes in these operations.[25] However, as discussed in the next section, the aircraft inventory (for NOx in particular) is dominated by commercial aircraft emissions. Thus, the most important changes to note in Table II-1 are the significant increases in air carrier landings and takeoffs.

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[23] The LTO projections are taken directly from FAA's Terminal Air Forecast (TAF). The TAF Forecast Method states that FAA performs linear multiple regression analysis to project national counts which are then split out to individual airports. These numbers are reviewed by an FAA analyst and are approved by each region and district. There is no additional information about the development of the inventory.

[24] Air carrier, air taxi, and general aviation are further defined in the next section.

[25] Emissions from military aircraft are not included in this inventory due to lack of available data with sufficient detail to match the rest of the inventory. As military aircraft account for less than one percent of LTOs at Logan and Manchester airports and four percent of LTOs at Bradley, this omission does not significantly impact the inventory.

Figure II-1: 1999 and 2010 Landing and Takeoffs (LTOs) [26]

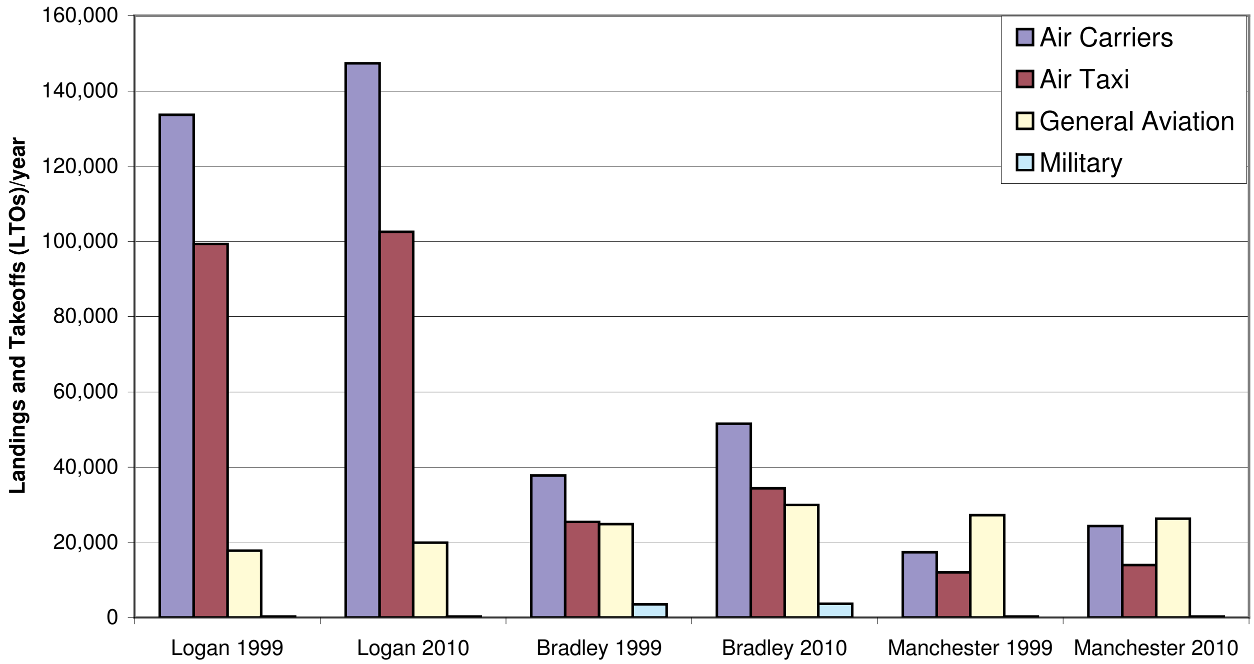

Table II-1: 1999 and 2010 Landings and Takeoffs (LTOs) at the Airports of Study[26]

	Logan			Bradley			Manchester		
	1999	2010	Change	1999	2010	Change	1999	2010	Change
Air Carriers	133,706	147,351	10.2%	37,776	51,580	36.5%	17,340	24,370	40.5%
Air Taxi	99,314	102,466	3.2%	25,463	34,353	34.9%	11,983	13,901	16.0%
General Aviation	17,769	19,999	12.5%	24,869	29,959	20.5%	27,258	26,320	-3.4%
Military	294	262	-10.9%	3,515	3,615	2.8%	264	264	0%
Total	**251,083**	**270,078**	**7.6%**	**91,723**	**119,507**	**30.3%**	**56,845**	**64,855**	**14.1%**

[26] 1999 data from FAA ATADS Database; 2010 data from FAA Terminal Air Forecast Database. Both are available at http://www.apo.data.faa.gov.

B. Aircraft Emissions

Like all combustion engines, aircraft engines produce a host of criteria and other pollutants that affect ambient air quality. Unlike many other sources, however, aircraft emit pollutants over a range of altitudes, and their emissions may have different impacts at different altitudes. Emissions below the mixing height[27] contribute to ground-level air pollution, while certain types of emissions may have a greater potential impact on climate change when emitted above the mixing layer. This study considers only aircraft emissions below the mixing height. Monthly average mixing heights at the airports studied ranged between 1,930 and 4,510 feet.

Aircraft are generally grouped into four categories when FAA counts LTOs. These denominations are based on the operator of the aircraft, not on the aircraft, per se. Air carriers own and operate at least one aircraft that seats at least 60 passengers or has a payload of at least 18,000 pounds.[28] Air carriers may also own smaller aircraft, but the LTOs of these aircraft are reported in the air carriers' totals. Air taxis operate only smaller certified aircraft,[29] usually fly short routes, and are considered regional or shuttle carriers. General aviation consists of small planes that are usually privately owned or belong to corporations. Military aircraft sometimes fly from commercial airports. As previously mentioned, due to a lack of specific information about the types of military aircraft used, emissions from this small sector were not included in the inventory.

All aircraft operate through a range of power settings while active below the mixing height. These power settings can be described by four phases of operation: approach, taxi/idle, takeoff, and climbout (Figure II-2). The approach phase begins as a plane enters the mixing height during its descent and ends when the plane touches down. All low-power movement on the ground is included in the taxi/idle phase. The takeoff phase begins when the engines are set to full power to start down the runway and continues until the plane has reached an altitude of 500 feet.[30] Takeoff is immediately followed by the climbout phase, which concludes when the plane leaves the mixing height. These four phases collectively constitute the landing and takeoff (LTO) cycle. A fifth phase,

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[27] The mixing height is the elevation below which air and pollutants will mix. Vertical mixing processes are extremely complicated in the lower atmosphere; however, under typical conditions some vertical transport mechanisms are generally well understood. For example, as a parcel of air is warmed at the ground, it starts to rise. As the parcel rises, it mixes with surrounding air and slowly cools. As long as the parcel remains warmer than the surrounding air, it will continue to rise, mix, expand, and cool. When the (now dilute) parcel and the surrounding air are the same temperature, the parcel stops rising, thus defining the top of the mixing height, or boundary layer. Any pollutants emitted within the boundary layer will eventually become uniformly mixed in this fashion. Conversely, any pollutants emitted above the mixing height will not mix down to ground level. As the ground warms during the day, air parcels become warmer and can reach higher in the atmosphere before cooling to the temperature of surrounding air. Thus, the mixing height grows to a higher altitude as well. This daily expansion and contraction of the boundary layer can re-entrain pollutants that have may have accumulated above the mixing height overnight.

[28] "Airport Activity Statistics of Certificated Air Carriers, Twelve Months Ending December 31, 1999". U.S. DOT, Bureau of Transportation Statistics, Office of Airline Information, Washington, D.C., 2000

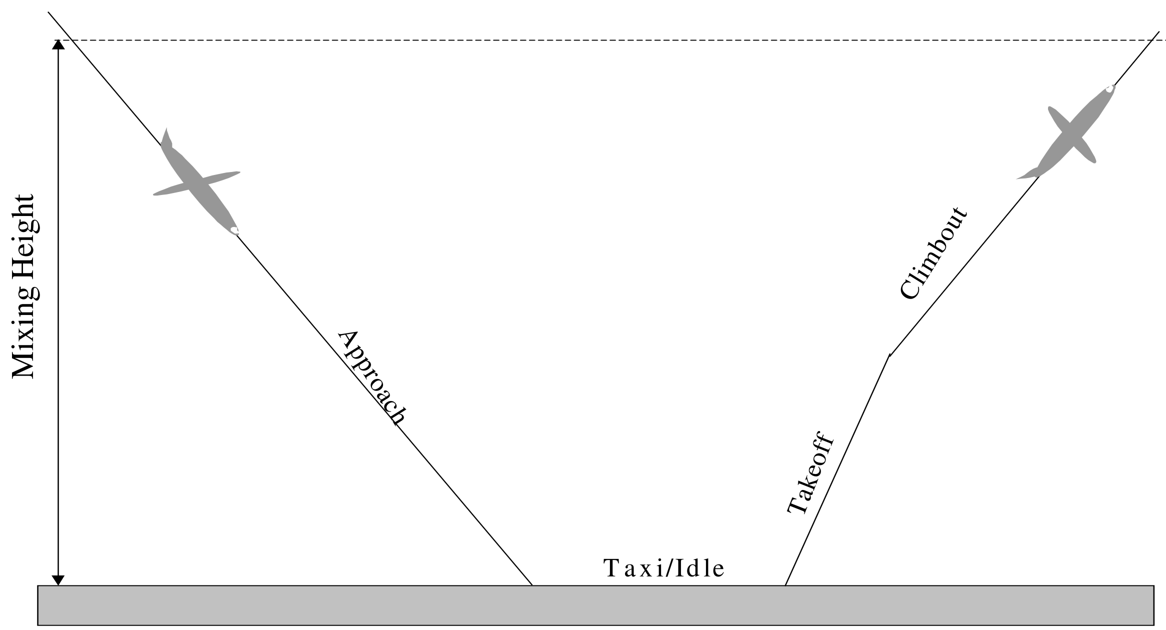
[29] An air taxi operator , as defined in 14 CFR 298.3, "directly engages in the air transportation of persons of property or mail, … do[es] not directly or indirectly utilize large aircraft," [defined in 14 CFR 298.2 as "any aircraft designed to have a maximum passenger capacity of more than 60 seats or a maximum payload capacity of more than 18,000 pounds"] and follows other regulatory guidelines set forth in the same chapter.

[30] This study incorporates recent FAA data indicating that takeoff lasts until a plane has reached 1000 feet. See section B.1 Methodology, Discussion of Model Inputs in this chapter for more information.

reverse thrust, is sometimes also considered. Reverse thrust describes the practice of setting the engines to full power in the reverse direction to slow the plane upon landing.

The time spent in each mode of the LTO cycle (time-in-mode) depends on aircraft speed, and, for some phases, on the mixing height. ICAO and EPA have established default times-in-mode for the LTO cycle, as shown in Table II-2. These times are based on an average mixing height of 3000 feet and are used for regulatory purposes.[31]

Figure II-2: The Landing and Takeoff (LTO) Cycle



The LTO cycle, as defined by ICAO, is made up of four phases of aircraft operation. The approach phase begins when the aircraft enters the mixing height and ends when the plane lands. The taxi/idle phase includes all low-power movement and idle time on the ground. Takeoff begins when the brake is released on the runway and continues until the plane moves to the lower-powered climbout phase at an altitude of 500 feet. The climbout phase continues until the plane leaves the mixing height.

During the LTO cycle, aircraft produce a host of pollutants. Past inventory efforts have typically focused on emissions of NOx, carbon monoxide (CO) and HC, but other pollutants such as sulfur dioxide (SO_2), carbon dioxide (CO_2), particulate matter (PM), and toxics are also emitted. The following sections discuss the methodology used in this study to calculate aircraft emissions and present the resulting estimates for emissions in 1999 and 2010. Results are presented for NOx and HC for all sources, and for other pollutants as available. Note that projected 2010 emissions for Logan do not account for the 2001 Massport Air Quality Initiative described in Chapter IV.[32]

[31] More information about regulations can be found in Chapter V.

[32] Logan International Airport has experienced decreased demand since the events of September 11, 2001. Massport anticipates that it will not be necessary to undertake actions to meet the objectives of the Air Quality Initiative for several years.

Table II-2: ICAO and US EPA Default LTO Cycle Times-in-Mode (minutes)

	Commercial Carriers	Air Taxi	General Aviation	Changes with Mixing Height
Approach	4.0	4.5	6.0	Yes
Taxi/Idle	26.0	26.0	16.0	No
Takeoff	0.7	0.5	0.3	No
Climbout	2.2	2.5	5.0	Yes
Reverse Thrust	0.25	0	0	No

B.1 Methodology

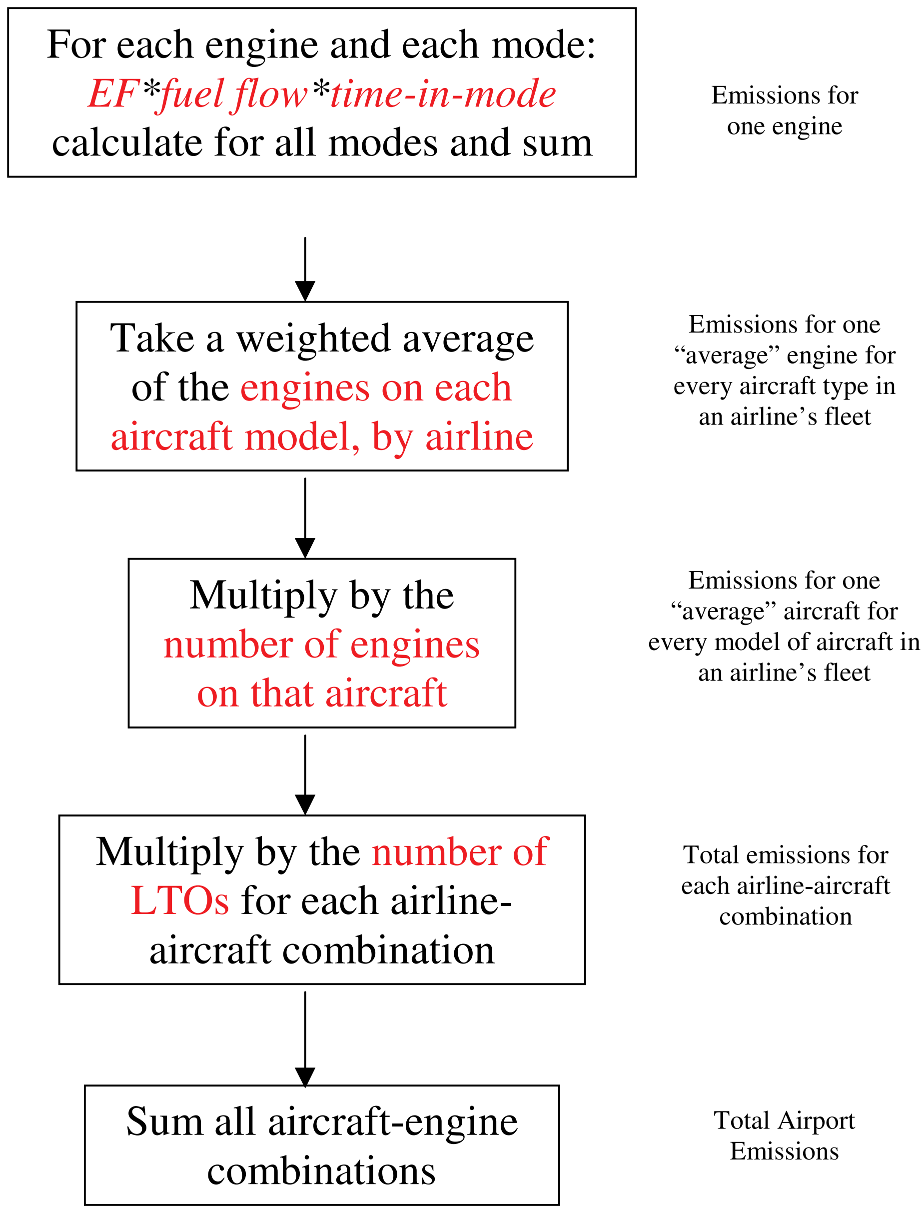
This section provides an overview of the methodology used in this study to calculate aircraft emissions. A complete description of the methodologies and sources used to estimate aircraft emissions can be found in Appendix B Section A.

NESCAUM used an Excel-based aircraft emissions model developed by Energy and Environmental Analysis, Inc. (EEA) to calculate aircraft emissions at Logan, Bradley, and Manchester. The EEA model reports emissions in tons of pollutant for any group of modeled aircraft. Aircraft emissions estimates are based on a number of factors, some of which are the same for all inventories and several that are airport-specific. The consistent factors include aircraft and engine fleet mix, engine emission factors, and fuel flow. The airport-specific factors include number of LTOs and the time spent in each phase of the LTO cycle.

Calculating emissions for aircraft engines involves multiplying emission factors (in pounds of pollutant emitted per thousand pounds of fuel burned) by the fuel flow rate (pounds of fuel per minute) by the number of minutes in a given mode. This is done for all modes of the LTO cycle. The approach for calculating aircraft emissions is illustrated schematically in Figure II-3 and is further described below.

Engine-specific emission factors exist for all four of the LTO modes mentioned above. The EEA model includes standard data for emission factors and fuel flow, as well as default values for time-in-mode and mixing height. In the inventory presented in this chapter, only the emission factors and fuel flow rates were incorporated without change, though they were not used in the conventional manner; after emissions were calculated for each engine, a weighted average of engine models was taken for each model of aircraft owned by each airline. LTO data for airline-aircraft combinations were then used to complete the inventory. Sources for the various data used in the NESCAUM inventory are listed below in Table II-3.

Figure II-3: Aircraft Emissions Calculation Flowchart



These calculations were made for each pollutant of interest.

Discussion of Model Inputs

Emission Factors and Fuel Flow Rate: Fuel flow rate and emission factors for NOx and HC were obtained from the ICAO Emissions Databank. ICAO requires engine manufacturers to submit emissions data as part of the engine certification process. These emission factors are the same as those recommended by EPA and used in the EDMS model. The emission factors and fuel flow rates are measured for each of the four LTO cycles, and are reported in pounds of pollutant emitted per thousand pounds of fuel burned. The emission factors were gathered from newly manufactured engines and do not account for deterioration.[33]

Aircraft/Engine Combinations: Since several models of aircraft engines can power the same aircraft body, the assignment of engines, and therefore emission factors, to specific aircraft bodies must be determined. Data on the type and number of engines used on aircraft in service around the world are available from Jet Information Services' World Aircraft Inventory. This inventory also includes the number and types of planes owned by commercial carriers and governments worldwide, and specifies the engines used on those planes. In the NESCAUM inventory, engines were assigned as listed in the World Aircraft Inventory, and a weighted average of engine types for each aircraft body in an airline's fleet was developed. For example, weighted averages were taken for Continental's Boeing 727-200s (four engine models on nine planes), Continental's Boeing 737-300s (two engine models on 65 planes), and FedEx's Airbus 310-200s (four engine models on 40 planes), etc. The aircraft/engine combinations for the projection year were created using Boeing and Airbus forecasts and current orders to adjust the current fleet mix.

Time in Mode: For each operation mode in the LTO cycle, ICAO has determined a default time, as shown in Table II-2. NESCAUM modified these times when more accurate data was available. The default taxi/idle time was replaced with monthly, airport-specific taxi times from DOT's Bureau of Transportation Statistics.[34] These substitutions reduced taxi/idle time for Manchester and Bradley airports, and in most cases increased taxi/idle time at Logan. The default times for approach and climbout were adjusted with meteorological data from mixing height stations near the airports of study. Mixing height data from US EPA's Support Center for Regulatory Air Models (SCRAM) were used to calculate monthly average times-in-mode for approach and climbout. Flight profile data from FAA's Integrated Noise Model (INM) were incorporated. These new data, indicating that takeoff power is sustained to 1000 feet of altitude, not the 500 feet of altitude assumed in the ICAO default times, were used to increase the modeled takeoff time. Reverse thrust time was not affected. The impact of using these data is explained later in this chapter.

Changes to these revised times-in-mode were minimal for the forecast year. Because meteorology is not expected to change significantly, no changes were made to the times for approach or climbout. Similarly, no changes in takeoff operations are expected, so takeoff times were not changed. By contrast, as airports experience growth that leads to congestion, taxi/idle times are expected to change. Taxi/idle times were adjusted based on information from airport planning

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[33] As engines age and parts wear, engine combustion processes tend to become inefficient, especially without proper maintenance. These inefficiencies tend to lead to increased fuel consumption and increased emissions, or "deterioration" in cleanliness of the engine. However, because aircraft engines are continually maintained to meet strict safety standards, parts are kept in good condition. Studies of emissions deterioration under cruise conditions (Lukachko, 1997) show results from competing influences. Performance deterioration with age (increased fuel burn per minute) occurs and implies higher NOx emissions. However, deteriorations in different engine components have opposing effects, and overall changes in NOx emissions at cruise conditions can be either positive or negative, and are of small magnitude (-1% to 4%). The performance deterioration has diminished very slightly with newer engines, but the magnitude of the resultant NOx emissions could be larger, since newer engines emit more NOx at their higher temperatures and pressures. It is impossible to extrapolate these effects to the LTO cycle without further research.
[34] US DOT, Bureau of Transportation Statistics. *Airline On-Time Statistics*. Available online at <http://www.bts.gov/ntda/oai/index.shtml>.

documents. Planning documents that discussed future taxi/idle times were only available for Logan, so only Logan's taxi/idle time was adjusted.

Table II-3: Data Sources Used in Aircraft Emissions Estimates

Data Source	Commercial Aircraft	Air Taxi and General Aviation
Emission Factor and Fuel Flow	1) For NOx and HC: ICAO Engine Exhaust Emissions Databank, supplemented with data from EDMS, FAA's FAEED model, and EPA's AP-42 model[35] 2) For Toxics: EPA 1996 National Toxics Inventory	
In-Air Time-in-Mode	1) EPA's Support Center for Regulatory Air Models (SCRAM) Mixing Height Data 2) Default time-in-mode from EPA Procedures for Emission Inventory Preparation, Mobile Sources 3) FAA aircraft performance data from the Integrated Noise Model	
Ground Time-in-Mode	Department of Transportation (DOT) Bureau of Transportation Statistics taxi/idle statistics	Default time-in-mode from EPA Procedures for Emission Inventory Preparation, Mobile Sources
1999 Aircraft/Engine Combinations and Inventory	Jet Information Services' (JIS) World Aircraft Inventory	FAA's 1996 "Census of U.S. Civil Aircraft"
2010 Aircraft/Engine Combinations and Inventory	Airbus and Boeing forecasts	No change from 1999
1999 LTOs	Airline-aircraft LTOs from Table 7 of DOT Bureau of Transportation Statistics activity statistics	FAA Tower Statistics
2010 LTOs	FAA Terminal Air Forecast (2000)[36]	

[35] FAA's Aircraft Engine Emission Database (FAEED) was the recommended model for estimating aircraft emissions, but has been replaced with EDMS. EPA's "Compilation of Air Pollution Emission Factors," also known as AP-42, provides look-up tables of emission factors for many on-and of-road vehicles. Section II, Nonroad Vehicles, was last updated before the 1990 Clean Air Act Amendments, and EPA has no current plans to update it .

[36] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

LTO data: LTO data for commercial air carriers were gathered from Table 7 of DOT's "Airport Activity Statistics of Certificated Air Carriers, Twelve Months Ending December 31, 1999." These data present the number of LTOs by airline for all makes of aircraft serving each airport. LTO data for air taxi and general aviation aircraft were gathered from 1999 FAA Tower Statistics. These data give total LTOs for all aircraft in these categories, with no subdivisions for aircraft make. LTOs for the projection year were obtained from FAA's Terminal Air Forecast (2000), which is calculated annually for all airports.

B.2 Aircraft Emission Results

Results are summarized and presented below in Tables II-4 through II-10. NOx, HC, and some toxic emissions for air carriers, air taxis, and general aviation aircraft for the three Northeast airports are presented. Results are first presented for the 1999 base year; projections for 2010 follow.

Emissions Estimates for 1999

Nitrogen Oxides Emissions from Aircraft

NOx emissions for the three airports are presented in Table II-4. NOx is primarily produced during high-power engine use, mainly during the takeoff and climbout phases of the LTO cycle. NOx emissions from air carriers dominate the inventory at each airport, even though air carrier LTOs make up less than half of total LTOs at Manchester and Bradley airports. General aviation aircraft at Manchester make a larger proportional contribution to total emissions than at any other airport.

As expected, air carriers dominated the NOx inventory for several reasons. First, air carriers had a significant number of LTOs at each of the three airports (53%, 41%, and 31% of total LTOs at Logan, Bradley, and Manchester, respectively). Second, on an engine-per-engine basis, air carriers produce more pollutants per minute and burn more fuel per minute than the smaller aircraft. Third, many of the air carrier aircraft have three or four engines, whereas air taxi and general aviation aircraft have only one or two. These factors result in air carriers contributing approximately 67 to 90 percent of the total aircraft NOx inventory for these three airports. The results of the inventory calculation indicate that controlling air carrier NOx emissions is an important strategy in reducing overall airport-related NOx emissions.

Table II-4: 1999 Aircraft NOx Emissions at the Airports of Study (tons/year)

	Logan	Bradley	Manchester
Air Carriers	2482.0	620.3	164.2
Air Taxi	179.7	52.3	20.0
General Aviation	2.4	3.9	3.3
Total	**2664.1**	**676.5**	**187.5**

Hydrocarbon Emissions from Aircraft

Table II-5 details HC emissions at the three airports studied in this report. HC emissions are highest during low-power engine use, especially the taxi/idle phase of the LTO cycle. At Logan, air carrier HC emissions dominate the HC inventory, but to a lesser extent than they do for NOx. The fraction of HC emissions from air carriers is much less than their contribution to NOx emissions (69% of HC versus 93% of NOx at Logan). At Bradley and at Manchester, air taxi and general aviation produced the majority of HC emissions. This is because at Manchester, general aviation flights outnumbered air carrier traffic by 1,950 LTOs, and HC emissions from a single general aviation LTO were more than triple that for an air carrier LTO. The reason for this difference in emissions may be related to engine efficiency. The results of the emissions inventory show that reducing HC emissions from all types of aircraft will be necessary to reduce airport-related HC emissions.

Table II-5: 1999 Aircraft HC Emissions at the Airports of Study (tons/year)

	Logan	Bradley	Manchester
Air Carriers	390.1	55.8	13.6
Air Taxi	165.2	36.4	14.8
General Aviation	6.8	9.8	7.0
Total	**562.1**	**102.0**	**35.4**

Comparison with Existing State Implementation Plan Airport Inventories

States include airport emissions in the inventories used to develop state implementation plans (SIPs) for attaining federally prescribed National Ambient Air Quality Standards (NAAQS). Aircraft emissions are generally calculated using FAA's EDMS model, though Massachusetts incorporates Logan Airport's own emissions estimates directly into its SIP. US EPA calculates national aircraft emissions and allocates them to individual airports and counties based on LTOs. Table II-6 shows the NOx and HC emissions from airport sources reported in each state's SIP for the airports studied. Inventories in Connecticut's and New Hampshire's SIPs reflect 1996 emissions.

Table II-6: State-Reported NOx and HC Emissions from Aircraft (tons/year)

	Logan	Bradley	Manchester
Inventory Year	1999	1996	1996
Source	Logan ESPR	EDMS 3.0	EDMS 3.0
NOx (tons/year)	2038.9	79.2	92.5
HC (tons/year)	287.3	63.9	52.9

As can be seen from comparing Tables II-4 and II-5 to Table II-6, state EDMS aircraft NOx emissions estimates are lower than NESCAUM's analysis. This is due in part to the fact that some SIP numbers were prepared for 1996 (vs. 1999 for this analysis). A further explanation for the discrepancy is the fact that NESCAUM incorporated FAA's takeoff profile data, which doubles takeoff from 500 to 1,000 feet. EDMS 3.0, used to calculate aircraft emissions for SIP purposes, uses an altitude of 500 feet for takeoff, though EDMS 4.0 subsequently incorporated the 1,000-foot takeoff height. Of the four phases of the LTO cycle, the greatest NOx emissions occur during takeoff. Thus, increasing the amount of time in takeoff mode will increase NOx emissions considerably.

Toxic Emissions from Aircraft

In addition to emitting NOx and HC, aircraft engines emit considerable amounts of toxic air pollutants. Emissions estimates for 14 air toxics were calculated for the three airports in this study. These toxins are either known or suspected human carcinogens, or have non-carcinogenic, adverse health effects.

Toxic emissions from aircraft were calculated using US EPA emission factors for the 14 compounds.[37] For all toxics except lead, the US EPA emission factors are expressed as a percent of total HC. Emission factors for each toxin are provided for the entire LTO cycle for air carriers, air taxi, and general aviation. For example, benzene emissions are 2.37 percent, 3.72 percent, and 4.09 percent of total HC emissions from air carriers, air taxis, and general aviation aircraft, respectively. NESCAUM calculated HC toxins, then applying the EPA emission factors to the total HC emissions (reported above) for the three different types of aircraft.

Aviation gasoline, used only for general aviation aircraft, is the only aviation fuel that contains lead additive. Most aviation gas currently sold is designated "100LL," meaning 100 octane and low lead. The current ASTM standard for lead in 100LL aviation gasoline is 0.56 grams of lead per liter,[38] and EPA estimates that 75 percent of lead is released, while 25 percent of the lead is retained in the engine system.[39] These factors were applied to fuel use in general aviation LTOs to estimate lead emissions.

Total tons of toxins were summed across the three types of aircraft for each airport. The results are presented in Table II-7.

Toxic emissions from the airports studied are high when compared with emissions from the largest stationary sources in each of the three states. While improvement is needed in the method used to calculate toxic emissions from aircraft, the inventory provides a rough approximation of

[37] "Documentation for the 1996 Base Year National Toxics Inventory for Aircraft Sources." US EPA, Emission, Monitoring and Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1999. Lead emission factor came from "Locating and Estimating Air Emissions from Sources of Lead and Lead Compounds." US EPA, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1998.

[38] "ASTM D910 Standard Specification for Aviation Gasolines," ASTM International, W. Conshohocken, PA, 1999.

[39] "Locating and Estimating Air Emissions from Sources of Lead and Lead Compounds." US EPA, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1998.

emissions, indicating that toxic emissions from aircraft greatly exceed those of the largest stationary sources in the three states.[40]

Table II-7: 1999 Aircraft Toxics Emissions at the Airports of Study (tons/year)

Toxin	Logan	Bradley	Manchester
1,3-butadiene	10.7	1.8	0.56
Benzene	15.7	3.1	1.2
Formaldehyde	82.1	12.9	3.7
Acetaldehyde	25.3	3.9	1.1
Acrolein	11.1	1.6	0.41
POM[41] as 16-PAH	0.061	0.0099	0.0029
POM as 7-PAH	0.0017	0.00041	0.00018
Sytrene	2.5	0.44	0.14
Ethylbenzene	3.1	0.74	0.33
n-hexane	1.0	0.22	0.089
Propinaldehyde	5.1	0.79	0.22
Toluene	18.1	4.7	2.2
Xylene	11.2	2.8	1.3
Lead[a]	0.18	0.27	0.21

[a] Lead emissions come only from general aviation aircraft. Lead content is significant only in aviation gasoline, not in jet fuel.

Emissions Projections for the Year 2010

Estimating emissions for the projection year (2010) required modifying a number of factors used in the base year analysis. The world aircraft inventory was adjusted based on aircraft purchase orders

[40] The EPA method of calculating toxic emissions from aircraft relies on only a few data points for toxic emissions and may not be representative of today's fleet mix.

[41] Polycyclic Organic Matter as 7-polycyclic aromatic hydrocarbons (PAH) and as 16-PAH. The 7-PAH compounds are benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene. The 16-PAH compounds are acenaphthene, acenaphthylene, anthracene, benzo(ghi)perylene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene.

and estimated scrappage rates. LTOs were forecast from FAA and other data.[42] Mixing heights were assumed to remain constant, but taxi/idle times were adjusted with information from airport planning documents. For Logan Airport, it was assumed that a new runway would not be in place by 2010. Table II-8 and Figure II-4 show projected aircraft NOx emissions for the year 2010 and the corresponding percent increase or decrease over 1999 inventory estimates.

NOx emissions are expected to increase at all airports and from most categories of aircraft. In the case of Bradley airport, NOx emissions increase more dramatically than LTOs (Table II-1); this is partially due to the introduction of quieter engines to meet the Stage III noise standards, which generally emit more NOx than the louder engines, and also in part to a strong increase in LTOs by large aircraft that emit more NOx than their smaller counterparts. Regionalization will also increase LTOs, and consequently NOx emissions, at Bradley and at Manchester airports. Manchester's general aviation emissions will decrease in 2010 due to a projected decrease in general aviation LTOs from 1999 levels.

Predicted HC emissions for the year 2010 are reported in Table II-9 and Figure II-5. HC emissions are generally predicted to increase, with the exception of emissions from air carriers at Logan and general aviation aircraft at Manchester. The reduction in HC from air carriers at Logan is significant enough to reduce total aircraft HC at that airport. Changes in emissions from air taxi and general aviation parallel changes in the number of operations by those aircraft (Tables II-1 and II-5). Overall, HC emissions are projected to increase more slowly than LTOs. This may be due to the introduction of new noise standards that generally increase NOx emissions and decrease HC emissions. As mentioned above, the assumption was made that a new runway at Logan would not be in place in 2010, thus taxi/idle times are greater in this scenario than they would be if the new runway were in place.

Future toxic emissions are expected to increase at Bradley and Manchester, with mixed changes at Logan. Predicted declines in toxic emissions at Logan Airport reflect the predicted decrease in HC emissions from air carriers in 2010. Since air carriers dominate the inventory of HC emissions at Logan, decreases in toxic emissions are seen in Table II-10. Some of the anticipated reductions at Logan are explained by the fact that emission factors differ for each type of aircraft. For example, toluene emissions are calculated as 11 percent of the estimated HC emissions from general aviation, nine percent of estimated HC emissions from air taxi, but only 0.7 percent of estimated HC emissions from air carriers. The increases in HC emissions from air taxi and general aviation aircraft, combined with their large contributions to toluene emissions, far outweigh the decrease in HC emissions from air carriers and the small contribution of toluene from these engines.

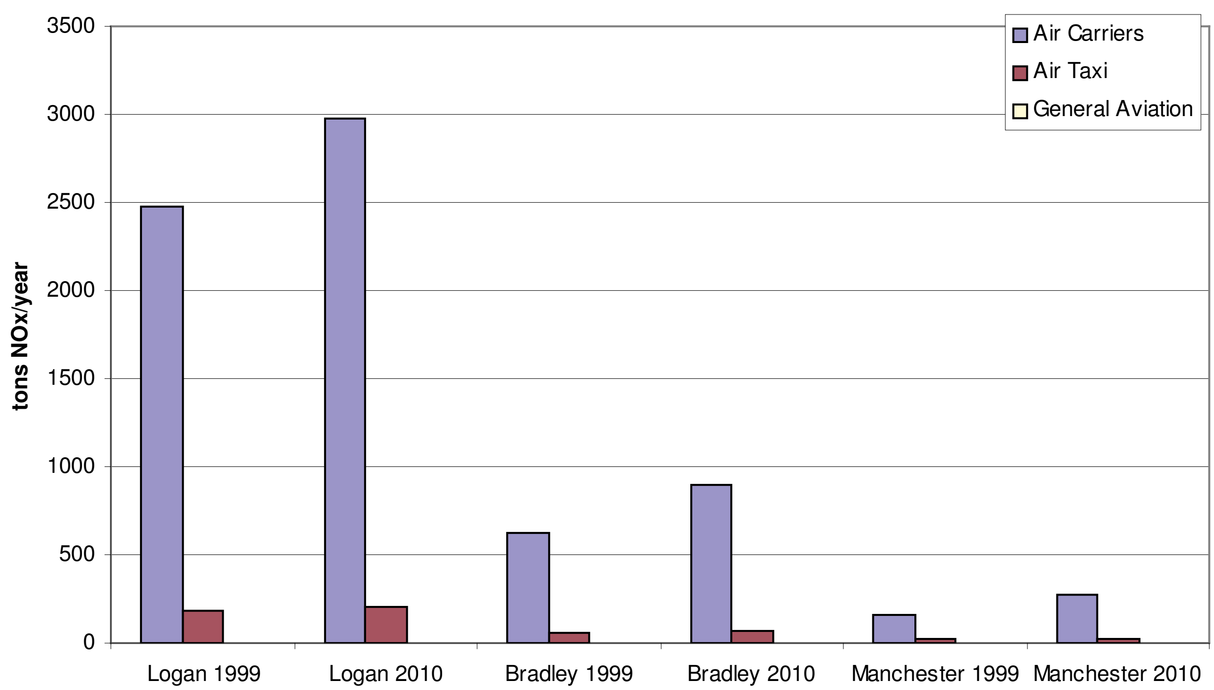
Lead emissions show a slightly different pattern, with projected increases at Logan and Bradley and a slight decrease at Manchester. These projections mirror changes in forecasted general aviation operations at the three airports.

[42] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

Table II-8: 2010 Aircraft NOx Emissions at the Airports of Study

	Tons/Year			Change from Baseline Year		
	Logan	Bradley	Manchester	Logan	Bradley	Manchester
Air Carriers	2977.0	901.7	269.4	19.9%	45.4%	64.1%
Air Taxi	201.7	70.6	23.2	12.2%	35.0%	16.0%
General Aviation	2.8	4.7	3.2	16.7%	20.5%	-3.0%
Total[43]	**3181.5**	**977.0**	**295.8**	**19.4%**	**44.4%**	**57.8%**

Figure II-4: 1999 and 2010 NOx Emissions



[43] Total change from the base year is a weighted average calculated as percent change in total NOx emissions from 1999 to 2010.

Table II-9: 2010 Aircraft HC Emissions at the Airports of Study

	Tons/Year			Change from Baseline Year		
	Logan	Bradley	Manchester	Logan	Bradley	Manchester
Air Carriers	261.1	56.7	17.8	-33.1%	1.6%	30.9%
Air Taxi	226.5	49.2	17.2	37.1%	35.2%	16.2%
General Aviation	8.1	11.8	6.7	19.1%	20.4%	-4.3%
Total	**495.7**	**117.7**	**41.7**	**-11.8%**	**15.4%**	**17.8%**

Figure II-5: 2010 Aircraft HC Emissions at the Airports of Study

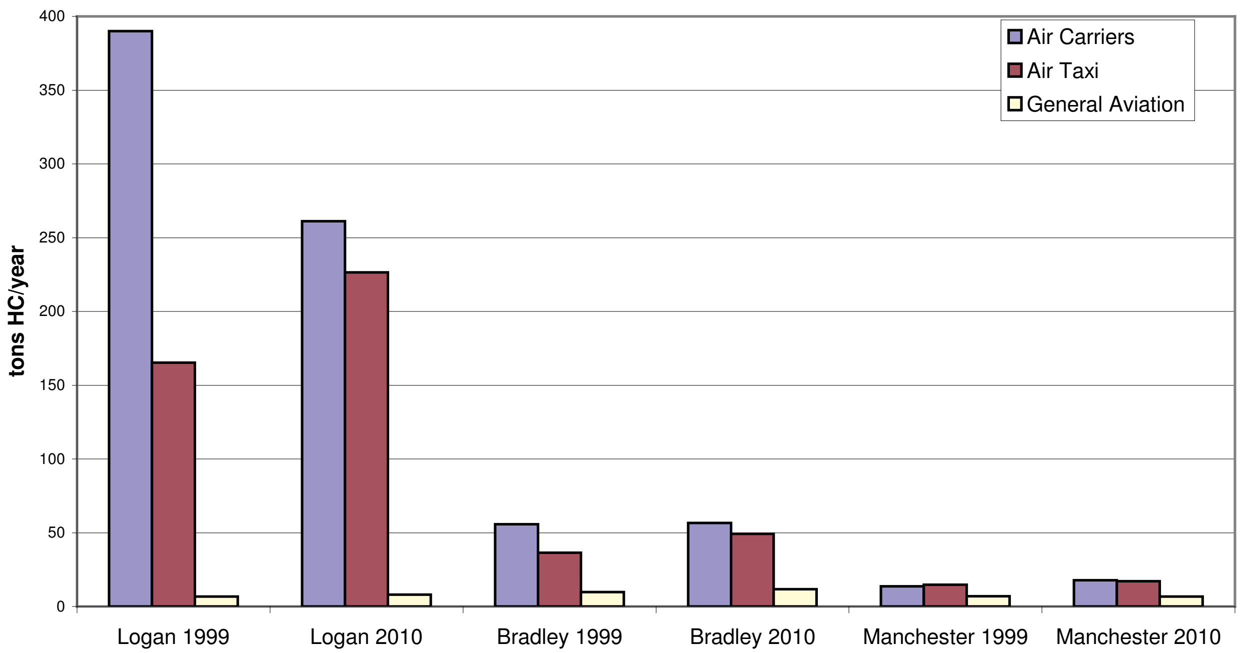


Table II-10: 2010 Aircraft Toxic Emissions at the Airports of Study

	Tons/Year			Change from Baseline Year		
	Logan	Bradley	Manchester	Logan	Bradley	Manchester
1,3-butadiene	10.2	2.0	0.68	-4.7%	11.2%	21.4%
Benzene	16.6	3.7	1.3	6.2%	18.8%	15.2%
Formaldehyde	75.4	13.9	4.6	-8.2%	8.1%	24.8%
Acetaldehyde	23.2	4.2	1.4	-8.4%	7.8%	25.3%
Acrolein	9.6	1.7	0.53	-13.5%	3.0%	28.9%
POM as 16-PAH	0.058	0.011	0.0036	-5.2%	10.5%	23.5%
POM as 7-PAH	0.0021	0.00052	0.00020	22.7%	26.8%	10.6%
Styrene	2.5	0.50	0.17	-1.9%	13.4%	19.3%
Ethylbenzene	3.8	0.94	0.36	22.7%	26.9%	10.7%
n-hexane	1.34	0.29	0.10	37.1%	35.1%	16.0%
Propinaldehyde	4.7	0.85	0.28	-8.9%	7.3%	26.0%
Toluene	23.3	6.1	2.4	29.2%	29.2%	9.6%
Xylene	14.0	3.6	1.4	25.8%	28.0%	10.1%
Lead[a]	0.21	0.33	0.21	19.7%	20.4%	-3.8%

[a] Lead emissions come only from general aviation aircraft. Lead content is significant only in aviation gasoline, not in jet fuel.

B.3 Discussion

The NESCAUM method for estimating aircraft emissions is similar to the standard method, but incorporates a few important differences. The NESCAUM method was developed specifically to be compared against EDMS 3.0 and to improve upon the methods used in that model. Since the NESCAUM model was developed, some of the changes incorporated in the NESCAUM model have been added to EDMS 4.0 and higher.[44]

[44] Changes to the aircraft emissions inventory portion of EDMS v. 4.0 and higher include flight profile data and the ability to change the mixing height.

Standard inventories use FAA's EDMS model, the tool required by FAA for aircraft emission inventories. EDMS generally follows the same basic emissions calculation as the NESCAUM model (emissions = emission factor * fuel flow * time-in-mode) and utilizes the same data for emissions factor and fuel flow, but many of the inputs are different. For example, EDMS 3.0 requires the user to assign one engine to each make of aircraft for the entire airport, whereas the NESCAUM model incorporates a world aircraft inventory that reflects actual engine and aircraft populations. Most inventories use the default times-in-mode suggested by ICAO instead of the airport-specific times developed in this study. The standard methodology incorporates landing and takeoff (LTO) data by aircraft for the airport being studied, whereas the NESCAUM method uses more specific LTO data for aircraft models by airline. These differences are summarized in Table II-11.

The NESCAUM methodology for estimating aircraft emissions yields robust results that overcome some deficiencies of the standard methodologies by using an inventory of aircraft/engine combinations owned by each airline, tallied for a specific calendar year. NESCAUM also calculates the mixing height and adjusted times-in-mode for each airport. At the airports studied, the annual mixing height is below the default of 3000 feet, tending to reduce emissions estimates compared to the standard methodology. Moreover, because the NESCAUM method calculates monthly emissions, it is sensitive to seasonal changes in mixing height. This is important as some air quality concerns, such as ozone (which is formed primarily in the summertime), are seasonal in nature. Additionally, NESCAUM incorporated FAA flight profile data that suggested that the takeoff phase of the LTO cycle extends to an altitude of 1000 feet, not the default of 500 feet. This lengthens the time-in-mode for the takeoff – the highest-powered phase – while simultaneously decreasing the time-in-mode for the climbout phase, causing a net increase in calculated NOx emissions.

Despite the additional data used in the NESCAUM methodology for estimating aircraft emissions, uncertainties remain in all aviation inventories. First, the NESCAUM model and EDMS are based on data from the ICAO Emissions Databank, measured at four power settings representing the four phases of aircraft operations in a *reference* LTO cycle. These power settings may not be characteristic of actual LTO cycles. For example, the taxi/idle phase includes aircraft movement at speeds up to about 30 miles per hour as well as idling on the runway and at the gate. A single power setting of seven percent captures only an average emission factor, and does not include any emissions changes for acceleration. Second, engine safety requirements effect emissions during takeoff. In two-engine planes, each engine must be strong enough to support the aircraft if the other should fail. This means that each engine is capable of much greater thrust than is needed to lift the plane, so many takeoffs are made at "reduced thrust," with corresponding reduced emissions. The assumption that takeoff occurs at full power then, likely overestimates emissions. Because information about actual in-flight operations is considered confidential and is not always recorded automatically during flights, it is very difficult to gather accurate data about this factor. The same overestimation is included in EDMS. Third, emission factors do not reflect deterioration in either model; the effects of this omission are not well known (see footnote 33 on page II-9).

Table II-11: Methodology Comparison of EDMS and the NESCAUM Model

Modeling Item	**Standard Method Using EDMS 3.0**	**NESCAUM Method**
Basic equation	EF * Fuel Flow * TIM * Number of Engines * LTOs	EF * Fuel Flow * TIM * Number of Engines * LTOs
Emission Factor and Fuel Flow	ICAO Databank	ICAO Databank
In-Air Time-in-Mode	Default from ICAO rule, can be changed by user	Default from ICAO rule scaled by monthly mixing height, incorporating FAA takeoff profile data
Ground Time-in-Mode	Default from ICAO rule, can be changed by user	Monthly airport-average taxi times as recorded by DOT
1999 Aircraft/Engine Combinations and Inventory	Default engine set to most popular in U.S. fleet; can be changed by user	Engines assigned for aircraft owned by each airline, based on World Jet Inventory
2010 Aircraft/Engine Combinations and Inventory	Default engine set to most popular in U.S. fleet; can be changed by user	Engine assignments for new aircraft based on Boeing and Airbus forecasts
1999 LTOs	User-supplied	Airline-specific LTOs from DOT Bureau of Transportation Statistics
2010 LTOs[45]	User-supplied	User-developed forecast LTOs

C. Auxiliary Power Unit Inventory and Method

Auxiliary power units (APUs) are small engines that provide electricity and conditioned air to a jet aircraft while it is parked at the gate. In addition, APUs must be able to provide auxiliary power in the event of engine failure during flight. These engines are smaller versions of regular jet engines and have similar methods of combustion, so the methods used to calculate their emissions are similar.

[45] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

C.1 Methodology

The model developed by NESCAUM to calculate aircraft emissions also calculates emissions from APUs. Information about aircraft/APU assignments and data on emission factors and fuel flow rates are hard-coded into the model. The LTO data for aircraft also apply to the APU section of the model, and the user can input an APU time-in-use for each airline/aircraft combination or use default times-in-mode. Though NESCAUM strove to use the best, most complete data available, actual data for gate time, the availability of power and preconditioned air at airport gates, and the fraction of aircraft utilizing these services were unavailable. Therefore, for this study, time-in-use was calculated as the scheduled time between arrival and departure of each aircraft. No adjustments were made for late or delayed flights. Without specific information about the number or location of gates with power and preconditioned air, or about the fraction of planes taking advantage of these services, we made no adjustment for the use of gates with power or preconditioned air.

For the forecast year, times-in-use were adjusted by the same factor as the taxi times in the aircraft emissions forecast. This adjustment accounts for congestion in the forecast year. Planning documents that discussed future taxi/idle times were only available for Logan, so APU times were adjusted only at Logan. The sources of the data included in the model and the full methodology used to calculate APU times-in-use are discussed in Appendix, Section B.

C.2 Results

Tables II-12 and II-13 show current (1999) and projected (2010) NOx and HC emissions from APUs at the three airports studied, respectively.

Table II-12: 1999 APU NOx and HC Emissions at the Airports Studied

	Logan	Bradley	Manchester
Total NOx (tons/year)	144.9	29.7	7.9
Total HC (tons/year)	12.4	3.6	0.9

Table II-12 shows NOx and HC emissions from APUs for 1999. As expected, emissions correspond to airport size, with Logan having the highest and Manchester the lowest emissions. NOx is primarily produced during high-power engine operation, while HC are mainly produced during low-power operation. Calculated NOx emissions are about 10 times larger than HC emissions, showing that APUs function under significant load during operation. APUs are found only on air carrier aircraft, and add an emissions burden to this category of about 5.5 percent for NOx. The ratio of HC emissions to aircraft emissions is about three percent at Logan and six percent at Bradley and Manchester. Longer taxi times at Logan create more HC at that airport per LTO.

Table II-13: 2010 APU NOx and HC Emissions at the Airports Studied

	Tons/Year			Change from Baseline Year		
	Logan	Bradley	Manchester	Logan	Bradley	Manchester
Total NOx	233.1	62.0	18.6	60.9%	108.8%	135.4%
Total HC	11.9	3.3	0.9	-4.0%	-8.3%	0%

Table II-13 shows estimated NOx and HC emissions for 2010.[46] Logan is projected to continue to produce more emissions than the other airports, and its NOx emissions are forecast to be about 20 times larger than its HC emissions. Note that the changes from the 1999 baseline are much larger than the growth in LTOs or than the combined growth of LTOs and increase of APU time at Logan. The growth from the baseline and the change in the ratio of NOx to HC can be explained by the changes in the APUs on new aircraft expected to enter service in the coming decade. On many of the new aircraft, the APUs tend to have NOx to HC ratios of 20 or more on an LTO basis, whereas more of the older aircraft have APUs with NOx to HC ratios closer to four. This change in fleet mix also can explain why HC emissions do not grow at the Bradley and Manchester airports. APUs in newer planes have significantly lower HC emissions than those in older planes.

C.3 Discussion

Many approximations and simplifying assumptions were necessary to estimate emissions from APUs. First, data on APU emission factors and aircraft/APU combinations are sparse. These engines do not fall under the emission requirements for the main engines, and therefore are not subject to any controls or emission certification programs. Emission factors come from several sources, and work comparing conditions for emissions testing to in-use conditions for these engines is not available.

Second, time-in-use calculations included some substitutions. Time-in-use was calculated as the gate turnaround time, or the difference between arrival and departure times, for an aircraft. These calculations were made from airport schedules with varying levels of detail and completeness. For example, the schedule used for Manchester Airport only gave aircraft make (i.e., Boeing 737 or DC-9), whereas Bradley Airport's schedule also specified model (i.e., Boeing 737-300 or DC-9-50). The schedules did not include all of the aircraft listed in the LTO table, so substitutions of APU time-in-use were necessary. Substitutions were made using similarly sized aircraft, but the need for substitutions added a degree of uncertainty to the calculation that is difficult to measure. Schedules were not available for Logan's domestic flights, so APU times for Bradley were used in the Logan calculations.

Third, assumptions about the use of electrified gates were conservative. Because information about the number and locations of gates was not available, the APU emissions calculations assumed that no powered gates were in use. However, powered gates are in use at portions of the airports studied. This assumption pushes the results toward the upper limit of actual emissions.

To date, emissions from APUs have rarely been included in SIPs or other inventories. Though not a large contributor to airport emissions, these small engines produce a sizeable quantity of NOx and HC at airports. As can be seen from Tables II-12 and II-13, APU emissions represent approximately five percent of airport NOx emissions. Large increases in APU NOx emissions in 2010 can be attributed to growth at Bradley and Manchester due to regionalization. Although APUs are a relatively small source of emissions in comparison with aircraft engines, cost effective measures to reduce APU emissions exist, and are discussed in the next chapter.

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[46] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

D. Ground Service Equipment (GSE) Inventory and Method

This section presents the results of the GSE inventory for Logan, Bradley, and Manchester airports and describes the method used to calculate emissions. As was the case with the aircraft emissions inventory, it is anticipated that states in the region will be able to use the method and model described in this section to prepare GSE inventories for other airports in the region.

D.1 Background

Airport GSE are comprised of a large variety of vehicles and equipment that service aircraft during ground operations. Types of GSE vary by function and are designed for specific tasks such as facilitating passenger access, aircraft flight preparation and aircraft maintenance. A list of commonly used types of GSE and their function are described in Table II-14.

Table II-14: Description of GSE Types and Function

GSE Type	GSE Function
Aircraft Pushback Tractor	Includes narrow and widebody tractors used to push aircraft back from the terminal to the taxiway or to tow aircraft to and from the hangar.
Baggage Tug	Used to tow luggage trailers from the terminal to the aircraft and back.
Belt Loader	Mobile conveyor belt used to transfer baggage from trailers on the tarmac to and from the aircraft's hold.
Bobtail	Small vehicle consisting of a truck cab with no cargo bed mounted to the chassis. Used for a variety of operations.
Cargo Loader	Vertical lift device with integrated conveyor belts or rollers used to transfer containers, skids and pallets to the aircraft's hold. Cargo loaders are subdivided into upper and lower deck loaders.
Ground Power Units (GPU)	Ground-based mobile generator that supplies electricity to the aircraft while parked.
Lifts	Includes forklifts and heavy duty lifts used for moving cargo and equipment around the airport, storage areas, or hangars.
Service Trucks	Generally on-road vehicles that provide a variety of aircraft support operations.

There are three categories of GSE operators: individual airlines, fixed base operators (FBO) and airport management. Airlines are defined as air carriers holding a Certificate of Public Convenience and Necessity issued by the US Department of Transportation (US DOT) to engage in air transportation. Fixed base operators are service providers permanently located at an airport that provide a variety of services to airlines, passengers, and airport operators. In this study, the primary FBOs of interest are those engaged in GSE, fuel, and maintenance service contracts to airlines and airport managers. Airport management authorities are responsible for the day-to-day operation of airport facilities, including runway maintenance, grounds keeping, safety, and security.

Comparison with Existing Method to Calculate GSE Emissions

The approach taken in this study was to calculate GSE emissions from an inventory of equipment and hours of use at airports. The more common approach to developing GSE population and activity data is through the use of a regression equation that estimates GSE activity based on LTOs. While NESCAUM has performed such calculations in a previous effort, we chose to directly survey airports to create a bottom-up inventory for this analysis due to deficits identified with the regression methodology.[47] Two main shortcomings were identified in the existing regression equations. First, the regression approach may not provide an emissions inventory representative of airports in the Northeast. The studies which were used to develop the existing regression equations were located primarily in California and Texas, where snow removal equipment is not necessary and additional activity associated with delays and deicing was not found.[48] Second, the regression equations are derived exclusively from airline data. Using data solely from airlines excludes an inventory component crucial to airport operation: airport management vehicles. These vehicles operate at every airport and perform the day-to-day functions that keep the airport operating safely. Airport management vehicles include ground maintenance vehicles such as runway sweepers, grass cutting equipment, snow removal equipment and crash/fire/rescue vehicles.

D.2 GSE Emissions Inventory Model

The GSE emission inventory for each airport was calculated using a model developed for NESCAUM by EEA specifically for this analysis: the "GSE Emissions Calculator, v. 1.0," ("the model"). The model is built on a Microsoft Excel spreadsheet platform. Emissions are calculated using the following equation:

[47] "Heavy-Duty Engine Emissions in the Northeast," Northeast States for Coordinated Air Use Management, May 1997.

[48] The regression method was first developed for the California South Coast Air Basin FIP in 1995 (Draft Technical Support Document, Aircraft/Airports California FIP IFR, Energy and Environmental Analysis, Inc., prepared for USEPA, Motor Vehicle Emission Laboratory, 1995, pp. 2-59). This approach applies a statistically derived equation that associates GSE activity with aircraft LTOs. In 1999, a new regression equation was derived for estimating GSE populations which is more representative of airports outside of Southern California. ("Technical Support for Development of Airport Ground Support Equipment Emission Reductions," EPA420-R-99-007, USEPA, May 1999.) This new equation is based on inventories collected from fourteen airlines at ten airports. Although this inventory uses information collected from airports outside of California, six of the ten participating airports were located either in the southwestern U.S. Only two airports represent areas outside of the western United States. These are Boston's Logan airport and BWI located in Baltimore, Maryland.

$$E_{ti} = P_t \times ef_{ti} \times bHp_t \times rate_t \times lf_t \qquad \text{(Equation II-1)}$$

Where:

E_{ti}	=	total emissions of pollutant, *i*, in grams/day by all GSE type, *t*.
P_t	=	population of GSE type, *t*.
ef_{ti}	=	emission factor of pollutant, *i*, for GSE type, *t*, in grams/bHp-hr.
bHp_t	=	average loaded brake horsepower of the engine for GSE type, *t*.
$rate_t$	=	average daily hours of use of GSE type, *t*.
lf_t	=	load factor (the average operational horsepower output of the engine divided by the bHp) utilized in ground support operations by equipment type, *t*.

The default year for which the model calculates emissions is 1999; however, the user has the ability to model any year up to 2015 (as discussed later in this section).

The model uses the above equation to calculate GSE emissions by either the US EPA or CARB method, as specified by the user. The US EPA and CARB methods are used by US EPA in the *NONROAD* emissions model and the CARB *OFFROAD* emissions model, respectively. The primary differences between the US EPA and CARB models are the emission factors and assumptions made about deterioration of emissions over the life of the equipment. US EPA's draft *NONROAD* model uses a single emission factor for all GSE; CARB's *OFFROAD* uses emission factors for 20 specific and two miscellaneous categories of GSE.[49] While the CARB model deteriorates engine emissions throughout the life of the machine, the US EPA model stops deterioration when the useful life of the machine has been reached. Consequently, the CARB deterioration rates are higher than EPA's.[50]

Discussion of Model Inputs

The model requires users to input, at a minimum, specific equipment types (*t*) and the populations of each class of equipment (P_t). In addition, the user has the option to further customize the modeling run by inputting engine information (such as fuel type, age, and horsepower (bHP_t)) and vehicle usage characteristics (such as activity ($rate_t$) and load factors (lf_t)). The required and optional user-supplied inputs are listed in Table II-15. If the optional data (including load factor, emission factors, and horsepower) are not available, emissions are calculated using default values provided in the CARB (OFFROAD) or US EPA (NONROAD) models. This study calculated GSE emissions using both the US EPA and CARB methods and reports each separately to facilitate a comparison between the two models.

[49] The final NONROAD model version has not yet been released.
[50] US EPA and CARB use separate methodologies to determine deterioration rates; the model deteriorates engine emissions using either method, as specified by the user. Deterioration is also a function of the emission analysis year and the model year of each GSE (i.e., vehicle age).

Table II-15: Required and Optional Inputs to NESCAUM GSE Emissions Model

Model Input Parameter	Description	Required/ Optional
GSE type	Equipment type	Required
Population	Number of machines	Required
Fuel/engine type	Gasoline (2 or 4 stroke), diesel, LPG, CNG, electric	Optional
Model year	1995, 1996, etc.	Optional
Horsepower	Horsepower number as supplied by manufacturer	Optional
Load factor	As a percent of total engine power	Optional
Activity rate	Hours/day	Optional
Useful life	Hours	Optional
Gasoline fuel tank size	Gallons	Optional
Emission rate	g/bhp-hr; Individual for all pollutants modeled (HC, NOx, CO, PM, SO_2, CO_2)	Optional

To provide greater accuracy, the EEA model uses CARB values and methods for most inputs, such as load factor, horsepower, fuel type, activity rate and useful life, when the user does not provide specific information. The reason for this is that EPA currently groups all GSE into one vehicle class having only a single value for each of these input parameters, whereas CARB has identified twenty specific types of GSE and has two categories for miscellaneous GSE. Appendix, Section C contains more detailed information regarding the model and model inputs.

NESCAUM Survey

In order to assess the emissions impacts of GSE at the three airports studied as accurately as possible, NESCAUM developed a detailed characterization of GSE usage at each airport. This characterization includes vehicle population, fuel type, vehicle age, and hours of operation. The survey form sent to GSE operators at each airport can be found in Appendix, Section C. A total of 27 types of machines/vehicles were included in the survey, including nineteen self-propelled vehicles, such as pushback tractors and baggage tugs, and eight types of cart support equipment, such as ground power units and portable lighting equipment. In addition, six types of fuel were distinguished in the survey. Appendix, Section C provides a complete list of machine/vehicle types and fuel types included.

GSE Population and Activity Data Collection

Individual airlines, FBOs, and airport management authorities were initially contacted and asked to supply information on:

- equipment type (see Appendix, Section C, Table B.3-1 for a list of types),
- fuel type,
- internal combustion engine type (compression ignition or spark ignited),
- on road certification,
- number of pieces of equipment,
- annual hours of operation,
- horsepower, and
- fuel usage per year.

If the airline indicated that it was willing to supply the requested information, but did not return the survey form, an interview was requested and a NESCAUM representative visited that organization's offices to conduct the interview. In the case of Bradley and Manchester airports, few responses were elicited from the survey and interview requests; therefore a NESCAUM representative made site visits to each airport to collect population data based on a visual inspection of the airlines' fleets.[51]

Site visits at Manchester and Bradley airports involved counting GSE fleet vehicles from the airport terminals. These two airports do not have significant indoor storage areas for equipment, therefore most, if not all, of the GSE is parked outside. GSE vehicle counts were made for all fleets operating at each airport, including vehicles for which estimates had been provided by the operator. Data previously supplied by the paper survey were then used to validate the results of the visual inspection. The visually-collected population data correlated well with the survey data. The major confounding factor of the visual inspection method is the similarity of appearance between certain types of equipment, such as air start units, ground power units, and conditioned air units. In certain cases the surveyor must make a judgment as to the equipment's function. Another shortcoming of the visual inspection method is the inability of the surveyor to collect fuel type and usage information, as well as activity rates. NESCAUM recommends visual surveys of GSE populations only when more formal methods of inventory development (paper and interview type surveying) fail.

The survey data were compiled by airport into composite lists of vehicles that include all available individual vehicle characteristics and usage information. Where possible, load factors were derived from fuel usage and engine horsepower data collected in the survey.

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[51] This visual inspection was made before September 11, 2001. Repeating this survey would likely be more difficult under the current security practices at U.S. airports; however, states may have more success in working with airlines and airports than was found in this effort.

Since many paper surveys were returned with incomplete information, some identifying only population and engine fuel type, NESCAUM relied on the default activity rate data and load factors supplied by the model when values were missing. In very specific instances, NESCAUM was able to develop fleet-specific activity rates. For example, usage rates were not supplied for any snow removal equipment; however, snow removal operations were characterized in an interview with an airport manager. Based on this information and 1999 National Weather Service snowfall data recorded at each airport, NESCAUM estimated annual activity for these machines.

An additional complication arose related to the model's input requirements for very specific categories of GSE types. In some cases, categories of GSE equipment were identified in the survey which were not included in the GSE model. In these cases, the closest model type in terms of engine size and use characteristics was substituted. For example, the model does not provide a category for "Crash/Fire/Rescue vehicles," therefore these have been input into the model as "WB Pushback" tractors.[52] A full list of cross-referenced vehicles can be found in Appendix, Section C. Similarly, participants in NESCAUM's airport survey identified fuels that were not included in the model. Therefore the closest fuel was selected for use in the model. The two sources of energy primarily identified in the survey that were not included in the model are hybrid vehicles and vehicles fueled with Jet A, a type of jet fuel with combustion characteristics similar to diesel fuel. A cross-referenced listing of fuels identified in the survey and their model equivalents are listed in Appendix, Section C.

Load Factors Used

Engine load factor required special consideration in the NESCAUM study. Engine load factor is the ratio of the average power output from the engine when used at its rated power. The default load factors in the EEA model, as with other default inputs, are derived from the CARB or US EPA models, as chosen by the user. This is a measure of the utilization of the available power when the machine is in operation. In examining the default load factors supplied by the model (ranging from 0.20 to 0.90, Table II-16), a sensitivity analysis revealed that these were developed for activity rates that only account for equipment operating under load and exclude equipment idle time[53] (see the sensitivity analysis discussion in section D.3). The default values for equipment activity in the models are significantly lower than the usage information NESCAUM collected, indicating that idling time is not accounted for in the default activity rates. [54] The use of incompatible activity rates and load factors can significantly alter emission modeling results. The discussion of the sensitivity analysis performed on the GSE model delves further into this matter.

Since the GSE activity data collected through the NESCAUM survey included equipment operation time as well as equipment idle time, the default load factors supplied by the model seemed inappropriate for the NESCAUM dataset. Therefore NESCAUM calculated actual load factors (where possible) based on equipment fuel usage collected during the survey effort.

An estimate of load can be derived by the following equation:

[52] WB Pushback is the abbreviation for widebody aircraft pushback tractor.
[53] Since an engine uses relatively little of the available power during idling periods, a load factor which includes all time that the engine is running would be much lower than those used in the model.
[54] Since respondents reported hours of use differently, it is difficult to assess exactly what surveyed companies were reporting.

$$lf_t = \frac{BSFC_t(actual)}{BSFC_t(rated)} \qquad \text{(Equation II-2)}$$

Where:

lf_t = load factor (the average operational horsepower output of the engine divided by the bHp) utilized in ground support operations by equipment type, *t*.

$BSFC_t(actual)$ = actual brake specific fuel consumption [actual lb. fuel consumption of the engine] / [rated hp·hr]

$BSFC_t(rated)$ = rated brake specific fuel consumption [rated lb. fuel consumption of the engine] / [rated hp·hr]

Seventy percent of those responding to the paper survey provided activity data for their GSE fleets, while fuel consumption data were collected from seventeen percent of those surveyed. These data were used to generate load factors more characteristic of the fleets studied. Table II-16 displays the default load factors supplied by the model, compared with calculated load factors using the above method.

Model outputs

The model reports GSE emissions of CO, CO_2, NOx, SO_2, HC, and PM. The user has the flexibility to further specify how hydrocarbons should be reported: as total hydrocarbons (THC), total organic gases (TOG), non-methane hydrocarbons (NMHC), non-methane organic gases (NMOG), or volatile organic compounds (VOC). The model also affords the flexibility to specify how particulate matter emissions should be reported. The default setting for PM emissions is total PM, however the user can specify PM to be reported as PM_{10} or $PM_{2.5}$.

The model output parameters are listed in Table II-17. Emissions are reported by individual classes of vehicles and in composite form, where emissions from all equipment are summed by pollutant. The model automatically converts grams/day to lbs/day, short tons/day, kg/day or metric tons/day. If output units are not specified by the user, the model automatically reports emissions in lbs/day.

Table II-16: Adjusted Load Factors for Specific Equipment Categories

Model Equipment Name	Survey Equipment Name	Model Load Factor	NESCAUM Load factor
NB Pushback	Narrow Body Aircraft Pushback Tractor	0.80	0.12
	FE Loader	0.80	0.47
WB Pushback	Wide Body Aircraft Pushback Tractor	0.80	0.08
	Dump Truck	0.80	0.47
Air Cond. Unit	Conditioned Air Unit	0.75	0.39
Air Start Unit	Air Start Unit	0.90	0.02
Baggage Tug	Baggage Tug	0.55	0.02
Belt Loader	Belt Loader	0.50	0.07
Cargo Loader	Cargo Loader	0.50	0.06
Deicer	Deicer	0.95	0.07
Forklift	Forklift	0.30	0.09
Fuel Truck	Fuel Truck	0.25	0.08
GPU	Ground Power Unit	0.75	0.10
Lavatory Truck	Lavatory Truck	0.25	0.14
Lift	Lift	0.50	0.27
Maintenance Truck	Maintenance Truck	0.50	0.02
	Stairs	0.50	0.07
Service Truck	Service Truck	0.20	0.09

Table II-17: Parameters Reported by the EEA GSE Emission Calculator, v 1.0. All emissions may be reported in lbs/day, short tons/day, kg/day or metric tons/day.

Equipment Information	Exhaust Pollutant Species Reported	Evaporative Hydrocarbons (THC/TOG/NMHC/NMOG/ VOC) Reported, Attributed To:
• Equipment Type • Equipment Population	• Hydrocarbons: THC/TOG/NMHC/NMOG/VOC (user specifies species reported) • Nitrogen Oxides (NOx) • Carbon Monoxide (CO) • Particulate Matter: Total PM/ PM_{10} / $PM_{2.5}$ (user specifies PM size fraction reported) • Carbon Dioxide (CO_2) • Sulfur Dioxide (SO_2)	• Crankcase • Diurnal • Displacement • Spillage • Hot Soak • Running Loss • Total Evaporative Emissions

Projection of Future Year GSE Emissions

The model is not currently equipped to project future year GSE emissions; therefore, NESCAUM grew the GSE inventory in direct proportion to growth in LTOs at each airport. The growth factors employed are listed in Table II-18, and are based on the expected change in LTOs in the air carrier sector at all three airports. Logan airport is not expected to expand significantly before 2010, therefore only airline GSE fleets were grown (i.e., airport maintenance GSE fleets were not grown). In contrast to Logan, all vehicles in the Bradley and Manchester airport GSE fleets were grown, with the assumption that supporting the increase in air traffic will require each airport to undergo some amount of GSE expansion.

Table II-18: GSE Growth Factors 1999 – 2010 for the Study Airports

Airport	GSE Population Growth Factor
Logan Airport	1.102
Bradley International Airport	1.365
Manchester Airport	1.405

D.3 Emission Modeling Results

The GSE emission modeling results for NOx, VOC and total PM are reported in this section. Table II-19a reports the population and activity inputs at each of the airports studied for both the base and projected years. The subsequent tables (Tables II-19b–d) contain the emission modeling results for the primary pollutants of interest. Emissions were also calculated for CO, CO_2, and SO_2; however, as these pollutants are not of primary interest, these results can be found in Appendix, Section C. Emissions are reported using the US EPA and CARB methodologies. These emissions were calculated using the NESCAUM-derived activity rates and load factors, with population figures from the paper and visual surveys. Also included for comparative purposes are the SIP inventories for NOx, VOC, and CO supplied by Massachusetts and Connecticut.

Table II-19a: Basic Airport Modeling Input Values for Population and Activity

Airport	Equipment Population	Total Activity (Hours/Year)
Modeled Year: 1999		
Logan International Airport	1,173	1,617,439
Bradley International Airport	366	358,726
Manchester Airport	141	68,904
Modeled Year: 2010		
Logan International Airport GSE	1,276	1,769,508
Bradley International Airport GSE	480	473,263
Manchester Airport GSE	206	101,437

Table II-19b: GSE NOx Emission Results and SIP Inventories (1999 and 2010)[55]

Airport	EPA Exhaust NOx (Tons/Year)	ARB Exhaust NOx (Tons/Year)	SIP estimates Exhaust NOx (Tons/Year)
Modeled Year: 1999			
Logan International Airport	293	235	132
Bradley International Airport	96	78	Not Available
Manchester Airport	33	27	Not Available
Modeled Year: 2010			
Logan International Airport	291	235	Not Available
Bradley International Airport	110	90	Not Available
Manchester Airport GSE	35	29	Not Available

Table II-19c: GSE THC Emission Results and SIP inventories (1999 and 2010)

Airport	EPA Exhaust + Evaporative THC (Tons/ Year)	ARB Exhaust + Evaporative THC (Tons/ Year)	SIP Exhaust VOC (Tons/ Year)
Modeled Year: 1999			
Logan International Airport GSE 1999 Actual	233	120	58
Bradley International Airport GSE 1999 Actual	50	30	221
Manchester Airport GSE 1999 Actual	10	6	Not Available
Modeled Year: 2010			
Logan International Airport GSE 2010 Projection	253	130	Not Available
Bradley International Airport GSE 2010 Projection	63	39	Not Available
Manchester Airport GSE 2010 Projection	11	7	Not Available

[55] SIP modeling results in each of the following tables were supplied to NESCAUM by the Massachusetts Department of Environmental Protection and the Connecticut Department of Environmental Protection.

Table II-19d:GSE PM Emission Results (1999 and 2010)

Airport	**EPA Exhaust Total PM** (Tons/ Year)	**ARB Exhaust Total PM** (Tons/ Year)
Modeled Year: 1999		
Logan International Airport GSE 1999 Actual	30	12
Bradley International Airport GSE 1999 Actual	11	4
Manchester Airport GSE 1999 Actual	4	1
Modeled Year: 2010		
Logan International Airport GSE 2010 Projection	30	13
Bradley International Airport GSE 2010 Projection	13	5
Manchester Airport GSE 2010 Projection	4	1

Generally, CARB's *OFFROAD* method produces lower emissions estimates than US EPA's *NONROAD* model. The primary reasons for differences in emission estimates are variations in the emission factors upon which these calculations are based and differences in assumed engine deterioration rates. As stated previously, US EPA combines all GSE into a single category that contains only a single emission factor; CARB has separate emission factors for 22 categories of GSE.

Differences between state and NESCAUM estimates were the result of a variety of factors. First, Massachusetts and Connecticut used different methods in developing GSE emission inventories. Massachusetts used the EDMS model to calculate SIP inventories while Connecticut used a 1990 inventory supplied by US EPA and applied a growth factor to project future year emissions. Second, EDMS assumes a higher percentage of gasoline powered GSE than the NESCAUM survey results. Gasoline engines emit less NOx than diesels; therefore, EDMS is expected to predict lower NOx emissions than the EPA and CARB methods. EDMS, a traditional tool for GSE inventory development, associates a fixed GSE activity with each LTO. To reiterate, this study took an alternate approach, combining actual counts of airport GSE populations with activity from surveys of the equipment operators. Third, EDMS does not account for airport maintenance GSE; as a result EDMS may underestimate total GSE use and emissions.

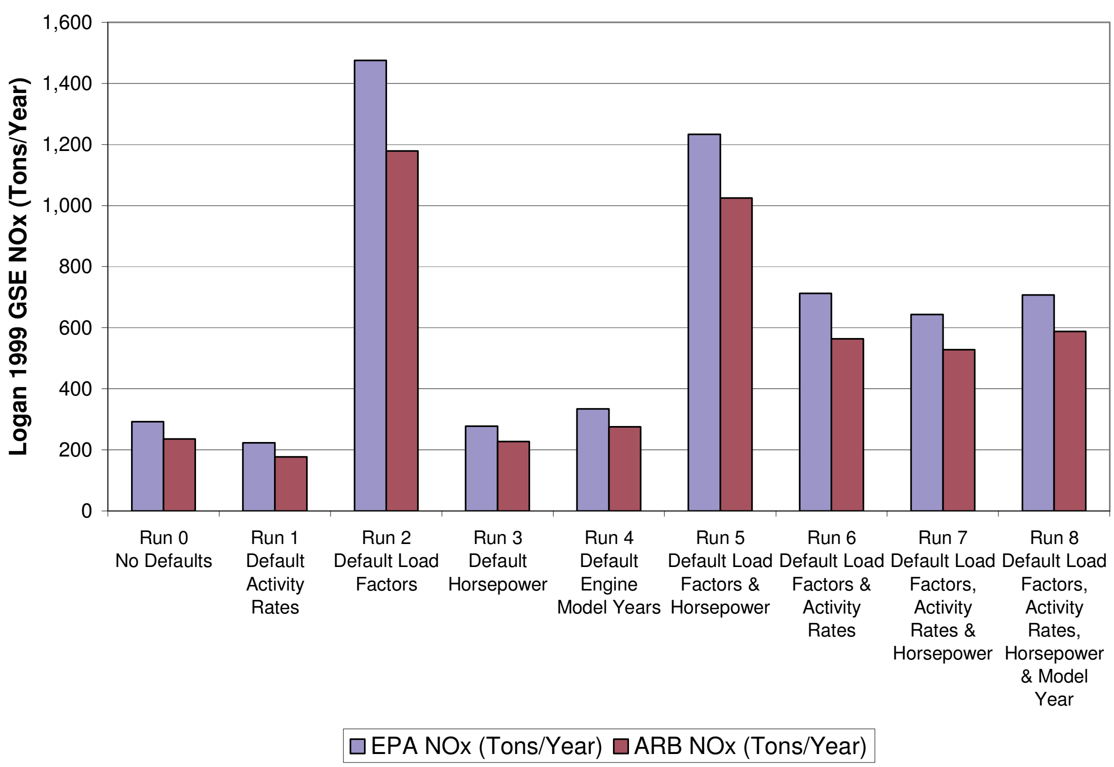
At the airports studied, GSE emissions of NOx and VOC range from seven to seventeen percent of aircraft emissions. In general terms, GSE can be expected to account for ten percent of airport emissions, as GSE activity tends to be proportional to aircraft activity. Figures II-7 and II-8 compare GSE emissions of NOx and THC (as calculated by the CARB method), respectively, to APU and aircraft emissions at each of the airports studied.

Model Sensitivity Analysis & Load Factor Adjustment Justification

Initial modeling runs used survey data of vehicle type, population, horsepower, model year, and hours of use with all other model inputs (load factor, useful life, etc.) set to default values. These runs showed GSE emissions of NOx and VOC at a similar magnitude to aircraft emissions. Based on fuel use alone, it is extremely unlikely that GSE emissions should approach those of aircraft emissions. Conventional wisdom indicates that GSE emissions of both NOx and VOC can be expected to be 10% of the aircraft emissions; thus, the unusually high emissions implied a modeling error. Examination of inputs used in the model (both collected and default) and discussion with the model developer lead to suspicion that the GSE activity data collected in the survey was incompatible with the model default load factors (Equation II-2). A hypothesis that the default load factors were developed for activity rates that account for equipment operating under load and exclude equipment idle time was explored.

In order to validate the hypothesis, a sensitivity analysis was performed using the EEA GSE model to determine the relative effects of the model's default parameters on emission calculations. Boston Logan Airport's dataset was used to perform these sensitivity analyses because it is the most complete data set available to NESCAUM and is the least reliant on default model inputs. This dataset was used in eight runs to perform sensitivity analyses evaluating combinations of default factors. The first four sensitivity runs adjusted only one parameter (activity rate, load factor, engine horsepower, or engine model year) to its default value; four additional sensitivity runs examined the relative effects of adjusting multiple parameters to their default values. The results of the NOx sensitivity runs are summarized in Figure II-6.

Figure II-6: Logan GSE NOx Emission Sensitivity Analysis Results



The initial modeling results are shown in Figure II-6 by Sensitivity Run 2, Default Load Factor. The high estimation of emissions occurs because the default load factors (which are high, see Table II-16) are combined with the survey hours of use (which include idling time). The product of the two large numbers overestimates emissions. Comparing Run 2 to Runs 1, 3, and 4 (using only default activity rate, horsepower, and model year, respectively), it is clear that default load factor is the problematic input.

Sensitivity Runs 5 through 8 indicate that the default load factor is counterbalanced to some extent by the other default parameters of the model. Load factor and activity rate are the two most closely linked input parameters. Activity rate is the time in which the vehicle or engine is operated, and load factor is calculated as full power divided by activity rate. If the activity rate includes engine idle time, the load factor should be relatively low, as very little power output is necessary for idling; however, if activity rate excludes idling time and only includes time in which the engine is performing its assigned task, the load factor would be higher.

Sensitivity Run 6 shows the impact of using default activity rates and load factors with the Logan dataset. When these default values are used in combination, the emissions fall between the results seen in Runs 1 and 2 (which use model default values). As expected, activity rate has the greatest effect on damping the impact of default load factors on emissions. In fact, Runs 6 through 8 show that the other factors have very little effect when default load factor and activity rates are used together.

NESCAUM took the "No Defaults" case as the best estimate of emissions. This run made use of all survey data and the NESCAUM load factors calculated from the survey (Table II-16). These results are of the expected magnitude of emissions compared to aircraft and make use of the best data available about the GSE fleet in the Northeast.

NESCAUM GSE Survey Reporting Results

As it is not possible to determine the exact number of GSE operating at each airport using the survey techniques employed for this report, percent data capture was estimated by using a combination of GSE data gathered at each airport and LTOs of individual airlines at each airport. One major issue confounds the ability to calculate GSE data capture rates: many airlines contract GSE services to FBOs. NESCAUM collected GSE data from the majority of FBOs operating at each of the airports studied; however, limited information was collected regarding the extent to which these FBOs service individual airlines.

At Bradley International Airport, approximately 80 percent of the GSE fleet was accounted for by NESCAUM based on the various survey methods employed (four paper and eleven visual surveys). At Logan International Airport, anywhere from 69 to 82 percent of the GSE fleet was accounted for, using the survey methods described. Of the 86 airlines that operated at Logan in 1999, GSE that service twenty-one air carriers were identified. This inventory is based on ten paper surveys, two in-person interviews and one telephone interview. Approximately 99 percent of the GSE population at Manchester Airport was accounted for with six paper and 11 visual surveys. Of the 21 airlines identified as operating out of Manchester Airport, all major-air-carrier GSE and two of four national-air-carrier GSE populations were accounted for; the remaining air carriers represent less than one percent of total aircraft activity at Manchester Airport. Appendix, Section C provides detailed information on survey reporting statistics.

No upward adjustments were made to the population data to account for the incomplete capture of GSE at these airports. Emissions at Bradley and Logan Airports may therefore be somewhat higher than the results presented here.

E. Conclusions

The emissions inventory presented in this chapter focused on aircraft, APU, and GSE emissions. It was the intent of the report organizers to include ground access vehicles and airport-related stationary sources in the study; however, resource limitations required a focus on the lesser-understood areas of aircraft and GSE emissions. It is generally accepted that state inventories account for ground access vehicle emissions using traditional mobile source modeling tools (US EPA's MOBILE model) and for stationary source emissions using AP-42 emission factors. Figures II-7 and II-8, respectively, show the contribution to NOx and HC from the three sources at each airport for 1999.

Aircraft emissions dominate the NOx inventory for the three airports in both 1999 and 2010. GSE and APU emissions combined represent approximately 15 percent of NOx emissions at each of the studied airports. Among aircraft types, air carriers dominate the inventory because they account for more engines, burn more fuel, and produce more pollutants per minute than air taxi or general aviation aircraft.

Aircraft are also a dominant source of HC emissions compared to APU and GSE. Aircraft account for approximately 80 percent of HC emissions at airports, except at Manchester where the figure is closer to 92 percent.

Figure II-7: Total Airport NOx Emissions 1999 (Aircraft, GSE & APU)

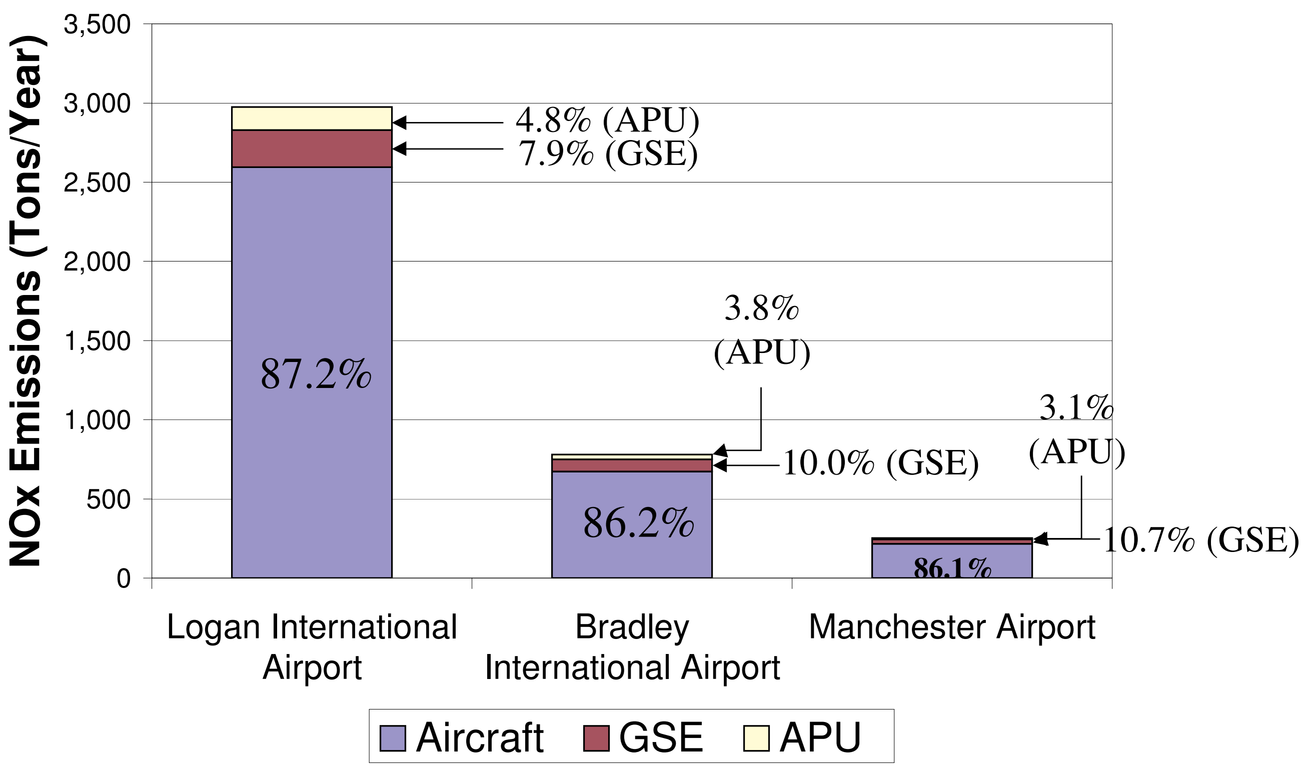
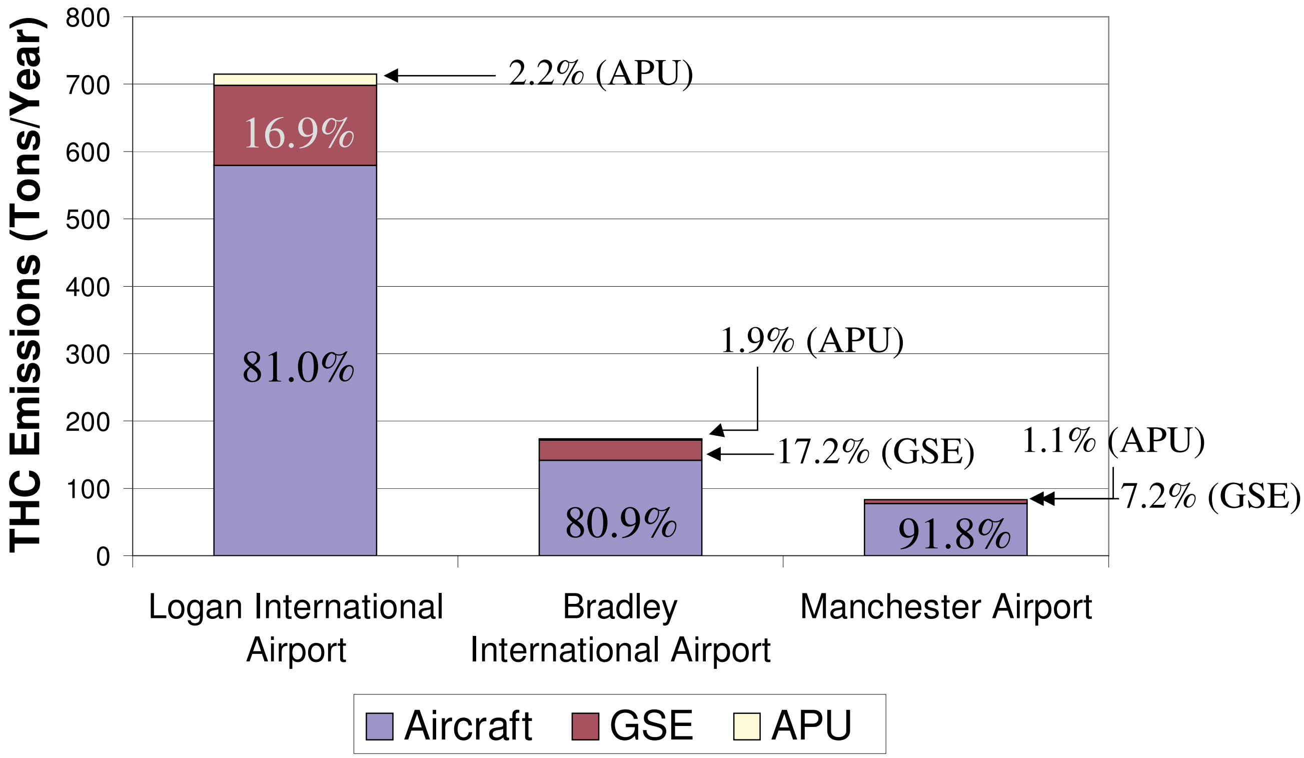


Figure II-8: Total Airport THC Emissions 1999 (Aircraft, GSE & APU)



Air taxi emissions comprised a larger percentage of total aircraft HC than NOx emissions in 1999, and an even greater share in 2010. Consequently, reducing both air taxi and air carrier HC emissions is important. This is especially significant for toxic emissions because air taxi HC emissions are high, and the toxic component of air taxi HC emissions is higher than for air carrier emissions.

The results of the inventories prepared for this report differed significantly from state SIP inventories, mainly developed in 1996. NOx emissions estimates in SIPs for aircraft were approximately 50% lower than the NESCAUM estimates (Tables II-4 through II-6). The same is true for HC with the exception of Manchester Airport, which reported higher HC emissions than this inventory. The differences in the SIP and NESCAUM inventories are due to the use of 1999 data (more flights than in 1996), different assumptions made regarding takeoff time for aircraft based on updated FAA data, and more specific data on aircraft/engine combinations. State SIP inventories did not include this updated information.

The primary driver for GSE forecasts is the forecast of LTOs. However, our forecasts for GSE also include assumptions about fleet turnover and the effects of the nonroad diesel rule. Effects from the recently-finalized gasoline nonroad engine rule are not included in our forecast assumptions.[56]

[56] The nonroad diesel and gasoline engine rules are further discussed in Chapter IV.

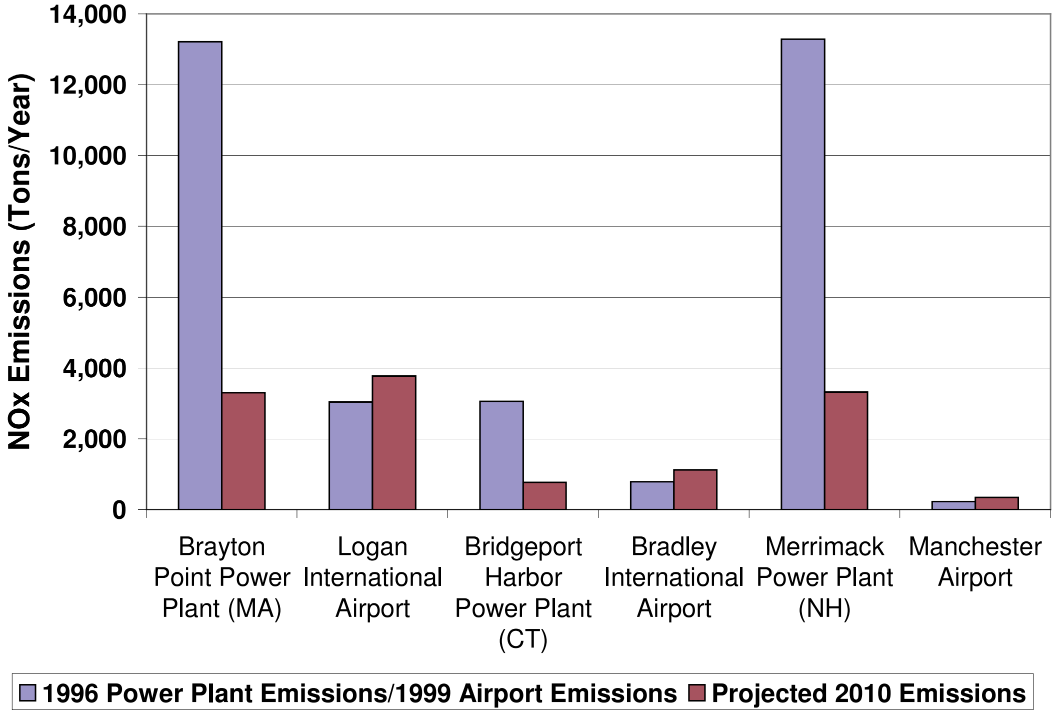
Continued improvements in emissions models, such as those incorporated in the EEA aircraft and GSE models, could improve state emissions inventories for airports. Future versions of EDMS, EPA's NONROAD model, and CARB's OFFROAD model should consider the findings of this report (especially regarding fuel use in GSE) and incorporate these changes. Allowing states to easily incorporate local data will also increase the utility of the models.

Airport-related NOx and HC emissions are expected to increase over the next ten years. [57] The three airports studied can expect growth rates in aircraft flights of 10% to 40% over the next ten years, based on FAA data. Aircraft, GSE, and APU emissions are predicted to increase at approximately the same rate, primarily because projected LTO increases were used to "grow" all three of these sectors. Regionalization will cause a greater percentage increase in air carrier and APU NOx emissions at Bradley and Manchester than at Logan.

Figure II-9 compares NOx emissions from large stationary sources in each of the three states with combined aircraft, APU, and GSE NOx emissions at the studied airports. Numerous control strategies imposed upon major stationary sources will lead to dramatic emissions reductions over the next decade, while emissions at airport continue to grow. In fact, Logan and Bradley airports will be greater contributors to statewide NOx emissions than these power plants in 2010. In New Hampshire, the largest utility will still exceed Manchester Airport's NOx emissions in 2010. This large growth in emissions underscores the importance of controlling airport-related emissions.

[57] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

Figure II-9: Major Stationary Source Emissions in Massachusetts, Connecticut, and New Hampshire[58]



[58] Stationary source emissions are based on state SIP inventories. Airport emissions are aircraft, APU, and GSE combined emissions calculated in this report.

III. Technical and Operational Measures for Reducing Airport Emissions

A. Introduction

This chapter describes options for reducing emissions at airports and examines the constraints, potential emission benefits, and where available, the costs associated with these options. The chapter is divided into three sections covering: aircraft, ground support equipment (including ground power units and auxiliary power units), and ground access vehicles.[59] Within each source category, control options are organized into two categories: technological and operational measures. Examples of technological control options include engine improvements, electrification, and alternative fuel technologies. Examples of operational control options include congestion management and changes in taxiing, takeoff, and landing procedures. Summary tables comparing emissions benefits,[60] as well as cost and cost-effectiveness estimates, are provided at the end of each source category section. The chapter concludes with a section describing how rail service could replace short-haul air travel.

B. Options for Reducing Aircraft Emissions

As noted previously, aircraft typically account for the great majority (45-85%[61]) of total airport emissions. A variety of aircraft types operate at commercial airports, including large commercial jets, smaller commuter aircraft powered by turboprop engines, piston–engined general aviation aircraft, and other miscellaneous aircraft. In addition, military aircraft also operate at some commercial airports. This chapter primarily focuses on measures relating to large commercial jets, since their emissions typically represent 80 percent of the total emissions inventory for all types of aircraft (i.e., air carriers, commuter, cargo and general aircraft). Sources of aircraft emissions include airplane engines and auxiliary power units used to provide electricity, ventilation, and air conditioning to the airplane at the gate. Control options for APUs will be discussed in the section on GSE since measures to reduce APU usage also reduce use of ground power units.[62]

B.1 Technology Options

Past trends in engine performance and efficiency improvements provide compelling evidence for the potential of technological advancement. Overall, the intensity of aircraft energy

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[59] The inventory presented in Chapter II did not include GAV emissions, however this chapter presents some available information and cost effectiveness estimates.

[60] In general, the discussion focuses on CO, NOx and VOC emission reduction benefits. Where available, information on PM reductions and fuel economy impacts (which directly affect CO_2 emissions) is also presented. Note that emission estimates from sources are given in terms of hydrocarbons (HC) rather than VOC. HC and VOC, though technically distinct in scientific terms, can be considered essentially interchangeable for the purposes of this discussion

[61] See Table I-5 and Figures II-7 and II-8.

[62] Ground power units are a category of GSE.

use has fallen by 60 percent since 1968. Most (57%) of that reduction is attributable to enhanced engine efficiency; the remainder is due to improvements in aerodynamic performance and load factor.[63] Specifically, cruising fuel economy has improved 40 percent over the last three decades (1.5% per year), while aerodynamic efficiency has improved at a rate of 0.4 percent per year and structural efficiency has remained constant despite greater passenger loads and more rigorous noise requirements. Aircraft energy use (fuel use per seat mile) over the next 25 years is projected to decrease by over 30 percent as airlines continue to make improvements.[64] Thus, even with the considerable gains of recent decades, opportunities for further improvement in aircraft engine design and engineering remain significant.

Aircraft Engines

Significant improvements in aircraft engine design are feasible and have been demonstrated by a number of manufacturers. For example, General Electric and other aircraft engine manufacturers are currently selling cleaner engines with "dual annular combustors" (DACs) that emit approximately 40 percent less NOx than conventional aircraft engines. Pratt & Whitney is currently manufacturing engines with its "Technology for Affordable Low NOx" (TALON), which provides NOx reductions of about 20 percent. However, both engines produce more CO and HC than their conventional counterparts, and also burn more fuel. Another approach currently in development by General Electric that will reduce NOx is called "lean premixed prevaporized" (LPP) technology and is expected in the fleet by 2005. GE and Pratt & Whitney are working on an engine that would reduce NOx by 40 percent relative to the 1998 CAEP/4 standard. This engine is expected to enter into service in late 2003, and is designed for the Airbus 380 and Boeing Growth 747 planes.[65] These examples demonstrate that cleaner technologies for aircraft engines are available today to reduce emissions.

Research programs currently underway could yield even greater emission reductions from aircraft engines. For larger engines, NASA's Advanced Subsonic Technology Program (AST) demonstrated a 50 percent NOx reduction goal (relative to the CAEP/2 standard) to technology readiness level (TRL) 6 in 1999. For regional engines, AST demonstrated a 50 percent reduction in NOx to TRL 4 in 1999 and TRL 9 is projected in 2005. The Pratt & Whitney "TALON" technology mentioned above was developed as part of the AST program. The second phase of the AST program is called the Ultra Efficient Engine Technology Program (UEET). The goal of UEET is to develop an aircraft combustor that will emit 60 to 70 percent less NOx than ICAO standards by 2006.[66] UEET also has a CO_2 goal of improving fuel efficiency for small and large engines by 8-10 percent and 15 percent, respectively. The planned scope of UEET is to demonstrate TRL 5 by 2004 for large and regional engines, and TRL 9 is

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[63] Load factor for aircraft refers to the fraction of the capacity (passenger or freight) being utilized on each flight.

[64] Lee, J. J., Lukachko, S. P., Waitz, Ian, A., and Schafer, A. "Historical and Future Trends in Aircraft Performance, Cost and Emissions," *Annual Review of Energy and the Environment*. Volume 26, 2001.

[65] www.enginealliance.com

[66] NASA programs develop technologies through a set of Technology Readiness Levels (TRLs) from "basic levels observed and reported" (TRL 1) to "system/subsystem model or prototype demonstrated/validated in a relevant environment" (TRL 6). Components are not ready for flight until they reach TRL 9, "actual system 'flight proven' on operational flight." As components move up in TRL and are incorporated into full engine designs, some emission reduction potential is lost, so the final engine will not show the full 70% reduction in NOx. The time required to progress from TRL6 to TRL9 depends on the technology and can take from 5 to 25 years.

anticipated to be demonstrated in 2007 to 2010. NASA also has a Quiet Aircraft Technology (QAT) program for noise reduction.

The European Commission's research goal for aircraft engines is to reduce NOx by 60 percent from the CAEP/2 standard by 2008 (TRL 9) and 80 percent by 2015. The Commission's CO_2 goals are a 12 percent reduction relative to 1997 best-in-service by the year 2008, and a 20 percent reduction by 2015. It could take many years for the emissions benefits of these technologies to accrue, given the slow turnover in the aircraft fleet.

While the most dramatic improvements are available in new engines, the emissions characteristics and performance of older engines can also be improved through retrofit options such as high-pressure turbine nozzles, steam injection, and upgraded gas turbines. For example, in 1999, Pratt & Whitney developed and certified a retrofit combustor "E-kit" for the JT8D-200 engine utilizing TALON technology. Retrofit kits for other engines are also available.

Regulatory mechanisms for promoting the introduction of cleaner aircraft (such as emissions standards or emissions-based landing fees) are discussed in the next chapter. Even absent regulatory intervention, some technological advances naturally penetrate the aircraft fleet as older planes are retired and replaced. Newer aircraft typically have lower emissions of NOx, HC and CO per passenger seat than the aircraft they replace. However, given the current trend toward improving efficiency through increased engine cycle pressure ratios, engines now being designed and developed may have higher NOx emissions than those currently being introduced (unless there is also a change in combustor technology).

Most of the advances that reduce noise or noxious emissions have occurred at the same time as reductions in fuel burn. As pressure ratio continues to increase to further reduce fuel burn, measures to improve fuel economy will continue to be in conflict with measures to reduce noise and NOx, and vice versa. However, active research programs in Europe and the USA are aimed at demonstrating new combustor and engine design concepts that reduce NOx emissions substantially while improving fuel burn. If these are successful, technologies could enter service on production engines within the next ten to fifteen years. Existing technologies are also available to improve efficiency without a resulting NOx increase. For example, improving by-pass air ratio will simultaneously reduce NOx and fuel burn. Under current ICAO standards, however, NOx emissions are allowed to increase linearly with engine pressure ratio. Thus, the structure of the current regulations does not encourage simultaneous efficiency increases and NOx reductions.

Aircraft Design

Many of the improvements cited above are projected to be achieved using the existing "swept wing" aircraft body configuration, without making significant design changes to the aircraft body. By developing new aircraft body materials and improving aerodynamic efficiency, greater reductions in fuel use and emissions could be realized. For example, the B2 bomber and the Raytheon business jet have achieved radical reductions in weight through the extensive use (over 80%) of composite materials in those aircraft bodies. While these aircraft designs are unique today, they could become the industry standard in the future.

A number of options for reducing aircraft emissions and fuel burn have been proposed in a report entitled "Air Travel - Greener by Design, The Technology Challenge."[67] The report examines aircraft engine and body designs that offer considerable promise to reduce aircraft engine fuel consumption and criteria pollutants. Some conclusions of the report are summarized below:

- Absent regulatory pressure or government support, the Greener by Design study predicts an improvement of 30-35 percent over the next 50 years in fuel burn from improving efficiencies to the existing swept winged, turbofan powered aircraft.[68]

- Other technology could be introduced to improve the fuel efficiency of "swept wing" aircraft, but would require regulatory pressure and or/government support. In airframe technology, the application of hybrid laminar flow control (HLFC) offers reductions of 15 to 20 percent fuel burn. When applied to engine nacelles, HLFC can result in both noise and fuel burn reductions.

- High bypass ratio turbofan engines should be designed with substantially reduced NOx and CO_2 emissions.

- The trend toward larger aircraft provides an opportunity for a large flying wing, or blended wing-body, configuration. This configuration offers significantly greater aerodynamic efficiency and also greater structural efficiency, with the prospects of appreciably reduced operating costs. While aircraft with this design will not likely be available for years, work should continue to identify and resolve the key engineering issues. Figure III-1 shows a blended wing-body configuration.

- Kerosene is assumed to be the only likely aviation fuel in the next 50 years. However, it is envisaged that liquid hydrogen may eventually become available as an alternative. All aircraft configurations considered in the Greener by Design report could be adapted to liquid hydrogen. Substantial reductions in emissions could be realized with this fuel change.

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[67] Royal Aeronautical Society, Society of British Aerospace Companies, British Air Transportation Association, British Department of Trade and Industry, 2001.
[68] This is less optimistic than a report published by the Intergovernmental Panel on Climate Change (IPCC), *Aviation and the Global Atmosphere,* where a 40-50 percent improvement was predicted.

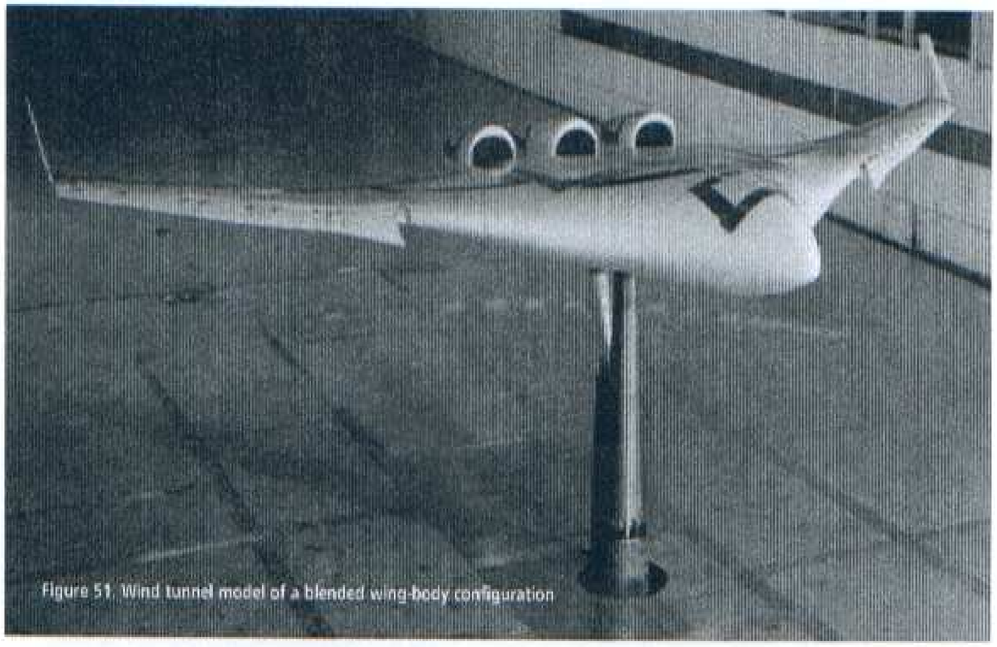

Figure III-1: Blended Wing-Body Aircraft Configuration

A report published by Arthur D. Little evaluated technologies for reducing aircraft emissions, both from aircraft engines and by re-designing aircraft bodies.[69] As part of the study, more than sixty technologies capable of enhancing aviation capacity and mitigating environmental impacts from aviation activity were evaluated. A subset of those technologies were chosen which provide environmental benefits. The report categorizes technologies as providing "substantial," "very significant," and "significant" emissions reductions. Table III-1 provides a summary of technologies listed in the report to control aircraft emissions, their environmental benefit, and the timeframe for adoption.

"Substantial" benefits are defined as providing up to 80 percent NOx reductions and 30 percent fuel efficiency gains. "Very significant" benefits provide up to 50 percent NOx reductions and 10 percent fuel efficiency gains, as well as a 20 percent reduced drag. "Significant" benefits provide up to 10 percent fuel efficiency gains, as well as criteria pollutant reduction benefits. The study estimated three timeframes for introduction: short term, medium term, and long term. Short term is defined as deployment before 2005, medium term as deployment from 2006 to 2015, and long term as deployment from 2016 to 2030. The engine technologies listed in Table III-1, such as staged conventional combustors and lean pre-mixed, pre-vaporized combustion technologies to reduce NOx, are all being considered as part of the UEET program mentioned earlier in this chapter. Airplane body changes, such as composite materials, blended wing body, micro-electro mechanical systems, and active laminar flow control systems, are designed to increase lift, and reduce airframe weight, drag, and turbulence.

[69] Arthur D. Little, "Study into the Potential Impacts of Changes in Technology on the Development of Air Transport in the UK," November, 2000

Table III-1: Summary of Technology Benefits from Arthur D. Little Study

	Short term (before 2005)	Medium term (2006 – 2015)	Long term (2016 – 2030)
Substantial Environmental Benefit	• Low NOx retrofit combustor	• Very high by-pass-ratio engines • Advanced surface movement guidance and control system	• Lean, pre-mixed, pre-vaporized combustion technology • Composite material primary structures incorporating latest aerodynamic concepts • Blended wing body
Very Significant Environmental Benefit	• Materials and turbo machinery improvements • Advanced material and cooling NOx reduction technology • Staged conventional combustors	• Staged lean burn combustor • Geared fan engines • Direct/free routing	• Active laminar flow (control) systems
Significant Environmental Benefit	• Very high frequency datalink	• Engines to generate electricity • Arrival management system • Departure management system • Automatic dependent surveillance broadcast for parallel runways	• Micro-electro mechanical systems

In sum, engine and aircraft designers can make choices as they move forward to improve efficiency and simultaneously reduce noise and NOx emissions. Researching and developing engines with increased bypass ratio is one approach. Taking steps to improve aircraft structurally and aerodynamically will also improve efficiency and simultaneously lower criteria pollutants. Structural and aerodynamic designs being discussed by the industry include blended wing-body, turbo engine fans, and the development of a wholly laminar flying wing. These designs have the potential to make quieter aircraft with decreased fuel burn and substantial NOx emissions reductions. New engine emission standards that encourage a move toward increased efficiency *and* reduced fuel consumption are needed in order to signal to the industry the importance of developing engines that meet both goals.

In addition to engine technologies, Table III-1 also includes technologies that can reduce aircraft taxi and idling times by improving the management of aircraft traffic on the runway. These technologies could augment operational measures discussed in the next section to reduce aircraft emissions associated with taxi and idling time. For example, advanced surface movement guidance, very high frequency (VHF) datalink, arrival and departure management systems, and automatic dependent surveillance broadcast systems are technologies that can reduce aircraft taxi and idling times by making the on-airport movement of aircraft more efficient. The technologies facilitate a constant rate of passage in all weather conditions, improve aircraft guidance and routing, coordinate the aircraft queue for take off, provide faster and more direct communication between air and ground crew, and optimize ground traffic flow in and around the terminal maneuvering area. Operational measures are further discussed in the next section.

B.2 Operational Options

A variety of options for reducing aircraft emissions are available which do not involve changes to current engines or aircraft design. These options generally fall into three categories:

- Improving airlines' overall operational efficiency (in terms of emissions per passenger served),
- Reducing taxi time, and
- Reducing power output during taxi, takeoff and landing.

Improving Airline Efficiency

Airlines can improve their operational efficiency by maximizing the number of passengers on each flight, thereby minimizing emissions per passenger. Airlines already have a strong profit incentive to increase their "load factors" – the percent of occupied seats on a given flight. For example, a single flight serving more passengers on a larger airplane may reduce emissions – and airline costs – compared to multiple flights using smaller airplanes to serve the same route. However, other considerations often apply, such as the desire to provide customers with frequent flight options. Depending on how landing fees are structured, it may also be more expensive in some cases to land one large airplane compared to two smaller craft. Beyond improving load factors, airlines could reduce emissions per passenger by managing their fleets to maximize the use of their cleanest aircraft, particularly into heavily trafficked airports that are especially susceptible to delays. The opportunity for this type of optimization depends on the size and diversity of a given airline's fleet.

Reducing Taxi Time

As discussed in Chapter II, aircraft emissions of CO and HC tend to be particularly high during taxi-in and taxi-out, when aircraft engines are operating at less than maximum efficiency. Hence, operational changes that reduce aircraft idling and taxi time can directly reduce pollutant emissions. A variety of options exist for reducing taxi time. For example, so-called "dispatch towing" – especially with high-speed tugs – can be used to move aircraft between the terminal gate and runway more efficiently and with fewer frequent stops than with standard practices. Since taxi-out time tends to be longer than taxi-in time, this option is likely to be most feasible on departing flights. Potential emissions benefits for this option are somewhat offset by additional emissions from the tow tug engine (unless it is electric powered) and from continued operation of the aircraft's APU for ventilation and electricity during towing.

Taxi time can also be reduced by airport designs that allow planes to stay close to runways between landing and takeoff. This can be accomplished by decentralized gate designs wherein passengers are brought to and from the aircraft by other transport vehicles. For example, Dulles International Airport near Washington, DC was originally designed to work this way. Again, the resulting reduction in aircraft emissions would be somewhat offset by increased emissions from ground passenger transport vehicles.

A broad set of congestion reduction measures can be used to further reduce aircraft taxi time. Such measures can include gatehold procedures that keep planes at the gate until they are ready for takeoff, thereby limiting unnecessary idling time on the runway. Widening, extending or building new taxiways can help reduce intermittent stops, increase access between taxiways, and allow for more direct taxi routes. Taxi turnouts designed to allow aircraft to enter or exit the runway at higher speeds can also reduce stops and expedite clearing of the runway to minimize delays. Another option that may be appropriate, provided safety concerns can be addressed, is allowing aircraft to access the runway at the intersection of the taxiway and the runway, as most aircraft do not need to use the full length of runway for takeoff.

In addition to congestion reduction measures on the ground, strategies to address in-air congestion can help reduce delays and unnecessary taxi time by minimizing the time that departing aircraft spend waiting for incoming aircraft – which have priority – to land. Strategies for reducing in-air congestion include using separate runways for commercial and smaller aircraft, which operate at lower speed, and reducing the longitudinal separation between inbound and outbound flights in the air to maximize the rate at which airplanes can leave and enter the airport vicinity.

The Arthur D. Little study summarized above described a number of technologies which, if introduced, could facilitate operational efforts to reduce taxi and idling times. These included: arrival and departure management systems, the A-SMGCS system, the automatic dependent surveillance broadcast (ADS-B), data-link flight information service, runway management system, and surface management system. The systems are designed to allow for aircraft movement rates under all weather conditions and to optimize traffic flow.

Minimizing Engine Use

A third category of operational strategies to reduce aircraft emissions involves minimizing engine use, particularly in inefficient, low-power modes during taxi and landing. For example, most large aircraft have two to four engines, one or more of which can be shut down during taxi. This not only reduces emissions, but allows the remaining engines to operate more efficiently at higher RPM, resulting in fuel savings, as well as lower HC and CO emissions per pound of fuel consumed. Potential reductions from this relatively simple measure are highest for departing flights, which generally have longer taxi times than incoming flights. Airports that encourage this practice, such as Heathrow Airport in the United Kingdom, typically leave it to the pilots' discretion, as shutting down some engines can reduce aircraft control and may be infeasible under certain conditions or with certain aircraft. In addition, it is necessary to take into account the fact that engines must be run two minutes prior to take off to achieve thermal stability and two minutes after landing to cool down.

A related measure that can help to substantially reduce NOx emissions is "derated takeoff," wherein engines are not set to full power during takeoff. Typically, full engine thrust is only needed under extreme conditions, such as in hot weather or with a heavily loaded plane, and engine thrust can be safely reduced from the maximum during takeoff.[70] Again, this option is relatively simple to implement, but may be constrained by other considerations, such as the need to clear the runway quickly to avoid congestion, or to follow a steep flight path to minimize noise impacts on surrounding communities. Engine power and emissions can sometimes also be reduced during landing by minimizing the use of reverse thrust to help slow the aircraft. On larger, heavier planes and at airports with relatively shorter runways, engines are often run near full power with the thrust reversers engaged during landing. This can produce substantial NOx emissions. Safety, runway length, and airport design (some airports require aircraft to slow significantly before exiting the runway) are key considerations in implementing this option. In addition, most pilots – in an effort to land the aircraft smoothly – will use as much of the runway as possible instead of forcing the plane down earlier. This promotes heavier use of reverse thrust. Air carriers have stated that they currently minimize engine use when feasible, but little data on the use of these techniques is available, so the extent to which further introduction of these measures is possible needs further exploration.

An approach currently being discussed to reduce aircraft emissions is improvement to the National Airspace System (NAS) with a focus on improvements in the Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM). CNS/ATM offers a number of operational measures to reduce aviation emissions. In the U.S., the airline industry is focusing on the concept of "Free Flight"[71] for its CNS/ATM modernization. Free flight would reduce the amount of air traffic control restrictions placed on flight routes and would allow wind-optimized cruise trajectories and altitudes, and more efficient surface traffic operations. In recent years, free flight has become technically feasible with advances in information systems. An FAA report estimated that 10 billion pounds of fuel could be saved in 2015 with National

[70] In addition, FAA requires one full throttle takeoff per month to ensure that the engines are capable of full thrust if necessary.
[71] In "free flight," operators have the freedom to select their path and speed in real-time. Restrictions are placed on some aspects to ensure separation, to preclude exceeding airport capability, and to ensure safety, among others.

Airspace System (NAS) modernization.[72] This would translate to an annual reduction of 209 million pounds of NOx, 211 million pounds of CO, and 59 million pounds of HC; these are reductions of over nine percent, 12 percent, and 18 percent, respectively. Most of the savings would occur above 3,000 feet in altitude (up to 94 percent); however, the proposed operational changes would still reduce approximately four million pounds of NOx below 3,000 feet in 2015 according to the FAA study.

Table III-2 shows the costs per ton of NOx, HC, and CO reduced for some of the operational measures described above.[73] These measures are inherently cost effective (reduced operating costs result in an overall cost savings), even before taking into account the reductions in pollutants that occur as a result of the operational changes. As would be expected, reductions in HC and CO are greatest for those measures that reduce idling time. Similarly, reductions in NOx are greatest for those measures that reduce full load engine operation.

As is discussed in the next chapter, more stringent engine emission standards could provide an impetus for further substantial improvement in the emissions performance of new aircraft engines. However, EPA has historically deferred to ICAO in setting standards, and while the EPA has authority to establish new engine standards, it must coordinate with FAA on the level of control proposed. Of the measures available to state and local authorities, the most likely to be implemented as "retrofit" measures at existing airports are aircraft towing, congestion reduction, reduced engine taxi, and derated takeoff. Each of these measures has very low costs which are more than paid back in operational costs savings. In each case, the high volume of aircraft traffic through many airports means that the relatively small percentage emissions reductions achievable from each measure on a per-flight basis translate into large potential emissions reductions in aggregate. Importantly, these types of strategies can also be implemented at airports without the need to make major changes to current structures and systems. Indeed, all of them have been implemented to some extent at certain airports, though the extent to which they are routinely practiced is unknown. Many other measures mentioned in this section will be feasible only for new airports, where they can be incorporated into airport design. Those that require changes to the aircraft fleet or to airline schedules will have to be examined in the context of cost and customer service constraints.

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[72] FAA, "The Impact of National Airspace System (NAS) Modernization of Aircraft Emissions", September 1998

[73] Information for Table III-2 comes from EEA 1994 and EEA 1997. Emission reduction percentages were calculated in several steps. First, emissions for one aircraft (a Boeing 737 or 767 in most cases) were calculated for baseline and controlled cases. Emissions were calculated as the product of emission factor (lb pollutant/lb fuel), fuel consumption (lb fuel/minute), and time in mode for one phase of the LTO cycle (standard time or adjusted time for the control measure). Percent reductions were calculated as controlled emissions minus uncontrolled emissions as a fraction of uncontrolled emissions. Emissions reductions reported in the table are for one aircraft operating in the effected phase of the LTO cycle.

Table III-2: Operational Options for Reducing Aircraft Emissions

Option	NOx emissions reduction	HC emissions reduction	CO emissions reduction	Other Benefits	Costs (NOx + HC + CO reductions)
Dispatch Towing	0.5-1%	0.2-5%	2-5%	Reduces fuel consumption; may also help reduce ground congestion (especially if high speed tugs are used).	Lower fuel costs result in reduced operational costs, thus emissions reductions accrue for free.[74]
Decentralized Gates	3%	10%	10%	Reduced fuel consumption.	"
Ground Congestion Reduction Measures	3%	10%	10%	Reduced fuel consumption and travel delays for passengers; more efficient airport operation.	"
Reduced Engine Taxi	10%	30%	30%	Reduced fuel consumption; simple to implement.	"
Derated Takeoff[75]	10%	0%	0%	Reduced fuel consumption; simple to implement.	"
Reduced Reverse Thrust	5-10%	<1%	<1%	Reduced fuel consumption; simple to implement.	"

[74] While aircraft operational costs can be expected to decrease, some of these measures could increase capital costs. For example, use of decentralized gates could require airlines to provide shuttle services between the terminal and the aircraft. These potential costs are not included in the above table.
[75] In some cases derated takeoff may already be the norm; anecdotal information supplied by air carriers indicates that many airlines already practice derated takeoff. In addition, while derated takeoff is cost effective as a control option, barriers besides cost exist.

C. Options for Reducing Ground Support Equipment (GSE) Emissions

As mentioned in Chapter II, airport ground support equipment is comprised of a wide variety of machines used by airlines and airports to service aircraft during ground operations and to maintain runways. Table II-14 describes the variety of equipment operating at airports and their functions. Four types of equipment dominate the GSE population: aircraft push back tractors, baggage tugs, baggage belt loaders, and tool carts. At the three airports studied, GSE accounted for nine percent of total aircraft emissions (excluding APU emissions).

The first emissions regulations for engines used to power diesel GSE were introduced for model year 1996.[76] Gasoline GSE emissions remain unregulated, although EPA finalized a rule in 2002 which will require significant reductions in gasoline GSE emissions when the rule is fully implemented (full fleet turnover will take about 30 years).[77] The new standards will phase-in between 2004 and 2007. Since emissions regulations for gasoline engines do not yet exist and relatively few diesel engines are controlled, large reductions from GSE emissions are possible as a cost-effective control option.

C.1Technology Options for Reducing GSE Emissions

This section discusses three approaches to reducing GSE emissions: (1) replacement or re-power of diesel and gasoline powered machines with alternative fuels such as natural gas, propane, or electricity; (2) gate electrification to reduce GSE, GPU, and APU use; and (3) retrofitting machines in existing fleets with emission control devices. The options discussed in this section include those currently being used to reduce emissions. No advanced technology options, such as hybrid electric GSE or fuel cells, are discussed here; while these technologies will likely be available in the near future, they are currently in the design or prototype stages.

Alternative Fuels

Three types of alternative fuels have been used at airports to reduce GSE emissions: propane (liquefied petroleum gas or LPG), compressed natural gas (CNG), and electricity. Converting gasoline or diesel powered GSE units to alternative fuels or electricity can achieve substantial emissions reductions. This option has been implemented at a number of airports to help meet ambient air quality standards in the area and to protect the health of airport employees and customers. In the past, baggage handler associations complained that workers are exposed to diesel and gasoline emissions while working in enclosed spaces. Sometimes GSE exhaust fumes enter the terminal, where they can affect other airline personnel and passengers; this has been the case at airports in New York and Denver, prompting airport authorities to promote fuel switching of GSE units at these locations.[78]

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[76] EPA, "Control of Air Pollution; Determination of Significance for Nonroad Sources and Emission Standards for New Nonroad Compression Ignition Engines at or Above 37 Kilowatts," June, 1994.
[77] EPA "Control of Emissions from Nonroad Large Spark Ignition Engines and Recreational Engines (Marine and Land-based), Final Rule, November, 2002.
[78] Arcadis, Geraghty & Miller, 1999

Compressed Natural Gas and Liquefied Petroleum Gas Replacement of Conventional Engines

Conversion or replacement of conventionally-fueled GSE machines with LPG or CNG can provide significant emissions benefits. Purpose-built CNG and LPG equipment are available as are conversion kits. For gasoline-powered equipment, conventional engines are able to use alternative fuels by replacing the existing carburetor or fuel injection system with a new system capable of handling CNG/LPG. Existing fuel tanks are replaced with high pressure tanks for CNG or low pressure tanks for liquefied natural gas (LNG). Modifications are also made to the engine controls.[79] Since diesel engines cannot be converted entirely to alternative fuels (as they do not have spark plugs) they are generally converted to dual fuel vehicles, which run 20 percent of the time on diesel and 80 percent of the time on alternative fuels.

The chief constraint in switching GSE to lower emissions fuels is the up-front capital cost of modifying existing gasoline or diesel engines to run on a different fuel, or the cost of purchasing new, dedicated alternative-fueled equipment.[80] In addition, installing alternative fuel facilities (especially in the case of compressed natural gas) requires significant capital outlay. Typically, it is far more costly to convert diesel-powered equipment than gasoline-powered equipment because the former requires the substitution of a modified engine (as mentioned above). Generally, diesel engines are not converted for this reason. Conversion costs for belt loaders and baggage tractors to LPG cost about $1,700. For aircraft push back tractors the cost is approximately $2,700. Conversions of gasoline powered GSE to CNG costs approximately $5,000 while the incremental cost for purpose-built CNG ground service equipment is approximately $30,000.[81] Additional costs for refueling and storage infrastructure also apply to CNG or LPG alternatives. LPG systems require pressurized tanks and CNG refueling infrastructure involves high-pressure storage units, electric-powered compressors, and a dispenser system. Accommodating this infrastructure may be complicated by space constraints at some airports and by additional safety and maintenance considerations.

CNG stations provide compressed natural gas for vehicle refueling (the gas is under pressure of 3,000 pounds per square inch, or "psi"). There are two types of stations: slow-fill and fast-fill. Slow-fill stations are less expensive but require fueling to take place overnight. The fast-fill method allows for re-fueling within an hour. A fast-fill station that can refuel 50 pieces of GSE equipment costs approximately $750,000. LPG uses a different system, in which the fuel is delivered to refueling stations in a liquid form and is kept in pressurized, insulated storage tanks.

Once installed, both CNG/LPG engines are often less costly to maintain and last longer, requiring less-frequent routine service than conventionally fueled engines. This is because diesel and gasoline contain contaminants that build up in the cylinders and exhaust system, and therefore

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[79] The fuel to air ratio is typically leaner for CNG than for gasoline vehicles. Because the compression ratio cannot be changed, converted gasoline engines are less efficient than dedicated natural gas engines. These factors lead to increased fuel costs and emissions (over dedicated CNG/LPG engines). Converted engines are sometimes calibrated rich rather than lean.

[80] Note that new, "dedicated" vehicles designed to maximize performance on alternative fuels typically produce greater emissions benefits that converted conventional vehicles. If conversions are not properly installed emissions can increase from the conventional systems. Because demand for alternatively-fueled vehicles and engines has been minimal to date, dedicated machines have not been developed at mass production levels and incremental costs are high relative to their conventional counterparts.

[81] The costs in this section come from the Energy and Environmental Analysis report of 1994

require more maintenance and overhauls than GSE using alternate fuels. Another area of savings is in fuel costs. For example, LPG cost is typically half that of gasoline. On the other hand, a significant drawback for some alternative fuels is the need for more frequent refueling.[82] Finally, the emissions benefits of some conversions or replacements may be mixed. For example, conversion kits that result in an engine running rich rather than lean can increase HC and CO emissions.[83] By contrast, the on-site emissions benefits of electrification are always positive and can be significant, especially since no power is used and no emissions are generated during idling.

Table III-3: Cost Effectiveness of CNG/LPG Equipment Use

Measure	NMHC emission decrease	CO emission decrease	NOx emission decrease	Cost Effectiveness[84]
CNG/LPG replacement of Diesel	30% (for properly calibrated, closed-loop systems)	30% (for properly calibrated, closed-loop systems)	65%	\$1,000 – \$3,000 per ton of VOC/CO/NOx combined
CNG/LPG Conversion from Gasoline	50% – 70%	45%	25%	Cost of conversion is more than covered by fuel cost savings over several years

Source: EEA 1997

Table III-3 summarizes the cost benefits in terms of tons of pollutants reduced for switching from gasoline or diesel to CNG/LPG. For the purposes of this calculation, CNG and LPG reductions were considered the same.[85] The analysis shows that conversion of gasoline to CNG or LPG provides a benefit due to fuel savings and lower maintenance costs. Replacement of diesel machines with CNG/LPG costs between \$1,000 and \$3,000 per ton for the combined pollutants reduced. In both cases, replacement of conventional equipment with CNG or LPG provides a cost effective emissions benefit. It should be noted that this cost-benefit analysis assumes that all CNG and LPG engines are the most recent available, are properly calibrated, and are closed loop systems. The

[82] More frequent refueling may be necessary because CNG/LNG has lower energy content per volume than gasoline or diesel. In addition, converted engines may be less efficient. For example, the compression ratio of an internal combustion engine designed to operate on gasoline cannot be modified, resulting in less efficient operation when the engine is converted to operate on CNG.

[83] Generally, however, the use of new closed-loop systems will reduce NOx, NMHC, and CO emissions. Furthermore, the addition of an oxidation catalyst to a CNG engine will virtually eliminate all CO and HC emissions. These technologies will be discussed in the next section.

[84] This analysis does not include costs for fueling infrastructure.

[85] This method may underestimate the emission reductions achieved by using CNG since there are no refueling emissions associated with CNG but there are with LPG.

emissions benefit could be much lower with some older, poorly-calibrated CNG and LPG equipment.[86] The analysis does not include the cost of fueling infrastructure.

Electric GSE

Ground service equipment is either purpose-built for electric power, or can be converted to electric power. Successful examples of both approaches can be found in the U.S. and in Europe. In electric GSE, conventional engines are substituted with electric motors and fuel tanks are replaced with lead acid batteries. Electric aircraft tugs, potable water carts, baggage conveyor belts, and other machines are commercially available. The benefits of electric GSE include the elimination of on-airport GSE emissions, noise, and the odor associated with gasoline or diesel machines. The costs associated with the use of electric equipment include installation of recharging units, incremental costs associated with the purchase of purpose-built electric GSE or conversion of conventional equipment, battery replacement, and mechanics and operator training.

The initial cost of purchasing dedicated electric GSE – which is, for example, 27 percent higher for an electric baggage tractor with batteries than for a diesel – is largely offset by fuel and maintenance costs savings over the lifetime of the machine (assumed to be 8 to 10 years, depending on the type of equipment). Some types of GSE, such as belt loaders, have an even lower incremental cost and thus a shorter payback time than baggage tractors. The maintenance needs of electric equipment are very different than their conventional counterparts. Electrical equipment requires very little routine service other than maintaining the battery's water and acid levels. Every 3,000 to 6,000 hours, however, lead-acid batteries must be replaced. Battery technology is improving, however, and alternatives to lead-acid designs tend to have longer lifetimes, although the initial cost is still significantly higher.

The cost of charging infrastructure should be included in any cost effectiveness calculation, as in the current analysis. Airport operators can choose from a number of types of charging infrastructures, including slow and fast charging, which will impact the cost of the conversion. Slow charging is the least costly option, but can require up to 8 hours of recharging time, while fast recharging can take 45 minutes. While the fast charging systems are more expensive, they have collateral benefits which should be considered, such as the convenience of periodic "opportunity" charging and the ability to increase battery life by as much as 300 percent. Slow charging can require the installation of more power stations since nearly all machines will need to be charged at the same time. To offset the costs of electric charging infrastructure, some companies are offering fast charging services which include design, start up, maintenance, and service over several years.

Table III-4 presents an analysis comparing the cost effectiveness of replacing diesel and gasoline GSE with electric GSE. The Nonroad Electric Vehicle Application (NREVA) lifecycle cost model, used for this analysis, was developed Energy Resources Group and Boston Systems and Solutions for the Electric Power Research Institute in 1997. The NREVA inputs include energy costs, tax rates, capital and operating vehicle costs, and charging infrastructure costs. Some of the assumptions of the model include:

[86] It should be noted that the costs reported for the use of CNG or LPG varied considerably among the Arcadis and EEA reports. However, improvements in CNG and LPG engine calibration have considerably improved emissions. Thus, all costs cited here represent costs associated with purpose-built and properly-calibrated engines.

- Electric vehicle charging takes place two times a day: 4 hours during peak times and 4 hours during non-peak times, so as not to under or overestimate costs associated with recharging.

- Extra battery needs and costs are estimated for individual equipment based on ERG/EPRI airport interviews.

- Tax data was taken from the U.S. Statistical Abstract and gasoline and diesel fuel prices from the U.S. DOE.

- Outputs are annualized in dollars per year for vehicle costs, charger, additional batteries, electric equipment, maintenance, and amortized capital costs of taxes.

- Electric costs are based on Southern California Edison rates.

- The model assumes that electric equipment lasts two years longer than conventional equipment. As a result, battery costs are amortized over a longer period than if the assumption is made that they operate for the same amount of time as diesel and gas machines.

- Assumes approximately 4,000 gallons of gasoline or diesel are used each year per piece of equipment.

- Emissions associated with power generation are not included.

- Horsepower, load factor, lifetime, and annual hours of use come from the ARB OFFROAD model.

While Table III-4 does not have columns for all of these inputs and assumptions, they are imbedded in the model calculations.

The Arcadis study concluded that certain types of electric equipment cost significantly less to purchase and operate than diesel or gasoline equivalents. For others, such as baggage tractors and diesel aircraft tugs, emission reduction cost ranged from $1,900 to $5,800 per ton. A cost of $1,900 per ton of NOx reduced is considered cost-effective according to the EPA guidelines established as part of the Ozone Transport Assessment Group (OTAG) process. It is important to note that the Arcadis study did not take into account electric utility emissions associated with the use of electric GSE. In some regions of the country, including the Northeast, including these emissions would somewhat reduce the emissions cost effectiveness of using electric GSE. Thus, a calculation of *net* emissions benefits at the regional level would have to account for the sources of power used and the efficiency of power generation, distribution, storage, and use.

Table III-4: Cost Effectiveness in Dollars per Ton of NOx Reduced for Electric GSE

Equipment	Fuel Type	ICE maintenance costs ($/year)	Electric replacement maintenance costs ($/year)	Total Cost Differential ($/year)	Annual NOx reduction (tons/ unit)	Lifetime NOx emission reduction (tons)	Cost Effectiveness ($/ton)
Baggage Tractor	Gasoline	1,461	1,472	794	0.4	3.4	1,900
	Diesel	1,461	1,411	1,337	0.2	2.4	5,800
Belt Loader	Gasoline	908	1,060	-668 [(a)]	0.2	2.1	Life-cycle cost Savings[87]
	Diesel	908	1,060	-1,182	0.1	.8	Life-cycle cost Savings
Aircraft Tug	Gasoline	4,116	4,237	-810	0.8	5	Life-cycle cost Savings
	Diesel	4,116	4,152	1,470	0.5	5.3	2,800

[(a)] A negative cost differential shows that the electric option costs less than the diesel/gasoline option.

Source: Arcadis, 1999

As mentioned above, several hundred electric GSE are in use at airports around the county. Tug, Charlatte, and other manufacturers offer a variety of purpose-built electric GSE. In programs developed by Delta, Southwest, and other airlines, GSE operators reported that, overall, electric GSE for baggage tractors and belt loaders performed as well as their diesel or gasoline counterparts. However, some types of GSE, such as tugs, are still not fully commercialized. At this time, a prototype aircraft tug is able to tow the heaviest of aircraft but for the most part, existing electric aircraft tugs can only handle the lighter aircraft. For other types of equipment, heavy or sustained load operation required by GPUs and some freight applications has not been fully proven with electric GSE.

Gate electrification to reduce GSE and APU use

Besides reducing emissions from individual GSE units, a number of options exist for minimizing the use of this type of equipment in the first place. So-called "fixed gate" designs can allow many of the services currently provided by mobile GSE to be provided by gate-based electrical equipment including:

[87] Life cycle cost savings indicates that maintenance and fuel costs savings over a period of 8 – 10 years more than offset the incremental cost of purchasing the electric equipment.

- Toilet disposal and fresh water delivery,
- Food catering,
- Baggage delivery from a conveyor belt system rather than mobile tractors, and
- Refueling from a gate-based hydrant and filter system rather than a fuel truck.

Full incorporation of these systems can result in a "vehicle-free gate," largely eliminating on-site emissions from mobile GSE.[88] In addition, fixed gate designs can significantly reduce emissions from the aircraft APU and from ground power units (GPU) by allowing gate-based power and air hook-ups to supply energy directly to the aircraft. To implement this option, power must be converted from the type the utility supplies to the type that the aircraft uses. Different systems can be used to distribute power to terminal gates including:[89]

- Centralized fixed power and preconditioning systems,
- Point-of-use pre-conditioned air and power systems,
- Mini-central fixed power systems (electricity only), and
- Pneumatic power (air-conditioning only).

Centralized power and preconditioning systems include a centrally-located power supply or air-conditioning unit. Wiring or hoses are then connected from this unit to the individual gates to provide power or air conditioning throughout the airport. This type of system has the advantage of handling many aircraft and widely varying power loads.

Provided the fixed system is capable of supplying all the aircraft's electrical and air conditioning needs (not currently the case for most fixed systems in use today), APU use could be reduced from an average of 45 minutes per layover to approximately 7 minutes for a narrow body jet and from 120 minutes to 7 minutes for a wide-body jet,[90] with corresponding emissions reductions. Obviously, implementation of any of the above systems would require an up-front capital investment, but once installed, fuel and labor savings and other efficiencies generated by fixed gate systems tend to result in a relatively short payback time (less than 2 years). As an example, point-of-use gate based power provides a cost savings in fuel of $29 per hour over APU use. As a result, this system pays for itself in just over one year. For every year afterward, the airport receives both economic and emissions benefits. Besides their emissions and cost benefits, fixed-gate systems provide a number of other benefits: they are less obtrusive, reduce GSE-to-aircraft accidents, require

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[88] Some of these systems are largely intended for new terminal construction and can be extremely difficult to retrofit into existing terminals. A baggage conveyer belt is such an example.

[89] Specific codes and operational regulations that will affect the installation of such systems vary by airport. In addition, implementation of some systems may require changes to gate design or terminal layout, which may in turn be complicated by zoning and building regulations. Fully centralized power systems, for example, are difficult to install because all gates must be wired to a central location. However, mini-centralized systems may have difficulty managing widely varying power loads while point-of-use systems may have difficulty handling large loads.

[90] APUs must be run about 5 minutes prior to departure to conduct an initial flight check and to start the main engines, even if a fixed power system is used.

less fueling and little maintenance, and can significantly reduce the complexity of ground service operations.

Not all airports, however, are able to install fixed gate power. In some instances, providing power systems can be difficult for airports with power limitations on their incoming cable. Furthermore, the retrofit of fully centralized systems may be hindered by existing terminal architecture, and in these cases, centralized systems will be better suited to new terminal installation. Retrofit problems are less likely with mini-centralized and point-of-use systems. However, these two types of systems are not always able to handle widely varying loads or the largest aircraft.

Even with these constraints, fixed gate power and preconditioned air can be installed in existing and new buildings. Because of the cost, emissions, and operational benefits, gate based electrical power and air conditioning are already in widespread use. Several large airports including Los Angeles, Phoenix, and Boston have replaced up to 90 percent of APU-based power generation with fixed gate power.

Experiences with Alternate-Fuel GSE

Many airports have already begun to use alternate fuel GSE technology. The 1999 Arcadis study details a number of these efforts. Although none of the airports examined have information on emission benefits specifically stemming from the new GSE projects, they have useful information on costs and cost effectiveness. In general, commercially-available, electric ground service equipment performs well and has lower maintenance and fuel costs than conventional equipment. A number of examples from the Arcadis study are summarized.

Southwest Airlines at Sky Harbor Airport, Phoenix, Arizona

Southwest Airlines replaced some traditional systems with electric equipment. The airline uses electric baggage tractors, belt loaders, and narrow body aircraft tugs. With a fast-charging system called Electrix, charging time for baggage tractor batteries is reduced from 8 hours to 45 minutes. Short charging periods permit rotation of equipment being charged, requiring less space than a slower system would. Although the models of electric GSE used by Southwest are more expensive than conventional ones, the company believes that most have proven to be cost-effective. The baggage tractors and belt-loaders compensate for high initial costs by savings in fuel costs. The fast-charging Electrix system is more expensive than a conventional charger, but the installation cost is lower because it requires less modification to the existing system. A study commissioned by Electrix found that the cost benefit for the fast charging system over a conventional one is about $4/truck/day.

Southwest Airlines at Ontario International Airport, Ontario, California

Southwest Airlines' Ontario project is similar to the project at Sky Harbor. The airline electrified baggage tractors, belt loaders and aircraft tugs. No major infrastructure changes were necessary to install a charger system. Results of the conversion were similar to those at the Phoenix airport. The baggage tractor and belt loader performed well, while the aircraft tug proved to be cost-ineffective despite fuel cost savings. As discussed earlier, although electric vehicles and fast charging systems are more expensive than conventional ones, fuel savings and extended battery life makes the new systems most cost-effective.

United Airlines and the South Coast Air Quality Management District at Los Angeles International Airport, Los Angeles, California

United Airlines developed an electric aircraft tug with a large towing capacity and an inductive charging system for smaller electric tugs already being used by the airline at LAX. The tug uses an inductive charging system composed of a charging port and a charging station at a tug's parking space. The use of the electric tug required no infrastructure changes, while the inductive charging system required the installation of a charging system and the modification of tugs that would use it. The commercial version of the electric tug might cost between $50,000 and $125,000, depending on performance requirements and the size of the order.

Delta Airlines at Atlanta-Hartsfield International Airport, Atlanta, Georgia

Delta Airlines purchased 70 electric baggage tractors in 1996. The airline charges the tractors' batteries overnight. This more conventional charging system is satisfactory because the equipment is only operated 9-10 hours a day, which leaves sufficient downtime. The cost of each tug is approximately $25,000 excluding the battery. A conventional equivalent costs between $16,000 and $19,000.

American Airlines and Toyota Industrial Equipment Partnership

As a part of American Airlines' goal to electrify all of its GSE by 2010, the airline is working with Toyota in a 10-year partnership to provide electric forklifts on three-year leases. Airport operators are trained to charge the forklifts whenever they are not in use; this type of "opportunity charging" allows charging whenever it is convenient. The partnership decided to install one charger for each forklift. Although the total cost of the program has yet to be determined, the airline expects cost savings because of decreased maintenance.

Retrofit and Fuel Improvement Options

As noted previously, the current GSE fleet is comprised primarily of diesel and gasoline engines, with a small percentage of propane and CNG engines. This section discusses retrofit devices that are attached in the exhaust stream (usually as a replacement muffler) to control emissions. Retrofit devices include oxidation and 3-way catalysts, as well as particulate filters. In addition, alternate diesel fuels that work alone or in conjunction with the retrofit control technologies will be mentioned in this section.

Oxidation catalysts can be applied engines that run "lean," such as diesel and natural gas engines, to oxidize HC, CO, and PM to CO_2 and H_2O. Emissions of CO and HC can be reduced by as much as 90 percent, and an approximate reduction of 24 percent is seen in PM emissions. The cost for oxidation catalysts is approximately $7 per hp, or, on average, about $1,000 for a catalyst that would fit a typically sized GSE.[91] Oxidation catalysts can be retrofitted onto most highway and nonroad engines with little or no customization beyond sizing the catalyst. One limitation, however, is that catalysts may not be appropriate for machines in a state of poor maintenance or those that idle a substantial amount of time. Approximately 2 million oxidation catalysts have been installed on highway diesel vehicles, and several thousand on nonroad machines, to date. The technology is fully

[91] Personal communication with the Manufacturers of Emission Controls Association (MECA).

commercialized. While oxidation catalysts have been used most often to control diesel emissions, they can be used on natural gas engines to reduce HC and CO emissions.

Particulate filters for diesel engines can virtually eliminate particulate emissions. The filters trap both the soluble and the carbonaceous particles in a ceramic honeycomb and the particulates are burned to form CO_2 and H_2O by either “passive” or “active” regeneration. In passive regeneration, the exhaust temperature alone heats up the ceramic honeycomb to a level sufficient to burn off the trapped soot.[92] In active regeneration, an outside heat source, such as an electrical burner, is used to heat the ceramic and induce regeneration. Active systems are appropriate for those machines with cool exhaust temperatures or for machines that idle frequently. If active regeneration systems are used indoors, venting of the gases is necessary. Particulate filters cost $14 per horsepower, or approximately $3,000 to $5,000 per unit. Over 2,000 filters have been installed to date on nonroad machines, largely in the mining and materials handling sectors to meet mining and occupational health safety standards.

Finally, another approach to reduce diesel emissions is the use of water emulsion fuel. CARB has verified one product, PuriNOx, for use in diesel engines. The company that manufacturers PuriNOx (Lubrizol) is currently working with EPA to verify its product under the EPA retrofit program. Once verified, states will be able to claim SIP credits for NOx reductions resulting from the use of PuriNOx in diesel engines. Emulsified diesel reduces NOx emissions by 20 percent and particulates by 40 percent. Emulsified diesel fuels work by lowering combustion chamber temperatures and by improving fuel dissipation in the combustion chamber, thereby reducing the amount of unburned fuel and particulate that is produced. Diesel emulsion fuel can replace regular diesel fuel with no mechanical changes to the engine. Emulsified diesel fuel is available in most of the U.S. and costs approximately 10 percent more than diesel fuel.

While diesel engines can be equipped with oxidation catalysts to reduce PM, CO, and HC emissions, gasoline engines can be equipped with 3-way catalysts such as those used in automobiles to control NOx, HC, and CO pollution. These catalysts are designed to operate in the rich environment of spark-ignited engines. Tens of millions of 3-way catalysts have been installed in motor vehicles to meet exhaust emissions standards over the last 25 years. The same technology can be used in nonroad gasoline machines to reduce NOx, HC, and CO. Under optimum conditions, a 3-way catalyst can reduce these pollutants up to 70 percent. 3-way catalysts can be installed for approximately $500 per unit on most engine models. For some engine configurations, the retrofit of existing engines with 3-way catalysts may also require changes to the fuel system to ensure that the engines run at stoichiometry (balanced air/fuel ratio). These changes would increase the cost of retrofitting from $500 to $1,500 per machine. In either case, retrofit with 3-way catalysts would be an extremely effective control option given the low cost of installation and the large emission reduction benefits that can be achieved.

[92] Temperatures of 300 degrees centigrade are needed during 25 percent of operating time in order for passive regeneration to work. Passive filters will only work on those machines with fairly high load factors.

D. Options for Reducing Emissions from Ground Access Vehicles (GAV)

Ground access vehicles (GAV) are responsible for a sizeable amount of total airport emissions. As mentioned in Chapter I, Logan Airport found that GAV contributed 7 percent of airport-related NOx and 24 percent of airport-related HC emissions. In addition, airport-related trips make a significant contribution to overall emissions in many metropolitan areas, typically accounting for 2 to 4 percent of all motor vehicle emissions and 1 to 2 percent of the total emissions inventory. Since state SIPs account for passenger car trips to and from the airport separately from airport-related emissions, this report does not focus on passenger car trips to and from airports in private vehicles. This section focuses specifically on employee private vehicles, public transport vehicles and shuttles, and cargo vehicles for deliveries. As in previous sections, this discussion of GAV emissions reduction strategies is divided into technological and operational options.

GAV emissions estimates usually include a vehicle's entire trip, not just emissions that occur within airport boundaries. Since vehicles may make several unrelated stops during a trip to the airport, emissions from the total trip cannot all be attributed to airport-related activity. An offsetting under-assignment of emissions is possible however. Emissions associated with off-site, airport-related vehicle activity not directly related to the transport of passengers should arguably be assigned to the airport, but typically are not.

Calculating emissions for GAV requires collecting information on reference trip emissions. Reference trip emissions are those produced by all ground vehicles before any control measures are implemented. Calculations must also take into account: total airport vehicle miles traveled, total airport trips, trip length, passenger access mode (solo driver, car-pool), emission factors by vehicle type, parking characteristics, average idle time, and rental car fleet size. Traffic and environmental studies at individual airports provide a template for estimating the above factors.

D.1 Technology Options

Commercial vehicles that serve the airport, including taxis, rental cars, buses and shuttles, provide an opportunity for reducing emissions in the airport vicinity. Los Angeles (LAX), Baltimore-Washington International (BWI), Logan International, and Phoenix Sky Harbor Airports all have introduced CNG-powered shuttles and buses and are planning for continued growth in the use of alternatively-fueled airport vehicles.

Many of the costs and constraints associated with switching commercial GAV to alternative fuels are similar to those previously described for ground service equipment. Potential emissions reductions are significant, but the costs and logistical challenges of converting a large portion of the fleet and establishing the necessary refueling infrastructure can also be substantial, and can outweigh the short-term savings of fuel costs. Nonetheless, airports around the country are investing in alternative fuel infrastructure and vehicles. Once alternative fueling infrastructure is in place, it can accommodate both GSE and GAV.

For example, Logan Airport's procurement of airport-owned vehicles favors alternative fuels. All of Logan's 40-foot buses, which provide transportation to and from the subway, satellite parking, and between terminals, are now CNG-powered. At BWI, 65 percent of airport shuttle buses are currently CNG-powered and all future procurements will be exclusively CNG buses. At LAX, 40 percent of shuttle buses and 23 passenger cars (mainly police vehicles) are LNG-powered. In addition, the airport runs 84 CNG light trucks. Phoenix has converted 100 gasoline vehicles to CNG.

Emissions reductions anticipated from substituting diesels with factory-built alternative fuel vehicles are 5 percent from HC, 50 percent from NOx, and 90 percent from PM. Replacement of light-duty gasoline vehicles with CNG results in an 80 percent reduction in HC, and a 50 percent reduction in CO. These emission reductions assume purchase of factory-built, dedicated CNG vehicles, not conversions. Conversions are not complicated to install, but achieving good emissions and engine operation require a highly skilled mechanic and more routine maintenance.

In addition to procuring airport-owned alternative fuel vehicles, airports can encourage selective procurement by tenants. Private companies may also choose or be required to convert to alternative fuels (as part of a contractual arrangement with the airport operator). For example, Logan's Clean Air Partners program is designed to encourage tenants such as car rental companies, freight shippers, and airlines to convert their on-road vehicles to alternative fuels. Another example is the alternate fuel program enacted by Super Shuttle, which has purchased natural gas shuttle buses in several cities. In Phoenix, 90 of its shuttle buses are CNG powered. In addition, taxi cabs are excellent candidates for alternative fuels. Ford manufactures a dedicated natural gas CNG taxi (Crown Victoria). In New York City, an incentive program has resulted in the conversion or purchase of 200 CNG taxis. Similar programs could be put in place at airports.

Tables III-5 and III-6 summarize the incremental costs associated with purchasing alternative fuel vehicles instead of diesel-powered models, and the cost effectiveness in dollars per ton of pollutant reduced.

Table III-5: Incremental Cost for Purchasing Alternative Fuel Vehicles

Vehicle type	**Incremental purchase price for dedicated vehicle**
CNG bus	$40,000
CNG light-duty vehicle	$3,000 to $5,000
Light-duty LPG	$2,000
Electric light-duty bus	$12,000 to $30,000
Electric heavy-duty bus	$125,000 to $225,000

Source: EEA 1997

Table III-6: Cost Effectiveness of Alternative Fuel Vehicle Use

Vehicle type	Cost per ton of NOx, CO,[93] HC, and PM reduced
Light-duty CNG	$8,000
Heavy-duty CNG	$14,000
Light-duty electric	$44,000
Heavy-duty electric	$37,000

Source: EEA 1997

This analysis, conducted by EEA in 1997, takes into account the incremental cost of vehicle purchase and differences in maintenance and fuel costs. It does not account for additional costs related to the CNG fueling infrastructure. For electric vehicles, the analysis includes costs for a recharging station for each vehicle and assumes that batteries are replaced twice during the useful life of the vehicle. The cost analysis does not take into account the non-economic benefits of alternative fuel vehicles such as reduced noise, odor, and vibration, and increased customer satisfaction.

In addition to switching from conventional fuels to alternative fuels, retrofitting diesel and gasoline heavy-duty vehicles with oxidation catalysts, particulate filters, or 3-way catalysts is also technically feasible to reduce emissions. The same constraints described for nonroad engines would apply to highway vehicles. Retrofitting, especially with oxidation or 3-way catalysts, is a relatively low cost means of achieving emission reductions. Because of this, airport operators can include requirements or incentives in contracts with airport tenants to retrofit without imposing too great a financial burden on the operators.

D.2 Operational Options

Besides reducing emissions from individual vehicles, reducing vehicle trips to the airport and promoting efficient vehicle operation at the airport present important additional opportunities for reducing airport emissions. This section outlines strategies for reducing emissions from two broad, demand-based, airport-related vehicle emissions categories: airport employee trips and passenger trips resulting in congestion.

Reducing Employee Trips

Airport employee trips make up approximately 10 to 15 percent of all airport vehicle trips.[94] This is a relatively small percentage of total trips, and thus measures enacted to reduce employee vehicle miles traveled (VMT) will reduce a small percentage of overall airport VMT. We can assume, however, that some measures to reduce employee VMT may also reduce VMT generated by

[93] CO emissions are divided by seven in this cost analysis.
[94] EEA 1997.

airport passengers. For example, efforts to improve transit service at the airport could result in reduced overall VMT.

Most airports are served by one or more modes of public transport. The most common is bus service, though this tends to be perceived as a “low-value” way to access the airport. Rail links that provide direct service between terminals and metropolitan centers are likely to be more attractive to many passengers. At Boston’s Logan Airport, for example, an existing subway link is estimated to handle approximately 7 percent of all airport patrons, including employees. However, constructing new rail links where they do not already exist is capital-intensive. Door-to-door shuttle services, though typically private operations out of the direct control of airport authorities, can provide an important complement to other transit options. An example of a shuttle service that is reducing GAV VMT is Super Shuttle. They offer an environmentally friendly alternative to taxi, rental car, and private car trips. The decision to use natural gas vehicles at several airports has improved their environmentally friendly stance.

Airports can do a number of things to encourage employees to choose these transportation options instead of solo vehicle travel. These include advertising for bus, shuttle and rail service within the airport itself and enhancing access to transit stations from the terminal. To the extent that transit fares are significantly lower than airport parking fees, this can provide an added incentive for the use of public transit or shuttle services rather than private vehicles. Studies conducted by the University of California at Davis and others have shown that transit subsidies can significantly increase transit ridership.

Employee GAV emissions can also be reduced by strategies such as compressed work schedules, telecommuting, ride sharing, and parking pricing. For example, compressed work schedules allow employees to work longer hours but fewer days (e.g. a 10-hour per day, 4-day schedule), while telecommuting allows employees to work from home. In both cases, the number of work-related trips is reduced. Telecommuting works best for administrative employees at the airport whose jobs can be done at home and have more flexibility; this option is less likely to be feasible for many airport workers whose jobs require them to be physically present, including ticketing agents, baggage handlers, and food service personnel. For those employees who must come to the airport, employers can promote ridesharing and carpooling with incentives such as preferential parking, monetary rewards, or, as a negative inducement, the elimination of parking subsidies for personal vehicles. Effective implementation of these strategies must take into account the availability of attractive transit alternatives on the one hand, and the existence of low-cost parking options outside but near the airport on the other. Removing parking subsidies is, of course, only effective if airport parking was once free or employers subsidized parking. The measure may also be ineffective if low-cost parking options exist near the airport, as employees will simply begin to park there. Finally, it is crucial that alternate transportation options be in place, convenient and competitively priced for parking pricing or other transit inducements to have the desired effect.

Reducing Congestion at Airports

Apart from reducing airport-related travel demand, strategies to reduce idling and to improve the efficiency of traffic flow through airports present additional opportunities for reducing GAV emissions. Because many of the vehicles that access the airport spend a significant amount of time idling, numerous airports have attempted to implement idle restrictions for at least some types of GAV. These restrictions are most likely to be successful for commercial or cargo vehicles.

Idling restrictions may be difficult to impose in remote locations within the airport where drivers run engines for air-conditioning (such as at loading areas), or for drivers of private vehicles who are restricted from spending much time at curbside in the interests of congestion mitigation and airport security. In sum, overall emissions reductions achievable through idling restrictions may represent only a small percent of the airport inventory; nevertheless these small reductions can be quite cost-effective given the low cost to implement them (especially if no new personnel are needed to enforce restrictions). In addition, these efforts are particularly important in reducing exposure to PM and toxics.

Improved traffic circulation and congestion management can increase airport efficiency, improve customer satisfaction and lower total emissions. A variety of traffic management strategies can be implemented at most airports and are particularly feasible at new airports. For example, rental agencies, hotels and parking providers often provide shuttle services that run along the same route. Consolidated shuttles can cut down on emissions by providing one multi-stop service in place of several separate shuttles. The effectiveness of an airport shuttle depends on the degree of overlap of shuttle routes. EEA estimates that 50 percent of non-parking related shuttle services can be consolidated at most US airports. In addition, most airports already limit curb access to facilitate traffic flow. Such limits could be enhanced by curb access pricing schemes to further limit the number of vehicles at the curb at any point in time, and/or by creating holding areas for commercial vehicles and centralizing rental car offices. The costs of such measures are typically quite low, but obviously passenger satisfaction, convenience, safety concerns, and other objectives must be considered before they can be implemented.

E. Replacing Short-Haul Air Travel with Rail Service

One option that could reduce emissions from aircraft, GSE, and GAV is the replacement of short air trips with rail trips. In the Northeast, Amtrak currently carries more than half of all combined rail and air passengers between Boston and Washington, D.C. and three quarters of all passengers traveling between New York City and Washington D.C. With the introduction of the faster Acela service, Amtrak hopes to increase that market share. In Europe, several promising high speed rail projects are reducing air travel. These initiatives are described below. This section does not provide any cost effectiveness data since none are available at this time. The Arthur D. Little study discussed earlier in this chapter also lists magnetic levitation high speed rail as a option which could provide significant environmental benefits with a medium time frame for introduction.

E.1 Amtrak/Acela Express Train Service in the Northeast U.S.

In 2001, Amtrak held a 58 percent share of the 4.5 million air and rail trips for the entire Boston-Washington Northeast Corridor. Between Boston and New York City, air dominates with a 65.4 percent share, or 611,000 trips, versus 323,000 trips by rail. Between New York and Washington, Amtrak has a 76.3 percent market share. Amtrak's strategy is to protect its commanding market share south of New York, and to increase its market share north of New York to approximately 50 percent. Between mid-2000 and March of 2001, Amtrak increased its share of trips between Boston and New York City by nearly seven percent. This was partially a result of rail electrification into Boston in early 2000, which reduced the trip from to New York City from 5 hours to 3.5 hours. In January 2001, Amtrak partnered with Continental Airlines to create an air/rail codeshare (much like those in Europe, described below), allowing passengers from Philadelphia, PA; Wilmington, DE; New Haven, CT; and Stamford, CT to easily transfer from rail to air at Newark Airport.[95] This program will increase Amtrak passenger levels between some of these cities (for example, Amtrak offers 17 trains per day between Philadelphia and Newark – more than any airline) and replaces some discontinued air service to other cities. To develop other corridors nationally, Amtrak is focusing on densely populated regions with major cities located within a 300-350 mile range. Fifteen airports with a total of 45,000 short trips per month are potential candidates for new fast rail service.

<u>E.2 Germany</u>

The German federal government has set a target to reduce the environmental effects of air transport through the transfer of short-haul air traffic to rail service.[96] Several government and private initiatives have arisen out of this goal. Two such initiatives are discussed below.

As an alternative to air travel within Germany, the German railway company, Deutsche Bahn, offers "Rail & Fly / Fly & Rail" tickets. With these tickets, international travelers can use their airline tickets, from more than 80 international airlines, for travel on a connecting railway line. Therefore, instead of having to purchase a separate ticket for air and rail travel, passengers can purchase one ticket that includes both modes of transportation. The intent is to make it easier for airline passengers to utilize rail as a part of their travel plans, including possibly using rail for a portion of their trip instead of air travel.

In another program to greater utilize rail, Luftansa made a commitment to replace all domestic air travel from Frankfurt airport with rail travel by 2002. Part of the motivation for this policy is to open up landing slots at the Frankfurt airport by reducing or eliminating some short-haul flights. The company expects that the decision will free slots for more highly profitable international flights.[97]

<u>E.3 France</u>

Paris' Charles de Gaulle Airport[98] has worked with several airlines and high-speed rail service providers to encourage the use of high-speed rail service for the short-haul portion of a connecting flight. Luftansa, United, Air France, and American Airlines have developed a ticketing agreement with SNCF where passengers have the option of taking the TGV high-speed rail for the final, short-haul portion of their trip.[99] Under the American Airlines deal, passengers can extend their journey from Charles de Gaulle airport by taking the high-speed rail network to Lille, Lyon or Nantes. Likewise, the Air France agreement gives customers the option of taking the high-speed train from Charles de Gaulle to Lyon, Lille, Angers, Le Mans, Poitiers, Tours, or Brussels.[100]

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[95] Morningstar News, January 17, 2002. <http://news.morningstar.com/news/PR/M01/D17/1011277270525.html>
[96] Coalition Contract, 1998 and German Transportation Report, 2000.
[97] Friends of the Earth. *From planes to trains: realizing the potential from shifting short-flights to rail.* June 2000.
[98] With the recent addition of two new runways, Charles de Gaulle is now the world's eighth busiest airport with 516,657 aircraft operations in 2000 (ACI, 2000).
[99] The Train à Grande Vitesse (TGV) is the high-speed train in France and is owned and operated by the French national railways, Société Nationale des Chemins de Fer Français (SNCF).
[100] Friends of the Earth. *From planes to trains: realizing the potential from shifting short-flights to rail.* June 2000.

A growing number of passengers and airlines in Germany and France are introducing similar air-to-rail services.[101] Since the opening of the TGV terminal at Charles de Gaulle in 1994, the number of air/rail connecting passengers has grown steadily. Of the 1.3 million rail travelers who used the TGV at Charles de Gaulle in 2000, 850,000 were connecting passengers from either rail to air or vice versa. With the recently developed air/rail transfer possibility, some declines have been witnessed in short-haul flights at Charles de Gaulle. Domestic aircraft movements at Charles de Gaulle have declined from 62,410 in 1999 to 61,074 in 2000.[102]

In 1999, Air France developed a ticketing agreement with Thalys, the Belgian high-speed train, where passengers ticketed with Air France can use the train for their connection to Brussels. This agreement has yielded a dramatic shift from air to rail service. Prior to this agreement, Air France had approximately 1,825 flights a year to Brussels, but rail service has completely replaced air service and Air France has discontinued all flights from Charles de Gaulle to Brussels.[103]

While no estimates of emissions reductions have been developed for the programs in Germany and France, several estimates have been developed to determine the impact of replacing short-haul with rail service in other regions. One such study in the United Kingdom estimated that NO_X could be reduced by as much as 6,300 tons in 2015 if all domestic passenger traffic within mainland United Kingdom and half of international connections were transferred to rail. This analysis also examined replacement of air service with rail service for international services between London and other European airports. Under these scenarios, NO_X emissions were reduced by 2,500 to 7,000 tons by 2015, depending on the degree of replacement.[104]

Generally, air-to-rail programs seek to enable the transfer between these modes by providing easy access from rail stations to the airport, streamlining check-in by allowing easy transfer of bags from the airplane to the train, and by simplifying ticketing. The aim has been to make rail service more attractive and more competitive with air travel. The recent "World Business Council for Sustainable Development" report concluded that transportation emissions that contribute to global warming are growing in both developed and developing countries, and that recommended the support of the development and use of high-speed passenger rail to reduce air trips of 310 miles or less to reduce these emissions.

F. Conclusions

A wide range of options is available to reduce airport-related emissions. Technical options such as improving aircraft and engine design, introducing alternative fuels into the GSE and GAV fleets, and reducing overall air trips through improved high speed rail service are all viable options. Operational measures can also be extremely cost effective. Some of the most cost effective options outlined in the chapter are the introduction of gate and GSE electrification, as well as certain transportation control measures. In some cases, these improvements will take place by themselves as airlines move to increase efficiency, as can be seen with gate electrification. In other instances,

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[101] Tagliabue, John, "Airlines Feel Pressure of Europe's Fast Trains," *New York Times*. August 12, 2001. Included as Appendix C.
[102] Air France, 2000.
[103] Ibid.
[104] FOE, 2000. Values were converted from metric tons to short tons.

regulatory mechanisms will be needed to encourage introduction of emission reduction measures. The policy and regulatory options available to states will be explored in the next two chapters of this report.

IV. Policy Strategies for Reducing Airport Emissions

A. Overview

Chapter III describes technological and operational measures for reducing emissions from aircraft, ground service equipment, and ground access vehicles at airports. This chapter discusses policy strategies that could be used to compel or encourage the implementation of the technological and operational options to reduce emissions that were discussed in the previous chapter. This chapter is divided into two sub-sections. The first subsection discusses the general regulatory approaches that states and potentially localities could utilize, and the second subsection consists of case studies of programs that have been proposed or implemented at airports. Due to statutory or legal constraints -- or in some cases for political reasons-- some of the approaches described in the first portion of the chapter may not be available to environmental regulators, especially at the state and local levels. Notwithstanding, there are a variety of strategies that could be pursued. The innovative approaches described in the second portion of the chapter highlight how a number of the approaches mentioned in the first portion of the chapter have been applied in practice, some using a combination of policies. In most cases, these efforts encompass a range of emissions reducing measures.

B. Policy Options

This sub-section covers a number of the more promising regulatory opportunities for state and local policymakers to reduce airport-related emissions. Specifically, this portion of the chapter discusses: (1) standards and activity restrictions; (2) more innovative regulatory approaches like emissions-based fees, cap-and-trade, and "bubble" programs; (3) initiatives targeted at GSE and commercial GAV fleets; and (4) efforts to increase high-speed rail and reduce passenger GAV trips to the airport. For each policy, a general overview of the approach is discussed, along with several of the key design considerations and advantages of the option. While some of the potential legal barriers are highlighted, Chapter V provides greater detail on applicable legal considerations and preemption issues.

B.1 Emissions Standards

Emissions standards represent a viable mechanism for promoting the introduction of cleaner aircraft and equipment at airports. This command-and-control approach played an important role in past regulatory efforts to improve air quality in the U.S. and has dramatically reduced emissions from pollution sources as diverse as automobiles, waste incinerators and architectural coatings.

As a regulatory option, emissions standards have a number of important advantages. Chief among these is that they can provide certain, lasting, and substantial air quality benefits within a defined timeframe. Applied across a broad source category such as automobiles or aircraft, the cost of achieving standards on a per unit basis tends to be low and widely distributed among manufacturers and consumers. Moreover, standards can have an important technology forcing effect on driving future innovations in emissions control. Implementing this regulatory approach poses its own political, technical, and procedural challenges. Typically, a legislative mandate is followed by a rulemaking process where the feasibility and cost-effectiveness of achieving different emissions limits is evaluated. It often involves extensive coordination among different federal agencies, public notice and comment, and, in some cases, legal action by one or more stakeholders. The following section discusses how emissions standards could be applied to aircraft, GSE and GAV.

Aircraft Standards

Substantial reductions in aircraft emissions appear to be technically feasible through a combination of improved engine designs, structural innovations, and materials advances.[105] While aircraft manufacturers will have some incentive to incorporate these changes even without regulatory intervention -- for reasons such as increasing aircraft capacity or reducing fuel consumption -- emissions standards could greatly accelerate the rate at which pollution-reducing technology innovations penetrate the commercial aircraft fleet.

As discussed more fully in the next chapter, federal law currently provides the EPA with sole standard setting authority over aircraft engines. The U.S. has elected to conform its aircraft engine emissions standards to those developed by ICAO.[106] ICAO standards for aircraft engine emissions have been in place since 1981, when ICAO established its first SARP for aircraft. This first SARP covered emissions of NO_X, CO, and HC. These standards were amended in 1993 (commonly referred to as the "CAEP/2 standards") to establish a more stringent standard for NO_X, which was equivalent to a 20 percent reduction over the 1981 ICAO NO_X emissions standards. The CAEP/2 standards took effect in 1996 for all newly certified engines and in 2000 for all newly manufactured engines.[107] The standards were adopted by EPA in 1997, and are the current standards for aircraft engine emissions.[108] In April 1998, during the fourth CAEP meeting, a NO_X standard 16 percent more stringent than the CAEP/2 NOx standard was recommended. These CAEP/4 standards take effect in 2004. Since these new standards have been included in Annex 16, contracting states are expected to adopt them; EPA also plans to adopt them in the near future. While the new standards will affect engines certified after 2004, they will not require manufacturers to cease production of engines designed under the previous standard (Figure IV-1). A new NOx standard and production cut-off for the CAEP/4 standard is being considered at the next CAEP meeting (CAEP/6) in early 2004.

Given that some engine and aircraft designs remain in circulation for many years -- the average age of the U.S. fleet is about 11 years -- large decreases in emissions may not materialize for several years.[109] In the context of noise emissions from aircraft, ICAO has resolved this lag in technology uptake by recommending the phase-out of older aircraft.[110] A similar approach, or one involving incentives for early retirement of older aircraft, could prove useful in spurring greater uptake of newer aircraft in airline fleets.

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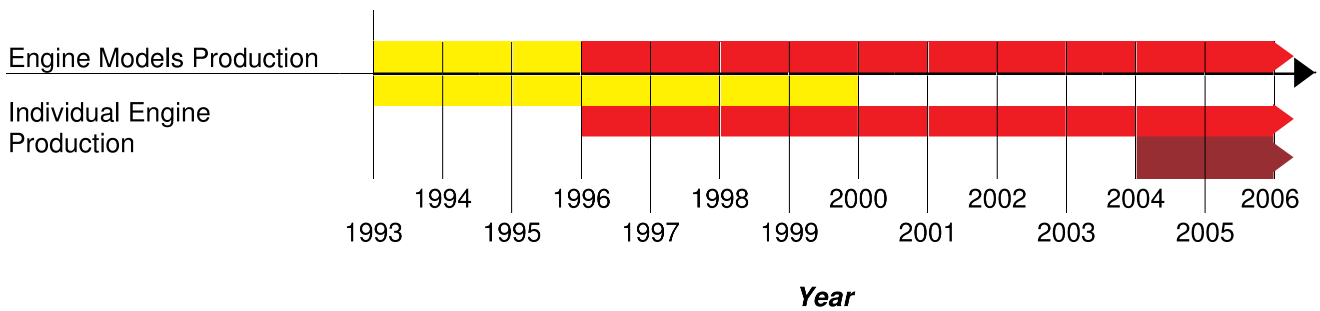
[105] See previous chapter for greater discussion.
[106] The standards that are established are the minimum that nations are expected to meet and thus do not limit States sovereignty in establishing more stringent standards.
[107] ICAO, Annex 16 Volume II.
[108] See 40 CFR Part 87 for more information on CO and HC standards.
[109] Data is weighted average as of June 2002 for 14 major carriers. For information on fleet age of a select number of U.S. carriers see: www.airsafe.com/events/airlines/fleetage.htm.
[110] All ICAO "contracting States" have typically agreed to these phase-outs; however, proposals for limited or regional phase-outs have also been introduced.

ICAO standards are on a rate-basis, and therefore do not control aggregate emissions at an airport or in an airshed.[111] The environmental impact of the program is therefore uncertain, since increased activity will lead to higher aggregate emissions even when the standards are met. Historically, the standards for aircraft engines have not been “technology-forcing”; many of the engines in service at the time the standards are established already comply with them.[112] Greater consideration of aggregate emissions and technology-forcing standards could help reduce emissions from aircraft. In addition, emissions standards have been based on the emissions performance of the aircraft engine. This feature does not account for the emissions impact of airframe designs. For example, an airframe with reduced drag will reduce fuel burn and thereby reduce all emissions. A standard based on the emissions performance of the whole aircraft, not just the engine, could further improve the effect of these standards.

Figure IV-1: Timeline for Engine Production Allowed Under ICAO NO_X Standards



Engines of a type or model for which the date of manufacture of the first individual production model was on or before 31 December 1995 and for which the date of manufacture of the individual engine was on or before 31 December 1999

Engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 1995 or for which the date of manufacture of the individual engine was after 31 December 1999

Engines of a type of model for which the date of manufacture of the first individual production model was after 31 December 2003

NOTE: ICAO adopted NOx standards for aircraft engines in 1981 and 1993. These standards applied to engines being designed and produced, and did not affect the emissions standards for engines in use at the time the standards were adopted. The current standard, adopted by EPA in 1997 and shown above in red, applies to engines models whose first manufacture was in 1996 or later, or to individual engines produced in 2000 or later. The new standard, passed by ICAO in 1999 but not yet adopted by EPA and shown above in maroon, applies only to engine models produced in 2004 and later. When this standard was adopted, the previous standard was not constrained, allowing engines produced under the current standard to continue in production after the new standard takes effect.

Given the international aspects of aircraft manufacture, sale and use, it would likely be politically problematic for the EPA to reassert its standard-setting authority over domestically sold aircraft. However, the U.S. could establish more stringent standards than those developed through ICAO, thereby influencing other countries and ICAO to follow suit. If standards were not internationally harmonized, this approach would likely raise concerns that U.S. carriers would be

[111] Aircraft emissions standards have been based on a per LTO-cycle basis in g/kN.
[112] See Figure I-4 in Chapter I.

placed at a competitive disadvantage, since U.S. airlines would be required to purchase potentially more expensive engine and airframe designs while non-U.S. carriers would not be required to make such investments. However, since a large share of aircraft are sold to U.S. carriers, engine and airframe manufacturers might be forced to design engines and airframes that meet U.S. standards.[113] Either this option, or an option involving wider international efforts to increase the stringency and improve the design of current ICAO standards, remains important in the array of regulatory tools available to governments for reducing airport emissions.

Meanwhile, state and local authorities accountable for meeting health-based ambient air quality standards are effectively pre-empted from establishing aircraft emissions standards. However, states may petition EPA to set stricter standards for aircraft engine emissions. The petition must be based upon "new information". States may also consider petitioning the U.S. Department of Transportation (DOT), since the establishment of aircraft standards by EPA is in consultation with DOT.[114] Additional opportunities exist for states to advance the development of more stringent standards. For example, states could seek opportunities to engage the FAA and EPA as they develop the U.S. position on new standards for CAEP/6 and future CAEP meetings.[115]

GSE and GAV Standards

The EPA sets emissions standards for on-road and nonroad engines. As mentioned earlier in this report, emission standards for diesel powered GSE were first promulgated in 1996, and have been proposed for gasoline powered GSE machines beginning in 2004 and 2007.[116] While the gasoline engine GSE standards will require manufacturers to use four-stroke, closed-loop engine technology with three-way catalysts, similar to the technology used for gasoline highway vehicles, the engines will not be optimized to run as cleanly as their heavy-duty gasoline highway counterparts. Further design improvements to the engines could be made, given that the engines are similar to those used in highway applications. Consequently, more stringent federal standards are feasible for this category of engines, and states should consider bringing this to EPA's attention.

In contrast, standards for diesel powered GSE do not require the use of advanced emission controls such as catalysts. Technology developments in recent years have led to the adoption of stringent PM and NOx standards for diesel highway engines. The same technologies designed to meet these standards could be used to reduce diesel GSE emissions. More stringent standards for diesel powered nonroad engines such as those used in GSE are economically and technically feasible, and should be introduced by the federal government.

For highway vehicles, three Northeast states have adopted the California Low Emission Vehicle Program (LEV) and several other states are participating in the federal Tier 2 program. Taxicab and van service emissions will be dictated by either of these two programs (depending upon

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[113] In 2000, U.S. customers bought approximately 57 percent of the civil jet aircraft shipped by U.S. manufacturers. See Aerospace Industries Association, *Aerospace Statistics*: 2001, series 21, available at: <www.aia-aerospace.org/stats/aero_stats/stat21.pdf>.

[114] See Chapter V for greater discussion of the legal aspects of such an approach.

[115] Such involvement may include regular one-on-one communications with these agencies, participating in existing forum on the development of the U.S. position for CAEP, and some level of participation in CAEP working groups.

[116] US EPA, in *Proposal for Cleaner Recreational Vehicles,* Sept. 14, 2001, included a proposed new standard for large spark-ignition engines, which would include all gasoline powered GSE engines. For more information see <http://www.epa.gov/otaq/largesi.htm>.

the state in which the airport is located). For new highway heavy-duty engines, new federal standards for diesel and gasoline will greatly reduce new engine emissions over the long term. However, in the short term, the federal government could require that older engines be retrofitted with emission control technologies in order to reduce emissions from existing, highly durable diesel engines found in buses and trucks, similar to the Urban Bus Program described below.

B.2 Activity Limits

Activity limits represent a blunt but potentially effective regulatory mechanism for limiting airport emissions. To implement this approach, state governments, localities, or airport authorities could limit total airport activity by, for example, limiting the total number of take-off and landing slots available each day. Several airports, including Chicago's O'Hare, Washington's National, and New York's Kennedy and LaGuardia airports have placed limits on landing slots to reduce congestion. Typically, slot limits are determined by the airport's capacity and are set separately for different categories of air operators (air carrier, commuter and general aviation).

For political and economic reasons it may be difficult to establish activity limits except in cases where airport capacity is already strained and safety is becoming an issue. Similar constraints would likely apply to any efforts to limit GAV activity. The FAA is the only body that can set airport LTO limits and is authorized to do so only on the basis of safety concerns. The emissions benefits of restricting activity at one airport might be partially offset by a resulting shift of aircraft activity to other airports in the region. Unless activity limits are designed to recognize the different emissions intensities of the various aircraft, they will fail to promote a preference for lower emitting aircraft.

B.3 Cap-and-Trade or "Bubble" Programs

In recent decades, market-based regulatory programs have increasingly been used to replace or complement "command-and-control" type approaches, such as emissions standards. The federal Acid Rain program, for example, imposes a cap on national emissions of sulfur dioxide from electric utilities, and leaves it to the companies to decide how to meet that overall cap. More recent regulatory efforts aimed at reducing NOx emissions from power plants for purposes of ozone mitigation have adopted similar programs at the state and regional levels. Under a cap-and-trade program, a cap (i.e., a limit) is placed on the total allowable emissions from the applicable source(s) and each individual entity can buy or sell emissions allowances in order to maintain emissions below the cap. Put simply, those sources that can reduce their emissions more cheaply will tend to "over-control" and sell the "excess" allowances, while those sources that cannot implement reductions cost-effectively will likely buy allowances instead. The advantage of a cap-and-trade type approach is that there is an assurance of the environmental benefit since, by definition, the total quantity of emissions from the covered sources is limited by the level of the overall "cap". In addition, the cost of compliance is reduced, since each marginal increment of pollution reduction required to meet the overall cap or budget occurs where it can be most cost-effectively implemented. The total cost of compliance, however, is unknown, since it depends on the market price of emissions reductions.

The same concept can be applied to airports, and has been proposed for Boston's Logan International Airport.[117] Conceptually, a "bubble" is placed around either the airport as a whole or for a distinct category of sources or operations within the airport (e.g. aircraft, APUs, GSE, GAV and stationary sources). Emissions within the bubble are then limited by a defined cap or budget. Caps may be fixed or decline over time.[118] The cap can be established in absolute terms (e.g., tons per year) or on a rate-basis (e.g., tons per LTO or passenger). Absolute caps provide certainty of the environmental outcome, since the level of emissions cannot exceed the emissions cap. However, under a rate-based cap, emissions would naturally grow with increased activity or units in operation. Emissions levels would therefore be uncertain; however, estimations of activity levels can provide some expectations of emissions.[119] Emissions from any individual source within the bubble may vary as long as the overall cap or budget is not exceeded. Usually, owners of sources are responsible for finding the most effective means to maintain emissions below the limit.

The first steps in establishing a cap-and-trade program include: defining the sources included in the cap, identifying the entities responsible for complying with the cap, estimating current and projected emissions from included sources, defining an appropriate cap level, and deciding whether the cap should be dynamic or fixed. In deciding whether a particular source or source category should be included in the cap, regulators should consider whether the source makes a significant contribution to overall emissions, and – crucially – whether emissions from the source can be reliably measured and verified.[120] In terms of which entities should be responsible for complying with an airport cap-and-trade program, the two leading options are likely to be the generators of emissions (i.e., air carriers and fixed-based operators) and those who administer and operate airports (i.e., airport authorities and localities). In the first option, air carriers and fixed-based operators would be responsible for the emissions associated with operating their equipment and for implementing needed control measures and/or purchasing additional allowances to cover any excess emissions.[121] While some other entity would need to oversee the program (i.e., track allowances and verify compliance, etc.), the advantage of this approach is that compliance responsibility rests with the same entities that have direct control over the emissions sources covered. The second option is for the airport authority to assume responsibility for complying with the cap, including developing emissions reduction programs and, if necessary, purchasing emissions allowances or offsets from other sources to cover excess emissions over the cap limit.

Measurement, verification and enforcement are critical elements of a successful cap-and-trade program and present perhaps the most difficult challenge in applying this regulatory approach to airports. The most successful cap-and-trade programs to date have been applied to power plants, a relatively homogenous source category for which emissions can be directly and continuously

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[117] See case studies later in this chapter.
[118] In theory caps could also be allowed to grow over time to accommodate increased demand. For example, a fixed growth rate could be applied to a given cap in anticipation of future growth. Such an approach could be used in the early years of a program to ease transition to a "hard" cap.
[119] Rate-base approaches have generally not been used in past cap-and-trade programs, since the aim is usually to provide absolute environmental benefits relative to the status quo. This can only be achieved if aggregate emissions are fixed or decline, regardless of demand growth. However, rate-based approaches for aviation may avoid some perception issues by encouraging efficiency rather than absolute improvements.
[120] See Chapter II for tools for measuring airport emissions and the contribution of the various sources.
[121] Obligations would need to be further defined to take account of flights flown under alliances and other partnerships, as well as shared usage of equipment.

measured by smokestack monitors. By contrast, airports include a wide variety of potential emissions sources. For many of these sources it would be impractical to measure actual emissions. Instead, emissions would have to be estimated using the types of modeling and emissions factor tools used to develop national and state emissions inventories.[122] To allow for consistent and reasonably accurate emissions estimates, inventories of fuel use, flight operations, and LTOs, as well as APU and GSE usage and GAV activity, would need to be uniformly measured and accurately recorded. In addition to necessary record-keeping requirements, successful enforcement mechanisms and stringent penalties for non-compliance are important elements of a successful cap-and-trade program.

Other important design issues include the allocation method used to distribute emissions allowances to sources at the outset of the program, provisions for trading and, if desired, additional flexibility mechanisms such as banking[123] and "open market"[124] trading. Briefly, choices of allocation methods include: (1) grandfathering (in which allowances are distributed according to historic emissions levels);[125] (2) auctioning (in which sources bid at auction for an initial allotment of allowances); and (3) output or performance-based allocations (in which all sources are assigned allowances based on a common emissions factor multiplied by their current or recent activity level).[126] Similarly, there are a number of options for defining the scope of trading. For example, assuming that air carriers have primary responsibility for implementing a cap on aircraft NOx emissions, allowance trading could be allowed: (1) within air carriers; (2) between a group of air carriers (up to and including all carriers); (3) between air carriers and other emissions sources covered by an emissions cap; and (4) between air carriers and other emissions sources not covered by an emissions cap (i.e., so-called "open-market" trading[127]). Finally, the consequences of non-compliance would need to be defined, particularly if the entity responsible for compliance is an airport authority or locality. If airport emissions exceed the cap, such an authority could be required to purchase allowances or offsets from sources outside the airport to compensate. The costs associated with this requirement could, in turn, be passed on to air carriers and other source operators or owners according to their contribution to the overall emissions inventory. This approach effectively creates a monetary incentive for all covered sources to do their part toward ensuring compliance.

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[122] Further discussion of available modeling tools such as EDMS may be found in Chapter II, which covers inventory development.
[123] Banking is when a source is allowed to "bank" or retain excess allowances from one compliance period and use those allowances in a later period.
[124] In open-market trading, uncapped sources generate project-based emissions reductions that are real, verifiable, and surplus.
[125] New entrants who do not have historic emissions on which to base their allocations are typically accommodated under a grandfathering system by a "set-aside" pool of allowances under the cap.
[126] For example, if annual NOx emissions from aircraft landings and take-offs (LTOs) is to be limited to 1000 tons per year and there are 10,000 LTOs at an airport each year, emissions from each LTO would need to be limited to 0.1 tons, on average. An air carrier with 1000 LTOs per year would receive an allocation of 100 tons per year (1000 LTOs x 0.1 tons/LTO) under a performance-based system. To maintain a fixed or declining cap, allocation factors would need to be adjusted over time as activity levels increase.
[127] Open-Market Trading (OMT) maximizes the compliance flexibility afforded to individual sources. However it presents the challenge of ensuring that eligible offsets are real, quantifiable, surplus (to reductions that would happen under other regulatory requirements), enforceable and permanent. Some states, such as Massachusetts and New Jersey have existing OMT programs. For overview of trading options see <http://www.evomarkets.com/mk_em.html>.

A cap-and-trade program could also be extended to a number of airports in an area. In essence, this would mean introducing airport bubbles in a city, airshed, and/or region, and allowing trading among the emissions sources within those bubbles. This approach provides the added incentive of increasing the size of the market and providing greater opportunities to find cost-effective reductions.

B.4 Fee-Based Programs

Like cap-and-trade programs, fee-based programs make use of market forces to promote cost-effective emissions reductions across a source category or facility. However, unlike a cap-and-trade program, the final level of emissions that will be achieved under a fee-based program is not known in advance. Rather, final emissions depend on the magnitude of the price signal relative to the cost of implementing reductions.[128] As long as businesses can reduce emissions for less than the cost of the fees they incur by not reducing emissions, they will implement control measures. As soon as the cost of control exceeds the fee, on the other hand, affected businesses will stop making reductions.

Given some of the technical difficulties and potential legal issues involved in implementing either "command-and-control" type emissions standards or cap-and-trade programs at airports, emissions-based fees may provide an attractive regulatory alternative for addressing airport emissions. Aircraft are already required to pay landing fees at most airports to cover the costs incurred by providing airport services. Currently, most landing fees are tied to aircraft weight: heavier planes pay larger fees than lighter craft. If landing fees were tied to the relative emissions performance of different aircraft, they would create an economic incentive for utilizing cleaner aircraft. Ultimately, this incentive should affect the behavior of airlines and engine manufacturers by: (1) encouraging carriers to utilize lower emitting aircraft for flights to airports with emissions-based landing fees; and (2) providing an incentive to develop and incorporate cleaner engines into future aircraft designs. Incorporating emissions considerations need not change the overall fees assessed to air carriers; a fee-based program could be designed to be revenue-neutral relative to the status quo.[129] Alternatively, fees could be set to collect extra revenues to fund emission reduction programs.[130]

An emissions-based charging system can take several forms. Key design issues to be resolved in structuring such a system include the level of the charge, determining activities and entities to be charged, and the use of resulting revenues. In setting the level of a charge or fee, one broad objective would be to ensure that the price signal is strong enough to produce an environmentally positive response. Within that broad objective, regulators have a number of options: they could simply restructure current fee levels to provide a marginal incentive for emissions reductions; attempt to estimate the specific fee level that would be required to achieve a

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128 Note that in a cap-and-trade program, final emissions are known, but final cost (in terms of the maximum amount spent per ton of reductions to achieve the cap) is not. In that sense, the choice between a cap-based program rather than a fee-based program translates to a choice between environmental versus cost certainty.
129 Under revenue-neutral fees, other fees in aggregate are reduced. Fees paid by individual entities can however change depending on the structure of the charging system.
130 At present, landing fees are generally not to be used to generate excess revenues above the cost of providing airport services. However, maintaining acceptable air quality standards may be construed as part of the airport's obligation in providing those services.

defined emissions target; or set fees to "internalize" the environmental costs of airport emissions.[131] Note that if fees are intended to achieve a particular emissions target it will be necessary to conduct an analysis of the sensitivity of air carriers, aircraft manufacturers and perhaps even airline customers to different price signals and adjust the level of the charge regularly to account for changes in price sensitivity. It is often difficult in practice to estimate the exact change in price needed to generate a given response since this requires accurate assessments of the responsiveness of individuals to these changes.

Another important up-front decision in designing a fee-based system concerns which emissions sources or activities will be covered and which entities will be charged. For example, a fee-based program could be designed to cover only aircraft LTOs or aircraft LTOs plus emissions from ground service equipment.[132] Fees could be based on actual emissions[133], aircraft and/or equipment movements (e.g. LTO cycles)[134], or fuel use.[135] If the chief purpose of designing a fee system is to reduce emissions, it will make the most sense to tie fees directly to emissions rather than to a proxy. For example, fees based on LTOs or equipment movements may reduce emissions by creating incentives to reduce activity, but won't directly promote preferential use of cleaner technologies. In terms of which entities are charged, obvious candidates are air carriers and (in cases where GSE is included) fixed based operators.[136] Ultimately, at least some of the cost would likely be passed on to airline customers (i.e., passengers). However, as noted previously, under a revenue-neutral fee, aggregate costs need not increase relative to existing landing fees and other airport charges. Since landing fees represent a small fraction (i.e., two to three percent) of operating costs, the impact of such an approach may be limited.[137] Furthermore, the decrease in other airport fees may offset existing funding for environmental projects and therefore have minimal impact on overall airport mitigation expenditures.

If a new emissions-based fee system is designed to be revenue-neutral, its proceeds are likely to go toward covering airport costs, just as current fees do. If additional revenues are generated, these can be spent in a number of ways. Obvious choices include using excess revenues to support additional emissions mitigation measures at the airport or in the region, or to support research and development into new aviation technologies that can further reduce pollution.

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[131] Several studies have been undertaken in Europe to evaluate the external costs of aviation emissions. For example, see INFRAS, *External Costs of Transport*, March 2000.

[132] Fees could be established separately for aircraft and GSE based upon the emissions from each piece of equipment. Alternatively, one fee could be placed on each aircraft LTO that includes an assumed or default GSE emissions increment. The assumed GSE emissions value could be differentiated based upon the type of aircraft being served (i.e., narrow-body versus wide-body) and its operation (i.e., short-haul versus long-haul).

[133] Preferably emissions can be monitored, but in many cases they will need to be estimated from information on engine type, activity level or fuel consumption, and other factors -- or by using default values, perhaps linked to the emissions characteristics of a piece of equipment as certified upon manufacture or sale. The latter approach has been used in Switzerland and Sweden, as described later in this chapter.

[134] While it is easy to track aircraft LTOs, accurately tracking movements by ground service equipment may present a significantly more difficult challenge.

[135] Tying fees to fuel use makes the most sense where reduction of CO_2 emissions is a priority objective. Emissions of NOx, VOC, and other pollutants of concern in a local air quality context, however, are not directly related to fuel use but rather depend heavily on engine design, operating conditions, etc.

[136] In theory, the airport authority could directly charge passengers or owners of cargo, but this is likely to be more complex than simply charging the air carriers who have direct control over equipment choices and allowing them to pass on the costs.

[137] See Massachusetts Port Authority, *Air Quality Initiative for Boston Logan International Airport,* March 2001.

To date, emissions-based fee systems have been implemented only outside the U.S., in Switzerland and Sweden. The program introduced at Logan Airport has a fee-based portion in addition to the airport “bubble”.[138] The viability of landing fees in a regional or national context must be carefully assessed (e.g., a regional program may encourage cleaner planes in that area, but a greater proportion of dirty planes would then converge on other regions). It should be noted that some fee-based systems could potentially face legal challenge as well; this is discussed more fully in the next chapter.

B.5 Innovative Regulatory Strategies for Reducing GSE and GAV Fleet Emissions

In addition to the regulatory approaches discussed previously in this chapter for limiting emissions from airports as a whole, or from aircraft as a particular source category, regulatory options may be available for limiting GSE and GAV fleet emissions. This section discusses how airport operators might craft control programs for either GSE or GAV fleets by: (1) promoting or requiring the purchase of cleaner alternatives when fleet vehicles or equipment are replaced or added; (2) developing a declining fleet emissions target; and (3) adopting a combined approach that utilizes both of these strategies. The federal Urban Bus Program[139] provides a useful model; though it targets only particulate emissions, it could readily be adapted for other pollutants.[140]

An approach modeled after the Urban Bus Program would incorporate a performance-based requirement and a fleet-averaging mechanism. Affected vehicles would be required to meet a specific emissions standard at the time the engine is rebuilt or replaced. The requirement would be automatically waived if no engines certified to meet the standard are available for less than a specified cost.[141] The program would contain “fallback” requirements specifying that “waived” engine families must be retrofitted to achieve a minimum percent reduction in emissions, relative to levels emitted with the original engine configuration. For airport-related vehicles, similar performance standards could be established for airport buses, shuttles and taxis, as well as for ground service equipment. Maximum stringency in the case of GAV might be CNG or electric technology; for GSE, electric machines would likely represent the cleanest commercially available technology.

Rather than being subjected to performance standards on an engine-by-engine basis, fleet operators would have the option of meeting a declining annual average emissions target across their entire fleets. The target level for each fleet (TLF) would be calculated for each year of the program. For any given year, the average emissions rate from all of the operator’s vehicles with a model year that is earlier than the beginning date of the program (e.g., 1994) must be at or below the TLF established for that calendar year. The requirement would apply until all pre-1994 vehicles have been retired from the operator’s fleet. Under the Urban Bus Program, TLFs are based on EPA’s determination of the projected emission level for each engine model year in the operator’s pre-1994 model year urban bus fleet.

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[138] These programs are discussed in the case studies presented at the end of this chapter.
[139] The Urban Bus Program was established in 1993 and requires that urban buses located in metropolitan statistical areas with populations equal to or greater than 750,000 (as of 1992) be retrofitted with emission control devices.
[140] The standard is 0.1 grams per brake-horsepower per hour (g/bhp-hr). The first engine meeting this standard was certified in 1998; subsequently a growing number of engine families have been able to meet the standard.
[141] In the Urban Bus Program, this cost is $7,940.

B.6 High-Speed Rail Service

As discussed in Chapter III, increased use of rail is a potentially viable option for reducing the number of short-haul flights between certain city pairs. Greater development of high-speed rail could expand the number of areas where rail can compete with short-haul flights. Replacing flights with rail service could reduce air emissions.[142] One study found that the ground-level NO_X emissions intensity, per passenger kilometer, of current short-haul air travel in the United Kingdom was greater than high-speed rail service on the majority of routes studied.[143] When evaluating the use of only electric high-speed rail, the study found that ground-level NO_X emissions were lower than air services on all routes.[144] The situation in the U.S. is obviously different; however, a comparable evaluation in the U.S. would highlight routes where high-speed rail could reduce emissions between certain city pairs.

Several factors affect the competitiveness of high-speed rail with air travel. Assessing these factors helps determine the viability of high-speed rail in a given location. The first issue is the distance between destinations, since travelers consider time an important factor in their choice of travel modes. In assessing viable routes, planners typically focus on regions with major cities within 370 miles of each other. Over these distances, high-speed rail can be time competitive when the time associated with transportation to/from the airport, check-in, taxiing, take off/landing, holding patterns, and other trip-related events are taken into account, especially when the final destination is a central city.[145] Another important factor in determining viable routes is the density of travel, i.e., those short-haul routes where there are a large number of passenger trips per day. Routes with high-density and short distances are prime candidates for high-speed rail. According to Amtrak, fifteen U.S. airports with a total of 45,000 short trips per month are potential candidates for new fast rail service.[146] Other important considerations for assessing the viability of high-speed rail are the costs and benefits of rail service compared to alternative travel options. This means weighing such factors as the costs of constructing a new runway or airport, the costs of expanding or adding high-speed rail service, and the potential to improve airport services and optimal resource use by reducing airport delays due to congestion. In regions where high-speed rail is already operating, costs may be associated with expanding and improving current rail service to accommodate more passengers (e.g., increasing the number of cars or the frequency of service) and with improving rail-air linkages so that passengers can use rail for the short-haul portion of their trip.[147] Where high-speed rail does not currently operate, costs will obviously be higher due to the need for large infrastructure investments in upgrading or laying new track, constructing power lines, and purchasing engines and cars. One study estimated that the cost of building new infrastructure ranged between two and 50 million dollars per route-mile, depending on the type of infrastructure.[148] The low-end estimate -- upgrading

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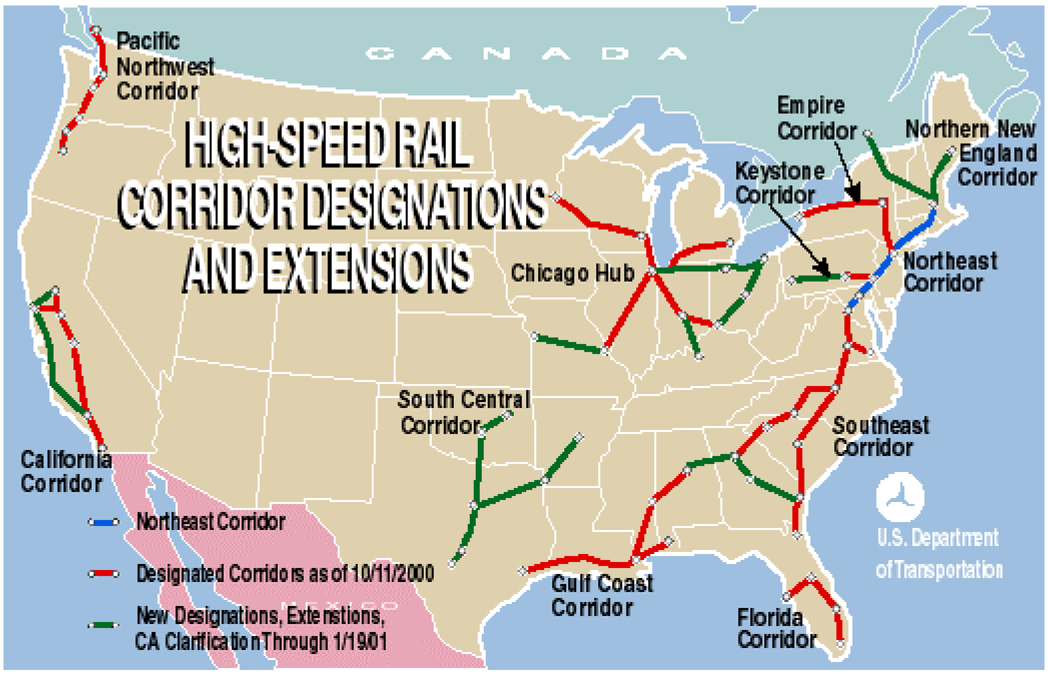
[142] See Chapter III for discussion of factors affecting the environmental performance of such a program.
[143] The study also found that high-speed rail had lower CO_2 emissions, CO, and VOCs. Emissions of PM10 were found to be broadly the same between these modes; however, variation occurred according to route. See Watkis et. al, *A Comparative Study of the Environmental Effects of Rail and Short-haul Air Travel*, September 2001.
[144] The majority of trains on these routes use electric traction; however, there are some diesel trains on the studied routes. The sensitivity analysis analyzed the routes with only electric trains.
[145] See European Federation for Transport and Environment, *Aviation and its impact on the Environment,* December 1999.
[146] Personal communication with Richard Remington (Amtrak), October 1, 2001.
[147] The program at Newark Airport, discussed later, is an example of an effort to better link the airport to the rail service in a given area. Also, see Chapter III for discussion of air-to-rail services in Europe.
[148] U.S. Federal Railroad Administration, *High-Speed Ground Transportation for America*, September 1997.

existing railroads -- allows maximum speed of 90-150 mph, whereas the higher-end estimate -- new railroad tracks -- would provide for speeds between 200-300 mph. In these options, policymakers need to consider long-term impacts and costs since it may require years of investment to build the necessary capacity.

The Federal Railroad Administration has designated ten high-speed rail corridors -- Pacific Northwest, California, South Central Corridor, Chicago Hub Network, Gulf Coast Corridor, Southeast Corridor, Florida, Keystone Corridor, Empire Corridor, and Northern New England Corridor (Figure IV-2).[149]

Figure IV-2: Dedicated High-Speed Rail Corridors



Source: US Federal Railroad Administration, 2001

A number of States are planning high-speed rail systems and making improvements necessary for the use of high-speed rail.[150] These States are typically planning to upgrade existing rail lines, rather than entirely new rail lines exclusively devoted to 150 to 300 mph trains, such as operate in other countries.

B.7 Reduced Passenger Private Vehicle Trips to and from the Airport

Reducing vehicle emissions has been a priority for many states and localities. Similar to other passenger trips, reducing emissions associated with trips to and from the airport can help improve local air quality. The attention paid to emissions from air travel-related passenger trips has varied by locality. Some areas have undertaken extensive programs to reduce passenger trips to airports by encouraging greater reliance on transit and ridesharing. For example, a number of

[149] These designations are done under section 1010 of the Intermodal Surface Transportation Act of 1991 (ISTEA) and Section 1103(c) of the Transportation Efficiency Act for the 21st Century (TEA-21).
[150] For more information on the activities states are undertaking see: www.fra.dot.gov/rdv/hsgt/states/index.htm

airports have raised parking fees or limited the number of available parking slots. Success in this regard has been mixed. Sacramento International Airport has found that, as a result of their parking limitations, people have avoided parking and instead utilized another person for pick-up and drop-off. This doubles the number of trips to/from the airport and increases emissions.[151] However, a combination of approaches at London's Heathrow Airport, such as higher parking fees combined with bus priority, has had some success in increasing the portion of employees and travelers utilizing public transportation.[152] The environmental result of such programs depends on many factors, including the ensuing transportation choice and emissions performance of the alternative mode. Depending on the current infrastructure, a variety of tools are available to local and state regulators. Where mass transit currently operates to the airport, improving the service may greatly increase ridership. For example, the monorail at Newark Airport was recently connected to the rail station, making it easier for passengers to access Amtrak, the PATH, and NJ Transit.[153] This has made access to New York City, the New Jersey suburbs, and other surrounding communities easier, since both rail and public transit are better connected to the airport. Other potential improvements include: (1) placing check-in counters close to the transit station (as has been done in Atlanta); (2) designating more convenient locations for bus stops; (3) providing adequate bus shelters; (4) giving buses priority over private vehicles and taxis within the airport (bus lanes, traffic signal priority); and (5) adding space for baggage in transit vehicles. At airports where transit service is limited, improving bus service should be the first priority, including designating priority bus lanes on the main approach routes to the airport and providing traffic signal prioritization for buses. While rail access does not make sense for all airports, it should be considered in regions that already have a rail system. The addition of airport rail connections is underway in Minneapolis, New York and San Francisco and is under consideration in the Dallas-Fort Worth area.

C. Case Studies

The remainder of this chapter describes specific initiatives being undertaken to reduce airport emissions in the U.S. and abroad. These include initiatives at Boston's Logan International Airport in Massachusetts and Sacramento International Airport in California, as well as initiatives in the South Coast of California and at several airports in the Dallas/Ft. Worth and Houston-Galveston-Brazoria areas of Texas. Overseas initiatives described here include a Swiss program that affects airports at Zurich and Geneva, and a Swedish program being applied to nine airports in that country. For each case study, chief elements of the pollution reduction effort are described together with the players involved, implementation timelines, anticipated costs and expected emission reductions. Where possible, actual emissions reductions to date are estimated using available data. Where emissions data were not available, general information was provided on the impact of these programs. Due to the innovative nature of the initiatives included here, many of these estimates are necessarily imprecise.

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[151] See Sacramento International Airport, *Parking and Traffic Studies at Sacramento International Airport,* presented at the Airport Air Quality Symposium, California, March 1, 2001.
[152] See BAA, *Travel Choices: BAA Heathrow's Travel Plan 2000/2001*, available at <www.baa.co.uk/pdf/heathrowtravel2001.pdf>.
[153] For more information see <http://www.njtransit.com/an_capitalprojects_project008.shtm>.

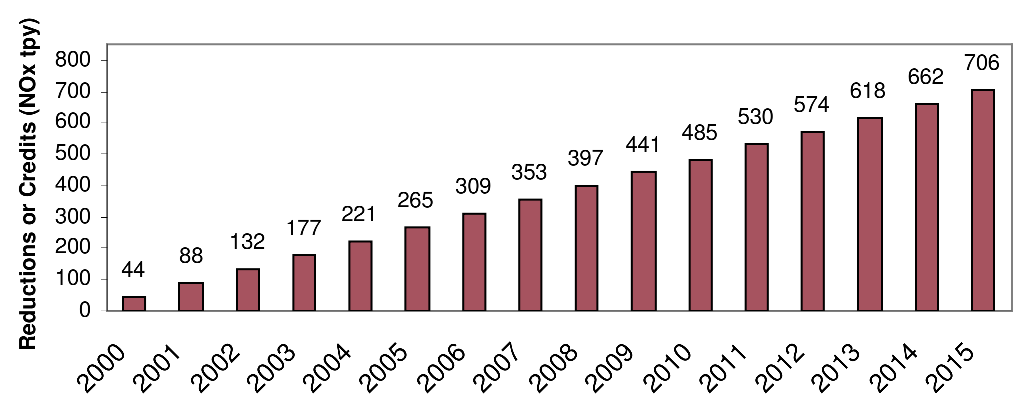
C.1Logan International Airport: Voluntary Emissions Limit

Logan International Airport (Boston-Logan Airport) in Boston, Massachusetts was the ninth busiest U.S. airport in 1999, as measured by total aircraft operations.[154] Total landings and take-offs by commercial aircraft at Boston Logan totaled 505,000 in 1999 and are predicted to rise to over 560,000 by 2015, a cumulative rise of about 11 percent over that period.[155] The airport is located in the greater Boston metropolitan area, which is classified as being in "serious" nonattainment of the one-hour National Ambient Air Quality Standard (NAAQS) for ground-level ozone, and routinely monitors exceedances of the more protective eight-hour ozone NAAQS.

In an effort to reduce airport-related emissions, Massport[156] has undertaken a host of measures in recent years, including converting its own fleet vehicles to bio-diesel, electricity or CNG; providing incentives for other fleet operators to use alternative fuel vehicles (including a 25 percent discount on ground access fees); and installing gate-based air conditioning systems to reduce reliance on aircraft APUs or ground-based power sources during layovers.

More recently, as part of its discussions surrounding the proposed building of a new runway at Logan, Massport proposed to develop a new Air Quality Initiative (AQI). Announced in April 2001, the AQI represents the first effort in the U.S. to voluntarily limit total emissions from an airport. Specifically, the Logan AQI seeks to mitigate any increases in airport emissions of NOx and VOC above 1999 levels.[157] By doing so, it is expected to eliminate a cumulative total of 6,000 tons of NOx, 1,000 tons of VOCs, 20,000 tons of carbon monoxide, and 32 tons of particulate matter by 2015. In addition, Massport estimates that meeting the AQI's NOx goals will require the airport to either further reduce emissions or purchase NOx credits of 44 tons per year (tpy) for 2000 and 706 tpy in 2015 (Figure IV-3).[158]

Figure IV-3: Expected NOx Credits or Reductions[159]



Source: Massport AQI, 2001

[154] One air carrier operation represents either a takeoff or a landing of a commercial aircraft with seating capacity of more than 60 seats.
[155] Federal Aviation Administration (FAA, 2000), T*erminal Area Forecast: Fiscal Years 2000-2015*, December 2000.
[156] Massport is the private entity that operates the airport.
[157] The Federal Aviation Administration and the Air Transport Association have raised concerns with the AQI in terms of its effectiveness and legality.
[158] Note: all emissions estimates for future years and the subsequent emissions reductions needed to maintain emissions below 1999 levels were developed prior to recent events, such as September 11th.

Achieving the necessary reductions will require a two-track effort. First, Massport will continue to implement and seek to expand existing initiatives, such as those noted above. Second, Massport will create or buy emissions reduction credits surplus to existing Clean Air Act requirements from stationary or mobile sources in the greater Boston metropolitan area and “retire” them (making use of Massachusetts’ “open-market” trading program, as described in the box below). In obtaining such credits, Massport has agreed to: (1) preferentially select mobile source credits to the extent that their cost does not exceed two times the cost of stationary source credits for the first two years of the program, and 1.5 times the cost of stationary source credits for the remaining years of the program; or (2) purchase stationary source credits at a ratio of 2:1 for each unit of offsets required in the first two years and 1.5:1 for every year thereafter.[162]

Massachusetts Open-Market Emissions Trading

In January 1994, Massachusetts became the first state to implement an open market trading rule that follows the guidelines recommended in the EPA’s Economic Incentive Program.[160] The Massachusetts program defines three types of credits: discrete credits, offset credits, and allowances. Massport will focus on purchasing discrete credits to meet its emissions goals.

Discrete credits[161] are traded in tons or partial tons of emissions (in this case, NO_X). Discrete credits are created when an emission source reduces emissions beyond the level that is required under existing regulations. These surplus credits may then be sold to a source that requires emission reduction credits in order to meet an emissions reduction requirement. Massachusetts requires that discrete credits are real, quantifiable, surplus, enforceable and permanent.

Initially, costs incurred to implement the AQI will be paid by airport tenants through a proportional increase in their current fees. There has been discussion to distribute implementation costs, over time, according to emissions perspectives. Overall costs will depend on the cost of reducing on-airport emissions and the cost of purchasing off-airport emissions credits. At present, Massport estimates that aggregate implementation costs will reach $15 million by 2015, an average expenditure of approximately $1 million per year. This estimate of compliance costs is based on projected spot market prices for discrete NOx credits over the 2001-2015 period as indicated below in Table IV-1.

[159] Emissions were calculated using the EDMS model and do not reflect impacts of recent changes in the industry.
[160] In 1995, EPA finalized its open-market trading rule, which specified the characteristics of a state program that would receive automatic Agency approval through a State Implementation Plan (SIP) revision. For more information, see <http://www.epa.gov/ttn/oarpg/t1/fr_notices/omtrsumm.pdf>.
[161] Discrete credits are rate-based emissions reductions that are awarded to emission sources that voluntarily reduce their emissions below their permitted limits. In contrast, Emission Reduction Credits (ERCs), are emission reductions expressed in tons per year.
[162] See 310 Code of Massachusetts Regulations, section 7.00, Appendix B for more information on the emission banking and trading regulation. This program excludes credits or offsets from the six largest power plants that are regulated under 310 Code of Massachusetts Regulations, section 7.29.

Table IV-1: Estimated Spot Market Price for Emission Credits

Purchase Period	Estimated Price Range ($/ton)
2001-2005	950-1,500
2005-2010	1,000-4,500
2010-2015	2,500-6,000+

Source: Massport AQI, 2001

Ultimately, the cost of the program per ton, will be equivalent to cost of the airport emission reductions and the price of open-market emission credits. The cost of open market NOx credits in Massachusetts and in most other states with open-market trading programs has remained fairly stable, at approximately $1,000/ton.

C.2Dallas/Ft. Worth and Houston Airports: GSE Voluntary Agreement

The state of Texas has four areas that are out of compliance with the NAAQS for ozone, two of which -- Houston-Galveston-Brazoria and Dallas/Forth Worth -- are also home to major airport facilities. The Houston-Galveston-Brazoria non-attainment area alone hosts three major commercial airports -- George Bush Intercontinental, William P. Hobby, and Ellington Field -- with aircraft operations in 1999 totaling 460,000, 258,000, and 133,188 respectively.[163] The Dallas/Fort Worth non-attainment area is also host to four commercial airports: (1) Dallas/Fort Worth International with 867,000 operations in 1999; (2) Fort Worth Alliance, with 214,939 operations in 1999; (3) Meacham, with 339,156 operations in 1999; and (4) Dallas Love Field, with 243,000 operations in 1999.[164]

In an effort to improve air quality in both of these non-attainment regions, the Texas Natural Resources Conservation Commission (TNRCC) has implemented a variety of programs and policies to reduce ozone precursor emissions. In May 2000, the TNRCC adopted a revision to the State Implementation Plan (SIP) for attaining ambient air quality standards that seeks to reduce NOx emissions from ground service equipment at the four commercial airports in the Dallas/Fort Worth area.[165] The rule calls for a reduction of GSE NOx emissions of 20 percent below 1996 levels by 2004; 50 percent below 1996 levels by 2005; and 90 percent below 1996 levels by 2008. Following litigation by the Air Transport Association of America and months of discussion among stakeholders, the rule was subsequently replaced by a voluntary "memorandum of agreement" (MOA) between the respective cities, the TNRCC, and the airport authority.

Under this agreement, parties to the MOA are obligated to assist air carriers in achieving the full objectives of the "GSE rule" (i.e., a 90 percent reduction in GSE NOx emissions by 2005). In line with that objective, the airlines committed to reducing GSE emissions by 75 percent relative to

[163] See FAA, 2000.
[164] Ibid.
[165] See 30 Texas Administrative Code §§114.400, 114.402, 114.406, and 114.009 ("GSE rule").

1996 levels. The Cities of Dallas and Fort Worth, and the Dallas-Forth Worth International Airport Board have agreed to reduce emissions by the remaining amount -- 15 percent below 1996 levels.[166] Required reductions can be achieved on-airport or in the surrounding Dallas/Forth Worth ozone non-attainment area. To implement the MOA, the TNRCC adopted "agreed orders" with American Airlines, Delta Airlines, and Southwest Airlines as revisions to the Texas SIP.[167]

Under the agreed orders, American Airlines will reduce NOx emissions from their operations at Dallas/Fort Worth International airport by 3.05 tons per day (tpd) by 2005. Delta and Southwest have agreed to implement increasing reductions in NOx from their 1996 GSE fleet emissions. Relative to this baseline, reduction targets are 25 percent before 2004, 50 percent before 2005 and 75 percent before 2008.[168] Under all three orders, airlines may choose their own means of compliance, which may include converting or retrofitting their GSE fleet and/or implementing controls on equipment (such as aircraft APUs) operated elsewhere in the Dallas/Fort Worth non-attainment area. In addition, the airlines may purchase NOx emissions credits and offsets, provided they are surplus to other regulatory requirements, and are real and verifiable.[169]

A voluntary agreement, with similar emissions reduction targets, was reached between TNRCC and Continental Airlines, Southwest Airlines, and the City of Houston[170] to reduce GSE NOx emissions in the Houston-Galveston-Brazoria non-attainment area.[171]

Table IV-2 lists 1996 emissions and expected emissions in 2007 absent the program for the airports located in the Dallas-Fort Worth and Houston-Galveston-Brazoria non-attainment areas under the above-described agreements.

Table IV-2: Estimated Uncontrolled GSE NOx Emissions (tons/day)

Airport Location	1996 Emissions	2007 Emissions
Dallas-Fort Worth Area	5.40	6.80
Houston-Galveston-Brazoria Area	3.83	5.65

Source: TNRCC, 2000a and TNRCC, 2000b

[166] The City of Dallas agreed to achieve a reduction in NO_x of 0.193 tons/day at Love Field; the City of Fort Worth agreed to achieve a reduction of 0.039 tons/day at Alliance and Meacham airports; and the Dallas/Fort Worth International Airport Board agreed to achieve a reduction of 1.305 tons/day at Dallas-Fort Worth International from CNG conversion of buses operated by the airport.
[167] See TNRCC Agreed Order Docket No. 2000-1149-SIP, TNRCC Agreed Order Docket No. 2001-0221-AIR, and TNRCC Agreed Order Docket No. 2001-0222-AIR.
[168] In addition, Delta and Southwest have agreed to replace or retrofit all ground service equipment purchased after 1996, as needed, to achieve a 75 percent NOx reduction relative to uncontrolled emissions levels. These vehicles must be installed with Reasonable Available Controls Considering Costs (RACCC) and those purchased after 2004 must install Best Available Technology (BAT).
[169] These actions must be creditable and result in equivalent emission reductions pursuant to the TNRCC Emissions Banking Program (30 Texas Administrative Code §101.29).
[170] The City of Houston agreed to achieve a NOx reduction of 1.809 tons/day within the Houston airport system -- namely, at George Bush Intercontinental, William P. Hobby, and Ellington Field.
[171] See TNRCC Agreed Order Docket No. 2000-0826-SIP, TNRCC Agreed Order Docket No. 2000-0827-SIP, and TNRCC Memorandum of Agreement between TNRCC and the City of Houston.

The NOx reductions that can be expected from this agreement depend on emissions growth between now and 2007, absent the program. Given the 1996 emissions shown in Table IV-2, GSE emissions in 2007 in Dallas-Fort Worth and Houston areas are estimated to be 0.54 and 0.38 tons of NOx per day, respectively, after the agreement is implemented. It is important to note that emissions from the GSE fleet in these areas could be larger than these estimates, since the agreements allow the purchase of equivalent emission reductions from non-GSE sources to meet the agreement. However, the total expected emissions reductions for the area would be equivalent to this amount regardless of where the emissions occur.[172]

C.3 California South Coast: Program to Reduce Aviation Emissions

In its 1994 SIP, the State of California requested that the Federal government undertake an initiative to reduce aviation emissions in the South Coast portion of the state. The South Coast of California includes five major airports: Los Angeles International, Ontario International, Burbank, John Wayne and Long Beach. In this SIP request, the Federal government was tasked with achieving aircraft reductions of 3 tpd of reactive organic gases (ROG)[173] and 4 tpd of NO_X.[174] Subsequently, EPA initiated a consultative process in California with stakeholders to discuss efforts to reduce aircraft emissions. At EPA's suggestion, the airlines proposed to work voluntarily with the regulatory agencies on developing the terms of an agreement under which the air carriers would reduce emissions from their fleets of ground service equipment. The California Air Resources Board (CARB) agreed to participate in the effort but indicated to EPA that, because the ground service equipment was under CARB regulatory authority, CARB would not recognize any emission reductions realized from such an agreement as meeting EPA's obligation to reduce aircraft emissions.

In 2002, seventeen Air Transport Association airlines[175] that operated at the five South Coast airports and CARB entered into a GSE voluntary agreement to reduce emissions in the South Coast. Under the agreement, by 2010, the participating airlines agree to reduce ROG + NO_x fleet average emissions from the 1997 baseline GSE fleet to 2.65 grams per brake-horsepower hour -- approximately an 80 percent reduction -- and to have 30 percent of this fleet consist of zero emissions vehicles (ZEVs) by 2010. For the "growth fleet," (those GSE added to the fleet after 2003, one year after the signing of the MOU), the participating airlines agreed to have ZEVs represent at least 45 percent of new GSE equipment by 2010.[176] Each GSE in the growth fleet must also meet established emissions standards at the time of its introduction into the South Coast fleet.

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[172] For comparison, the emissions reductions from all sources estimated to be necessary to bring these areas into attainment of the ozone NAAQS is 180 and 91 tpd in the Dallas-Forth Worth and Houston area, respectively (TNRCC, 2000a and TNRCC, 2000b).

[173] For purposes of this discussion, the term reactive organic gases (ROG) is interchangeable with the term volatile organic compound (VOC) used elsewhere in this report.

[174] California Air Resources Board, *The California State Implementation Plan for Ozone: Volume II*, adopted November 15, 1994.

[175] Airline signatories to the MOA include: Alaska Airlines, American Airlines, Continental Airlines, DHL Airways, Hawaiian Airlines, Midwest Express Airlines, Southwest Airlines, United Parcel Service, Airborne Express, America West Airlines, American Trans Air, Delta Airlines, Federal Express, Jetblue Airways Corp., Northwest Airlines, United Airlines, and US Airways.

[176] The agreement excluded cargo loaders, ground power units, air starts, and cargo tractors from this requirement. This equipment will be reviewed during a 2006 technology review to determine whether additional emission reduction requirements are technically feasible and appropriate.

The participating airlines also committed to reduce diesel particulate emissions by installing CARB-verified filters or oxidation catalysts according to phase-in schedules that vary depending on age and type of vehicle. The participating airlines are required to install diesel particulate filters for specific GSE categories where the technology is proven to be technically feasible, does not pose safety or reliability problems, and are cost-effective. Where these criteria are not met, participating airlines are required to install diesel oxidation catalysts. To support the development of diesel particulate retrofit technology, participating airlines and CARB agreed to undertake a jointly funded demonstration project.

The requirements of this MOU are to be met in aggregate by participating airlines and do not specify an established reduction strategy. By 2010, California estimates that this program will reduce NOx and ROG emissions by approximately a total of 2 tpd.[177]

C.4Sacramento International Airport: Targeted efforts at various airport sources

Several airports, including Sacramento International Airport (SMF), are located in the Sacramento area of California, which is classified as being in severe non-attainment of the ozone NAAQS. Aircraft operations at SMF have been steadily increasing since 1991, when total aircraft operations were 152,161. In 1999, total aircraft operations at SMF were 154,165; they are predicted to increase to almost 217,766 by 2015, an increase of approximately 40 percent.[178]

As discussed more fully in the next chapter, a state is responsible under federal law for ensuring that new or expanding airports do not interfere with the attainment or maintenance of air quality standards in a particular region.[179] As a result, airports in some states are required to receive a certificate from the state attesting to compliance with this requirement before implementing certain projects. California conditions issuance of these certificates -- known as Air Quality Certifications (AQCs) -- on the development of a mitigation program to provide reasonable assurance that proposed projects will "be located, designed, constructed, and operated in compliance with air quality standards".[180]

In 1982, the California Air Resources Board (CARB) issued an AQC to SMF for constructing a second runway. The AQC is valid until the airport reaches a threshold level of 7 million annual passengers, 139,000 annual air carrier operations, and 4,270 permanent public parking spaces. The airport was required under this certificate to develop an Air Quality Program with a goal of reducing total emissions by 30 percent by the time the threshold level is met.[181] To comply, the Sacramento Department of Airports (DOA) must reduce emissions from GAV, GSE, and aircraft. The DOA's Air Quality Program specifies a variety of projects including: eliminating aircraft "power-backs" from the gates; streamlining the ground queuing of aircraft; reducing aircraft taxi distances; installing bridge-mounted electric power and pre-conditioned air units; replacing off-road fuel tanker diesel engines with on-road diesel engines; requiring airport shuttle and taxi service

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[177] CARB. *Draft 2003 South Coast State Implementation Plan,* January 2003.
[178] See FAA, 2000.
[179] See Airport Improvement Act, Title 49, Section 47106 (c)(1).
[180] Heroy-Rogalski, Kim and Jim Humphries, *Evaluation of Air Pollution Emission Reduction Measures at Sacramento International Airport*, presented April 12-14, 1999.
[181] At the time the AQC was issued, the threshold level was expected to be met in the 2005-2007 timeframe. Due to higher than expected growth rates, this level was met prior to the expected dates.

providers to use low-emitting vehicles; purchasing compressed natural gas (CNG) vehicles; and installing photovoltaic solar panels to generate electricity. More detail on three of these measures is provided below; their emission reduction benefits are summarized in Table IV-3.[182]

Fuel Tanker Diesel Engine Replacements

SMF has replaced off-road diesel engines with on-road engines for nine fuel tanker trucks. Typically, on-road engines, which are subject to more stringent emissions standards, are cleaner than off-road engines.[183] Since 1994, the Sacramento DOA has re-powered four fueling trucks with on-road engines and ordered five new trucks equipped with on-road engines.

Use of CNG Shuttle Buses

The DOA owns 32 shuttle vehicles, which provide passenger service between the terminals, rental car area and parking lots. Over half of this fleet – 18 vehicles – has been replaced with CNG-powered buses; the remaining buses are diesel powered. To support its CNG vehicles, the DOA has made additional capital investments in fueling and maintenance infrastructure. In addition to the county-owned CNG vehicles, several private companies are utilizing airport CNG refueling stations.

Electrified Gates and Pre-Conditioned Air

Electric systems that supply power and air conditioning have been installed at 12 new passenger bridges at SMF. These bridges are equipped to handle power and air conditioning needs for wide-body aircraft. In addition, the gates are equipped with electrical capacity to provide recharging for electric GSE equipment.

The three measures highlighted above account for estimated reductions of 6.2 tons per year (tpy) of NO_X, 0.5 tpy of reactive organic gases (ROG), 0.2 tpy of PM10, and 5.6 tpy of CO at SMF.

Table IV-3: Emissions Reduced by Three SMF Program Measures

Measure	Emission Reductions (tpy)			
	ROG	**NO_X**	**PM_{10}**	**CO**
Fuel Tanker Replacement	0.4	5.5	0.2	1.3
CNG Buses	-0.7	6.2	0.1	-4.2
Electrified Gates & Pre-conditioned Air*	0.5	4.3	0.1-0.4	5.6-22.4
* With full utilization of the gates, the expected reductions in tpy are: 1.9, ROG; 17.3, NO_X; 0.4, PM_{10}; and 22.4, CO.				

Source: Heroy-Rogalsi and Humphries, 1999

[182] Heroy-Rogalski and Humphries, 1999 also shows cost-effectiveness of these measures, see Chapter III.
[183] California standards for off-road diesel engines require that NO_X emissions from engines over 175 horsepower (hp) do not exceed 6.9 g/bhp-hr. In contrast, similar on-road engines must meet a 4 g/bhp-hr standard for NO_X.

The largest NO_X reductions resulted from the introduction of CNG buses into the airline shuttle fleet. This measure had the added benefit of decreasing diesel particulate matter. However, it also increased ROG and CO emissions, which are of air quality concern. Replacing diesel engines on fuel tankers led to a decrease in the emissions of all targeted pollutants and required the lowest additional capital investment.[184] On the other hand, because the size of the tanker fleet is limited, total reductions achievable through this measure may be small compared to other options. The measure with the lowest NOx reduction benefit was the installation of bridge-mounted power and pre-conditioned air; however, greater usage of these gates would increase the total emission reductions from this approach and lower the cost of this measure.[185]

C.5Switzerland: engine emissions charge and airport emissions goal

Under Switzerland's Clean Air Ordinance (CAO), individual Swiss cantons[186] are obliged to develop air quality programs to reduce emissions when pollution levels exceed prescribed limits.[187] Subject to this obligation, the cantons of Geneva and Zurich petitioned the Swiss federal government to develop a strategy for reducing emissions from aviation-related sources, including evaluation of an emissions-based landing charge or incentive charge.[188] Responding to this petition, a Swiss Federal Council resolution in 1993 directed Switzerland's Department of Transport and Energy to prepare a strategy for introducing an emissions charging system for air traffic. The Federal Office for Civil Aviation (FOCA) subsequently developed guidance requiring that "When fixing landing charges, airports have to take into account differing noise and gaseous emissions of aircraft."

Most air travel in Switzerland passes through the airports in Zurich and Geneva. In 2000, total aircraft operations at Zurich and Geneva International Airports totaled 325,622 and 170,751 respectively, meaning that these airports ranked as the 43rd and 106th busiest airports worldwide.[189] Thus, the implementation of emissions-based fee systems at these airports will affect the majority of air travel in Switzerland.

In September 1997, Zurich airport introduced an emissions charge for all civil aircraft landing at the airport; the Geneva airport introduced a similar program in November 1998. The fee system utilized at these airports is based on a FOCA classification system designed to reflect NO_X and VOC emissions during the LTO-cycle.[190] It is structured to create incentives for increased efficiency and to normalize emissions incentives between large and small aircraft by accounting for the size of the aircraft. To calculate applicable emissions fees, an engine emission factor (EEF) is calculated as follows:

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[184] Ibid. The additional capital cost was $27,000.
[185] Ibid.
[186] Swiss cantons are roughly equivalent to U.S. states.
[187] The Swiss Clean Air Ordinance is comparable to the U.S. Clean Air Act. Just as the U.S. Clean Air Act requires states to devise State Implementation Plans to achieve national ambient air quality standards, Swiss cantons are required by the Ordinance to develop air quality programs to remedy excessive pollution levels.
[188] Cantons are required to petition the federal government if the measures fall within the competency of the federal government.
[189] Airports Council International (ACI), *ACI Traffic Data: World airports ranking by total movements-2000 (preliminary)*, 2001.
[190] For a detailed description of the system at Zurich airport see *Zurich Airport: Aircraft Engine Emission Charges*, January 2000.

$$EEF = (LTO\text{-}NO_X + LTO\text{-}VOC) / maximum\ thrust$$

LTO-NO_X and LTO-VOC represent grams of NO_X and VOC emitted during the LTO-cycle; maximum thrust is measured in kilonewtons.[191] Based on its EEF, an aircraft is classified into one of five categories (see Table IV-4) ranging from 5 (lower emitting) to 1 (higher emitting).[192] Fees are assessed according to the resulting EEF classification.[193] Thus an aircraft classified as 1 pays a surcharge equivalent to 40 percent of the landing fee, whereas an aircraft classified as 5 has no increase in landing fee.[194]

Table IV-4: Switzerland Emission Classes and Charges

Class		**Engine Emission Factor (EEF)**	**Landing Fee Increase** (in percentage)
Clean → Dirty	1	>100	40
	2	100 – 80	20
	3	80 – 60	10
	4	60 – 50	5
	5	<50	no fee

The emissions-based surcharges indicated above have been offset by other fee reductions such that the weight-based landing charges assessed to airlines at the Zurich and Geneva airports has been reduced by five percent to maintain revenue-neutrality. Airport-related emission reduction measures that were historically paid through general airport revenues are now being funded directly by emissions surcharges.

In addition to the emissions-based fee surcharges, Switzerland's federal Office for Environmental Protection has established a goal for Zurich airport to maintain total NO_X emissions below 2,645 tons per year.[195] This goal is aimed at limiting the potential for further emissions increases, not current emissions.

While the emissions impacts of the Swiss program have not yet been quantified, there are indications that the surcharge system is affecting airline behavior. After the emissions charge was

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[191] A similar system exists for turboprop engines (i.e., the majority of engines in general aviation aircraft). The equation is: EEF = (LTO-NO_X + LTO-VOC)/power, where power equals mg/hp.

[192] See <www.aviation.admin.ch/d/themen/luftfzg/emis_jet.pdf> for a list of aircraft classifications.

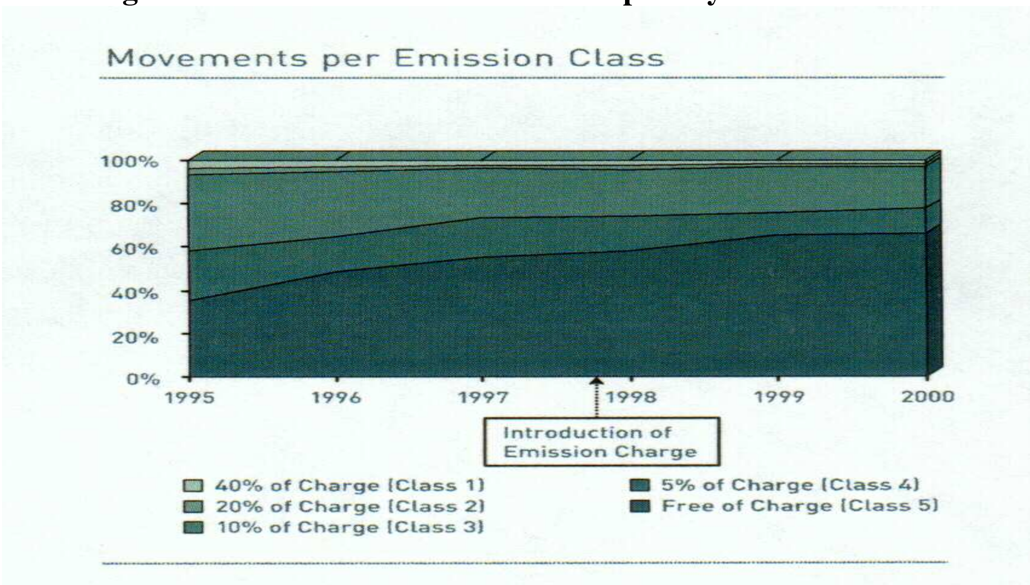
[193] Landing fees are paid at all airports to assist in paying for the operation of the airport and are typically based upon the maximum take-off weight of the aircraft.

[194] The average value for the LTO-emissions comes from the ICAO Engine Exhaust Emissions Data Bank. See <http://www.dera.gov.uk/aviation-emissions-databank.htm>.

[195] Unique Environmental Services (Unique), *Environmental Report 2000: Zurich Airport*, May 2001.

introduced in 1997, the percent of LTOs classified as lower emitting has risen, while the percent of LTO classified as relatively higher-emitting has declined (see Figure IV-4).

Figure IV-4: Movements at Zurich Airport by Emissions Class



Source: Unique, 2001.

Specifically, the share of aircraft movements with emissions factors classified as category 1 or 2 has decreased. At the same time the number of aircraft movements classified as category 4 or 5 has increased. Between 1997 and 2000, the share of total aircraft movements in class 5 increased from approximately 45 to 61 percent.[196] While these trends are highly suggestive of a positive emissions impact from the surcharge system, a more careful analysis of the benefits of the Swiss program would need to take into account a number of other trends that are likely influencing aircraft characteristics. For example, fleet turnover is probably partially responsible for the lower emissions of aircraft landing at Swiss airports in recent years. Despite the shift to cleaner aircraft, total emissions from aircraft have increased. From 1997 to 2000, aircraft emissions of NO_X at the Zurich Airport grew from 1,330 to 1,661 tons, an increase of almost 25 percent, while VOC emissions grew over 35 percent.[197] During the same period the number of LTOs at the airport grew by 18 percent (see Table IV-5).

Table IV-5: Aircraft-LTO Emissions at Zurich Airport (tons/year)[198]

	1994	1995	1996	1997	1998	1999	2000
NO_X	1,295	1,286	1,410	1,330	1,397	1,542	1,661
VOC	160	160	170	177	202	216	240

Source: Unique, 2001

[196] Ibid.
[197] Ibid.
[198] Metric tons were converted to short tons.

One explanation for the increased emissions is the growing number of flights at the airport -- approximately an 18 percent increase. However, despite the increased use of cleaner aircraft, the NO_X and VOC emissions per aircraft movement have slightly increased. This may be due to the types of aircraft landing at the airport and the design of the classification system. For instance, the emissions from some aircraft in class 5 may only be slightly better than the class 4 standard, while those in class one may be substantially higher emitters than the class 2 standard. However, insufficient information is available to explain this trend.

C.6Sweden: engine emissions charge

In 1989, Sweden introduced a NO_X tax on aircraft engines. It was narrowly designed to apply only to domestic flights on aircraft registered in Sweden. However, the tax conflicted with European Union directives, and it was eliminated in 1997. To replace the tax, the Swedish government asked its Civil Aviation Administration to design emissions-based landing fees. Such a system was subsequently introduced, in January 1998, at nine Swedish airports.[199] In October 2000, the same program was extended to all 19 airports owned by the Civil Aviation Administration.

The Swedish emissions-based fee program is similar to the one instituted in Switzerland and described in the previous sub-section. As indicated in Table IV-6, however, it differs slightly in that it provides for seven emissions classifications.

Table IV-6: Swedish Emission Classes and Charges

Class		**Average LTO-Emissions** (in g/kN)	**Landing Fee Increase** (in percentage)
Clean → Dirty	0	HC >19 *or* NO_X >80	30
	1	≤ 80 NO_X	25
	2	≤ 70 NO_X	20
	3	≤ 60 NO_X	15
	4	≤ 50 NO_X	10
	5	≤ 40 NO_X	5
	6	≤ 30 NOx	no charge

The revenues generated by emissions fees at Swedish airports are used to support an environmental fund that has helped pay for projects such as gate-based systems for supplying

[199] The original nine airports have the following characteristics in terms of total aircraft movements (and world ranking): Stockholm Arlanda, 279,383 (57); Gothenburg, 74,093 (235); Stockholm Bromma, 70,615 (241); Malmö, 49,472 (304); Luleå, 21,027 (442); Umeå, 20,173 (449); Sundsvall, 17,139 (467); Ångelholm, 12,581 (511); and Ostersund, 9,204 (553). Source: ACI, 2001.

electricity and pre-conditioned air. Meanwhile, base landing fees at Swedish airports have been reduced to ensure that the overall program is revenue neutral.

The direct impact of this charging system has not been evaluated. However, the Swedish government reports aircraft LTO-emissions from airports and airfields at the 19 locations where the CAA carries out airport operations, including operations at five military airfields. Since the introduction of the emissions charge at nine airports in 1998 and the remainder in 2000, aircraft LTO emissions of both NO_X and HC have declined (see Table IV-7).

Table IV-7: Aircraft LTO-Emissions at Swedish Airports and Airfields (tons/year)[200]

	1997	**1998**	**1999**	**2000**
NO_X	1,131	1,163	1,162	1,134
HC	229	257	263	228

Source: Swedish CAA, 2001

As the table indicates, there was an increase in NO_X emissions between 1997 and 1999; however, by 2000, NO_X emissions had declined almost to 1997 levels. This decline occurred despite growth in aircraft operations over the same period.

[200] Metric tons were converted to short tons.

V. Statutory and Regulatory Opportunities and Constraints

A. Overview

This chapter discusses the statutory and regulatory framework that underlies state efforts to reduce emissions from commercial aviation-related sources, and evaluates the legal opportunities and barriers for a number of emissions reduction approaches that are discussed in this report.[201] A discussion of state and local laws pertaining to aviation emissions sources is not included in this chapter; instead, the chapter provides an overview of the international and national policies that influence the ability of states to introduce programs to reduce emissions. The discussion focuses on the relevant sections of statutes, regulations, policies, and case law pertaining to various aviation-related emissions sources. The chapter is broken into two sections. The first section provides an overview of international and national policies influencing state efforts to reduce aviation-related emissions. The second section provides a preliminary assessment of state opportunities to reduce emissions, including the legality of or legal barriers to introducing policies at the state level. This chapter focuses on actions that states may take, and does not discuss the opportunities of the federal government or the international community to develop policies to reduce these emissions.

This study relies on relevant statutes and case law as well as interpretations of case law provided through work on aviation emissions. The section on national statutes and state opportunities to reduce emissions was based on work undertaken for CCAP by a legal consultant (Kenneth M. Resnik, Esq.).

B. Statutory and Regulatory Policies Surrounding State Action

This section of the chapter is broken into two parts: relevant international policies, and relevant U.S. laws.

B.1 International Law

International aviation policies are largely coordinated through the International Civil Aviation Organization. Many nations also develop bilateral agreements (known as air service agreements) in an effort to coordinate international activities. Understanding the international guidance and policy towards aviation emissions is important since nations, including the United States, aim to coordinate activities with those of other countries. However, as in any international policy, individual countries retain their national sovereignty to establish policies in accordance with national priorities. Therefore, the international framework provides a basis for action, but is not binding on individual nations.

[201] The statutory and regulatory context for military aircraft is not covered in this chapter since it is beyond the scope of this report.

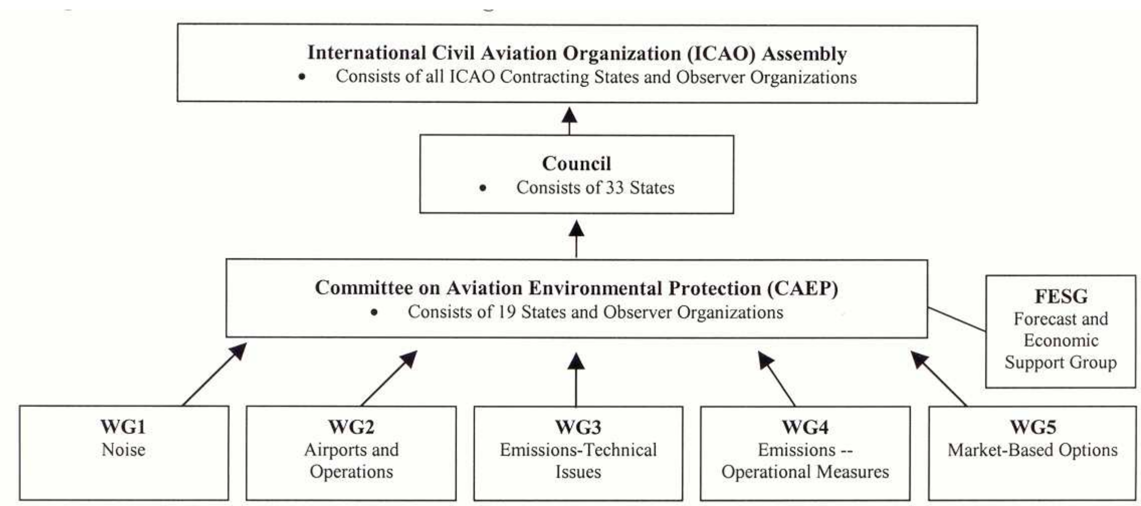
International Civil Aviation Administration

The International Civil Aviation Organization (ICAO) was created in 1947, under the Convention on International Civil Aviation (often termed the "Chicago Convention"). To date, 187 nations have signed the Chicago Convention and are thus contracting States (i.e., nations) to the ICAO. The Chicago Convention established the aim of ICAO as follows: "that international civil aviation may be developed in a safe and orderly manner and that international air transport services may be established on the basis of equality of opportunity and operated soundly and economically."[202] The position of ICAO on the environment was stated at the 1972 United Nations Conference on the Human Environment:

> [i]n fulfilling this role ICAO is conscious of the adverse environmental impact that may be related to aircraft activity and its responsibility and that of its member States to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the human environment.

ICAO functions as a sub-body of the United Nations that seeks to foster the planning and development of international air transport. The environmental practices of ICAO are largely undertaken by the Council's Committee on Aviation Environmental Protection (CAEP), which makes recommendations to the ICAO Council on environmental issues pertaining to aviation. CAEP recommendations are aided by detailed discussions in working groups (see Figure V-1 for overview of ICAO's structure for environmental work). The recommendations developed by CAEP are to be technically feasible, economically reasonable, and environmentally beneficial.

Figure V-1: Overview of ICAO's Structure for Environmental Work



[202] ICAO, Convention on International Civil Aviation, signed on December 7, 1944.

In relation to controlling aviation emissions, ICAO functions include: establishing standards and recommended practices and developing guidance on the use of taxes and charges.

Standards and Recommended Practices

Under the Chicago Convention, all participating nations have an obligation to adopt the ICAO standards to the extent possible. However, a nation that does not adopt the ICAO standards must provide a written explanation to ICAO describing the "differences between its own practice and that established by the international standard."[203] Other nations are therefore absolved of their obligations to "recognize as valid" the certificate of airworthiness issued by that nation since that certificate will not have been issued under standards "equal to or above" ICAO standards.[204] In other words, nations do not have to allow aircraft belonging to that nation right to travel through their airspace.[205] Recommendations agreed to by the ICAO Assembly are established as Standards and Recommended Practices (SARPs) and are included in Annex 16 to the Chicago Convention. After ICAO adopts a standard, it is put into effect by each ICAO Contracting State (i.e., nation). While ICAO seeks to establish common international standards for all aspects under its authority, the standards that are established are the minimum that nations are expected to meet, and thus do not limit national sovereignty in establishing more stringent standards. However, due to competitiveness concerns, national policies are typically identical to those recommendations made by ICAO.

Guidance on Taxes and Charges

In addition to engine emission standards, ICAO has evaluated the role of environmental levies in reducing aircraft emissions for air quality and climate change purposes. ICAO separates environmental levies into two categories: taxes and charges. In current ICAO definitions, taxes raise general national and local governmental revenues that are applied for non-aviation purposes, whereas charges defray the costs of providing facilities and services for civil aviation. While the Chicago Convention did not explicitly discuss environmental levies, it contained several provisions related to them. Article 24 requires member States to exempt from customs duties and other similar duties any fuel imported and retained on an aircraft arriving from an international flight. Article 15 requires that charges should be applied in a non-discriminatory manner and that they may not be imposed "solely in respect" of the right of transit, entry or exit.

ICAO has given little guidance to date on emission-related levies. Current ICAO guidance on environmental levies is highlighted in a recent ICAO Assembly Resolution.[206] The resolution articulates a preference for charges over taxes, and states that:

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[203] Ibid, Article 38.
[204] Ibid, Article 33.
[205] If a nation fails to submit a written notification it will be in default of its obligations and risk mandatory exclusion of its aircraft from the airspace of others and the loss of its voting power in the Assembly and the Council (Article 87 and 88 of the Chicago Convention).
[206] The ICAO 33rd Assembly in A33-7, Appendix I reaffirmed a 1996 ICAO Council interim guidance on taxes and charges. See <www.icao.int/icao/en/assembl/a33/resolutions_a33.pdf>.

> the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions, for example to [sic]:
>
> a) addressing the specific damage caused by these emissions, if that can be identified;
>
> b) funding scientific research into their environmental impact; or
>
> c) funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations.[207]

This interim guidance also indicated that: (1) there should be no fiscal aim behind the charges; (2) the charges should be related to costs; and (3) the charges should not discriminate against air transport compared with other modes of transport.

Air Service Agreements

Air service agreements (ASAs) negotiated between nations traditionally seek a reciprocal balance of benefits for the airlines of the participating countries. These agreements establish a regulatory mechanism for the performance of commercial air service between the participating countries. A bilateral agreement places direct limitations on carriers from each of the contracting states, permitting air service only to those cities specified in the bilateral agreement. In the United States, bilateral air transport agreements do not require ratification from the Senate but can instead be signed directly by the President.

Worldwide, there are over 3,000 ASAs with typical provisions related to safety and security, the right to use airports in the other's country, fair competition, taxes and duties, and user charges.[208] Two such provisions are most relevant to this assessment, as they have implications for national and local efforts to control aviation-related emissions. The first provision typically exempts uplifted aviation fuel[209] from taxation. For example, the agreement between the U.S. and Malta exempts the "fuel, lubricants and consumable technical supplies introduced into or supplied in the territory of a Party for use in an aircraft of an airline of the other Party" from taxes, levies, duties, fees and charges.[210] Agreements with this provision limit the ability of nations to apply a tax on the fuel used on aircraft from another country and therefore limit efforts to reduce aircraft emissions by applying a tax on fuel-use. The second relevant provision in many ASAs applies to the cost basis of user charges, and limits what can be charged under such a fee. A large number of the ASAs state that user charges should be just, reasonable, equitably apportioned among categories of users and not unjustly discriminatory. Any program

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[207] International Civil Aviation Organization (ICAO), *Council Resolution on Environmental Charges and Taxes,* Adopted by Council December 9, 1996.

[208] User charges pay for the cost of aviation infrastructure. Typical charges include airport and air navigation service charges, which pay for the operation of the airport and the air traffic control systems.

[209] "Uplifted aviation fuel" is fuel on-board the aircraft upon takeoff.

[210] United States Government, *Air Transport Agreement between the Government of the United States of America and the Government of Malta*, October, 2000.

that seeks to reduce aviation emissions through user charges must often meet these criteria.

Recent ASAs in the U.S. have been developed under the "Open Skies" initiative.[211] Whereas past ASAs were developed with limited liberalization of aviation markets, open skies agreements expanded the liberalization efforts by permitting unrestricted international air service between the participating countries, without restrictions on where carriers fly, the number of flights they operate, and the prices they charge. These agreements therefore place further constraints on the ability of participating nations to impose restrictions on international aviation. In considering the legal merits of a given policy approach, due consideration should be given to ASAs; however, full consideration of the implications of ASAs is beyond the scope of this report.

B.2 U.S. Law

This section discusses national statutes and regulations affecting the control of commercial aviation-related emissions. It includes policies that directly shape the control of emissions from aviation and those that indirectly influence the regulation of aviation emissions. The Clean Air Act establishes a framework for state and national control of aviation emissions similar to that which applies to other emission sources. Additionally, regulations related to the control of aviation activity influence the ability of states to develop programs to reduce aviation-related emissions. The statutes discussed in this regard include: the Airline Deregulation Act, the Anti-Head Tax Act, and the Federal Aviation Act. Discussion is also provided on state petitions under the Administrative Procedure Act.

Clean Air Act

The Clean Air Act (CAA) establishes standards for six criteria pollutants: ozone, carbon monoxide (CO), lead, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter. These standards, termed National Ambient Air Quality Standards (NAAQS), establish minimum ambient levels for each pollutant that must be met by every area, but allows states to develop pollution control programs that result in less pollution than specified by the NAAQS. In drafting the CAA, Congress endorsed a particular scheme of regulation. Generally, while Title I of the CAA empowers the states to regulate emissions from stationary sources, and Title II of the CAA empowers the EPA to regulate mobile sources, other CAA provisions limit the extent of this dichotomy,[212] The following section highlights the relevant portions of the CAA as they relate to airport-related emissions; it assumes a basic familiarity with the CAA.

Aircraft Engines

Policy regarding the setting of standards for aircraft engines is detailed in Title II of the CAA. In section 233, Congress expressly preempted state power to regulate aircraft engine emissions:

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[211] The U.S. currently has 95 ASAs, including 53 bilateral open-skies” agreements and one multilateral open skies agreement. See <http://ostpxweb.dot.gov/aviation/> for detailed list of current U.S. agreements.

[212] It is important to note that Title I does not explicitly limit state authority to stationary sources, but merely extends that authority to the states.

> No state or political subdivision thereof may adopt or attempt to enforce any standard respecting emissions of any air pollutant from any aircraft or engine thereof, unless such standard is identical to a standard applicable to such aircraft under this part.

Although EPA has the authority to promulgate emission standards for aircraft engines, that authority is limited. Section 231(b) provides that such regulations will take effect "after such period as the Administrator finds necessary (after consultation with the Secretary of Transportation) to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period." Further, section 231(c) dictates that such regulations will not take effect if "disapproved by the President . . . on the basis of a finding by the Secretary of Transportation that any such regulation would create a hazard to aircraft safety." The responsibility for enforcing the standards lies with the Secretary of Transportation who has delegated responsibility to the FAA.

Nonroad Engines

The CAA classifies engines and vehicles that are not used on the road as nonroad vehicles. In this regard, most GSE is classified as nonroad vehicles. The control of emissions from nonroad engines is outlined in section 209 of the CAA Amendments of 1990. Section 209 gives EPA the authority to establish emissions standards for new nonroad engines and vehicles. In relevant parts, section 209(e)(1) outlines federal preemption for certain types of nonroad equipment:

> No state or political subdivision thereof shall adopt or attempt to enforce any standard or other requirement relating to the control of emissions from either of the following new nonroad engines or nonroad vehicles subject to regulation under this chapter – (A) [Construction and agricultural equipment], (B) [Locomotives].

Further specifications for the control of other nonroad equipment is outlined in section 209(e)(2), and provides that:

> (A) In the case of any nonroad vehicles or engines other than those referred to in subparagraph (A) and (B) of paragraph (1), the Administrator shall, after notice and opportunity for public hearing, authorize California to adopt and enforce standards and requirements relating to the control of emissions from such vehicles or engines . . .
>
> (B) Any State other than California which has plan provisions approved under part D of subchapter I of this chapter may adopt and enforce after notice to the Administrator, for any period, standards relating to the control of emissions from nonroad vehicles or engines (other than those referred to in subparagraph (A) or (B) of paragraph (1)) and take such actions as are referred to in

> subparagraph (A) of this paragraph respecting such vehicles or engines if – (i) [standards must be identical to California], and (ii) [two year notice period].

Under this authority, the standards "shall achieve the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the engines or vehicles to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology."[213]

Among other rulemaking activities related to section 209, EPA issued an interpretive rule, stating, in part, that "EPA believes that states are not precluded under section 209 from regulating the use and operations of nonroad engines, such as regulations on hours of use, daily mass emission limits or sulfur limits on fuel."[214] In Engine Manufacturers Ass'n v EPA the D.C. Circuit Court of Appeals upheld EPA's rule in this regard.[215]

On-road Vehicles

On-road vehicles using the airport (e.g., GAV) are subject to the same set of regulations and requirements as similar vehicles serving non-airport facilities. Under section 209 of the CAA, states are prohibited from adopting or attempting to enforce emissions standards for new motor vehicles or new motor vehicle engines. However, Section 209 authorizes California to adopt "standards (other than crankcase emission standards) for the control of emissions from new motor vehicles" with a waiver from the EPA. Upon the adoption of such a standard by California, Section 177 permits other states to follow suit and adopt the identical policy. The CAA gives states the authority to establish Transportation Control Measures (TCMs) in ozone non-attainment areas in order to reduce emissions from on-road vehicles. A variety of TCMs have been introduced at airports including: express bus service from remote parking areas, ridesharing, mass transit, parking management, and free bus service.

Stationary Sources

The CAA under Title I specifies a set of responses to emissions of stationary sources, and a variety of regulations have been developed in response to these requirements. Under the CAA, stationary sources at airport facilities are treated the same as stationary sources off the airport; therefore, they must meet the same regulations as similar off-airport sources. The control of stationary sources is contingent on the facility type and the applicable rules for such a source.

Indirect Sources

Section 110 of the CAA confers broad authority on the states to regulate indirect sources. Congress has provided that states could include "indirect source review

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[213] 42 U.S.C., section 213 (a) 3.

[214] 59 FR 31306, 40 C.F.R. Part 89, Appendix A to Subpart A.

[215] 88F.3d 1075, 1094 (1996)), hereafter referred to as Engine Manufacturers Ass'n v EPA.

programs" in a State Implementation Plan (SIP).[216] An "indirect source" is defined as "a facility, building, structure, installation, real property, road, or highway which [sic] attracts, or may attract, mobile sources of pollution."[217] Further, the previous section clearly states that airports are "indirect sources," providing that as expressed in section 110(a)(5)(B):

> The Administrator shall have the authority to promulgate, implement and enforce regulations under subsection (c) of this section respecting indirect source review programs which apply only to federally assisted highways, airports, and other major federally assisted indirect sources...(emphasis added).

In order to regulate indirect sources, states would need to include an indirect source review program in their SIPs and provide details on the program. A number of states currently have such a program included in their SIPs.[218]

General Conformity

Federal entities are prohibited under Section 176(c)(4) of the CAA from taking actions in nonattainment or maintenance areas, which do not conform to the SIP of a given area. The EPA promulgated regulations ("General Conformity Regulations"[219]), applicable to everything but highways and mass transit[220], to ensure that federal actions conformed to the SIPs.[221] The purpose of conformity is to: "(1) ensure Federal activities do not interfere with the budgets in the SIPs; (2) ensure actions do not cause or contribute to new NAAQS violations, and (3) ensure attainment and maintenance of the NAAQS."[222] All federal actions are covered unless otherwise exempt (e.g., actions covered by transportation conformity, actions with clearly de minimis emissions, exempt actions listed in the conformity rule, or actions covered by a presumed-to-conform listing by a specific agency).

Conformity can be demonstrated by: (1) showing emission increases are included in the relevant SIP; (2) the State agreeing to include the emissions increases in its SIP; (3) in areas without SIPs , showing no new violations of NAAQS and/or no increases in the frequency/severity of violations; (4) using offsets, and (5) implementing mitigation measures. Some emissions are excluded from conformity determination, such as those already subject to new source review; those resulting from the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or compliance with other environmental laws, and indirect emissions from the actions and projects that are not reasonably foreseeable, or that are not under a continuing program responsibility

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216 42 U.S.C., section 110(a)(5)(A)(i).
217 42 U.S.C., section 110(a)(5)(C).
218 States that have such requirements include: California, Connecticut, Minnesota, New York, North Carolina, Oregon, Utah, Vermont, and Wisconsin (FAA, 1997).
219 40 CFR 93.150-160.
220 Highways and mass transit are covered under EPA's Transportation Conformity Regulations (58 C.F.R. 62188).
221 58 C.F.R. 63214.
222 U.S. EPA, *General Conformity Website*, see: <www.epa.gov/ttn/oarpg/genconformity.html>.

of the relevant agency. In September 2002, the FAA and EPA released a guidance document that provides answers to a specific set of questions on implementing general conformity for airports. [223]

The Airline Deregulation Act

The Airline Deregulation Act (ADA), passed in 1978, introduced fare and route competition, and permitted unrestricted entry into the air passenger marketplace by new domestic carriers. Section 41713(b)(1) of the ADA limits the power of states with regard to price, route, or service in that it specifies:

> Except as provided in this subsection, a State, political subdivision of a State, or political authority of at least 2 States may not enact or enforce a law, regulation, or other provision having the force and effect of law related to a price, route, or service of an air carrier that may provide air transportation under this subpart.

The Anti-Head Tax Act

The Anti-Head Tax Act (AHTA) was originally passed in 1973. It provides the foundation for Passenger Facility Charges[224] at airports. The guidelines for such charges is specified in section 40116(c):

> A State or political subdivision of a State may levy or collect a tax on or related to a flight of a commercial aircraft or an activity or service on the aircraft only if the aircraft takes off or lands in the State or political subdivision as part of the flight.

The statute also specifies that "[e]xcept as provided in subsection (d) of this section, a State or political subdivision of a State may levy or collect . . . reasonable . . . landing fees . . . from aircraft operators for using airport facilities of an airport owned or operated by that State or subdivision."[225] Subsection (d) does not permit states to "levy or collect a . . . fee . . . first taking effect after August 23, 1994, exclusively upon any business located at a commercial service airport or operating as a permitee of such an airport other than a . . . fee . . . wholly utilized for airport or aeronautical purposes."

The Federal Aviation Act

The Federal Aviation Act, originally passed in 1958, grants the FAA sole responsibility for the nation's civil-military system of air navigation and air traffic control. Among many other provisions, the Federal Aviation Act provides that "[t]he Administrator of the Federal Aviation Administration shall promote safe flight of civil aircraft in air commerce . . . "[226] In addition, two sections of the Act specifically address noise. Section 44715(a)(1)(A)(ii) dictates that the Administrator of the FAA, "as he

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[223] For more information, see: <www.epa.gov/ttn/oarpg/conform/airport_qa.pdf>.
[224] Passenger Facility Charges are applied to the ticket price and are used to pay for the operation of the airport.
[225] 49 U.S.C., section 40116(e)(2).
[226] 49 U.S.C., section 44701(a).

deems necessary" shall promulgate regulations to "control and abate" aircraft noise. The Act further dictates that the EPA must be consulted in this process.[227] Another section of the Act specifies that "noise policy must be carried out at the national level."[228] Specific provisions of the Act will be discussed below where appropriate.

The Airport and Airway Development Act

The Airport and Airway Development Act (AADA) of 1970 authorized the Department of Transportation (DOT) administrator to set minimum safety standards for airports and issue operating certificates for airports meeting those standards. In relevant part the Act states:

> (1) The Secretary [of Transportation] shall not approve any project application for a project involving airport location, a major runway extension, or runway location unless the Governor of the State in which such project may be located certifies in writing to the Secretary that there is a reasonable assurance that the project will be located, designed, constructed, and operated so as to comply with applicable air and water quality standards . . . [229]

State Petitions

States may petition the EPA to set stricter standards for aircraft engine emissions. The Administrative Procedure Act provides that "interested person[s]" have the right to petition an Agency to amend or repeal a rule.[230] Since the EPA sets standards for aircraft engine emissions as part of its rulemaking capacity, any interested person may petition the Agency to revise the rule. Further, EPA's denial of such a petition would be reviewable by the U.S. Circuit Court.[231]

C. Opportunities for State Actions

It is clear from the structure of the CAA (see above) that states may not simply impose regulations governing emissions from aircraft engines. Thus, a state could not issue a regulation dictating that individual aircraft engines operating in that state emit less than a certain amount of NO_X. This does not necessarily mean that states cannot promulgate and defend regulations to reduce aggregate airport emissions. The following section discusses a variety of opportunities for states to develop programs to reduce airport-related emissions. The opportunities evaluated in this legal analysis include: (1) regulation of the ground-level operation of aircraft; (2) programs to limit the emissions of GSE; (3) emissions-based landing fees; (4) regulation of GAVs; (5) "airport bubbles"; (6) state petitions; and (7) other opportunities (see chapter IV for greater details on these programs). This section broadly examines legal issues related to aviation and to implementing of these options. It is impossible to predict the success or failure of any

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[227] 49 U.S.C., section 44715(a)(2). See also 49 U.S.C. §§ 44715(c) and 44715(d).
[228] 49 U.S.C., section 47521(3).
[229] 49 U.S.C. 47106(c)(1)(B).
[230] 5 U.S.C., section 553(e).
[231] Oljato Chapter of the Navajo Tribe v. Train, (hereafter Oljato), 515 F.2d 654, 66-67 (D.C. Cir. 1975).

particular regulation in the abstract; the drafting of that regulation is particularly important in determining whether it will withstand scrutiny. This section also addresses whether a particular course of action by the states would be pre-empted by federal law, as pre-emption is a primary obstacle -- although by no means the only one -- facing state efforts to regulate airport emissions. Other obstacles must also be considered, and they receive cursory attention here. These obstacles include state regulations that would be impermissible because they violate the Commerce Clause or the Equal Protection clause of the United States Constitution.[232] Any potential course of action by a particular state would require detailed legal analysis before any attempt to implement it was made.

C.1Brief Review of Preemption Doctrine

The question examined in this section is whether federal law preempts state law or regulation in a particular area. Thus, a review of preemption doctrine is necessary. The Supremacy Clause of the United States Constitution provides that federal law takes precedence over state law, and thus federal law may preempt a state law.[233] Preemption is not intended to intrude unduly on state sovereignty.[234] In determining preemption, the sole consideration is the intent of Congress.[235] Congress must have intended for the enacted statute to preempt state law.[236]

There are three ways in which federal law can preempt state law. First, Congress may expressly state in a statute that it is preempting state law.[237] Second, Congressional intent to preempt state law may be inferred "where the scheme of federal regulation is sufficiently comprehensive to make reasonable the inference that Congress 'left no room' for supplementary state regulations", known as "field preemption."[238] Third, state law may be preempted if it actually conflicts with federal law, if it is "physically impossible" to comply with both laws, or if the state law is "an obstacle to the accomplishment and execution of the full purposes and objectives of Congress."[239]

C.2State Regulation of Ground-Level Operation of Aircraft

As a general proposition, states may seek to regulate emissions from airports by regulating the ground-level operation of aircraft, for example, limiting the time and manner in which an airplane may idle or regulating the means of supplying aircraft with power at the gate.

The Clean Air Act

As discussed above, section 233 of the CAA prohibits states from setting aircraft emissions standards. While some may argue that this restriction extends to regulating

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232 The Commerce Clause is Article I section 8. The Equal Protection clause is the Fourteenth Amendment.
233 U.S. Constitution, Article VI.
234 Shaw v. Delta Air Lines, Inc., (hereafter Shaw), 463 U.S. 85, 95 (1983).
235 California Fed. Savings and Loan Assoc. v. Guerra, (hereafter California Fed. Savings), 479 U.S. 272, 280 (1986).
236 Shaw, 463 U.S. at 95.
237 California Fed. Savings, 479 U.S. at 280.
238 Ibid at 281. See also Rice v. Santa Fe Elevator Corp., 331 U.S. 218 (1947).
239 Ibid.

ground-level use and operation of airline engines, it is unlikely that such an argument would succeed.

In regulating motor vehicles, section 202 of the CAA empowers EPA to set emissions limits for new vehicles, and provides that states "shall not adopt or attempt to enforce any standard relating to the control of emissions from new motor vehicles or new motor vehicle engines subject to this part." However, Congress also provided that "[n]othing in this part shall preclude or deny to any State or political subdivision thereof the right otherwise to control, regulate, or restrict the use, operation, or movement of registered or licensed motor vehicles.[240] The question is whether a similar scheme exists for aircraft. The CAA is silent as to whether the states retain the power to regulate ground-level use and operation of aircraft.

In California v. Navy, the court held that "Section 233 preemption is aimed at protecting the owner and the manufacturer of the vehicle and the engine against the 'chaos' of multiplex standards for entities which readily transverse state lines"(emphasis in original).[241] The Ninth Circuit Court of Appeals affirmed the district court ruling, agreeing that "if the state pollution regulations can be met without affecting the design, structure, operation, or performance of the aircraft engine, then the state emission regulations are not preempted by § 233."[242] Therefore, any operating requirements that were not deemed to oppose this portion could be upheld.

Since preemption of state power to regulate ground-level operation of aircraft would not fit the stationary scheme the courts found Congress was setting in the CAA, and would not subject manufacturers and owners or aircraft engines to myriad conflicting regulations, there is a strong argument that section 233 should be construed narrowly as not preempting such state regulatory efforts.

Preemption under the Federal Aviation Act

The FAA has articulated the position that the Federal Aviation Act "preempts state and local regulations of aircraft operations."[243] The FAA cites sections 40103(b) and (d), 41713, and 44715 of the Federal Aviation Act. Turning first to whether any of these provisions expressly preempt state regulation of ground-level aircraft operations, it is seemingly evident that they do not. Section 40103(b) provides that the Administrator of the FAA shall develop plans and policies for the use of airspace and "assign by regulation or order the use of the airspace . . ." The section further provides that the FAA shall prescribe air traffic regulations. Section 40103(d) appears inapposite, since it regulates the aircraft of the armed forces of foreign countries. Section 41713 is the ADA, and section 44715 allows the FAA to control aircraft noise.

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[240] 42 U.S.C. § 7502(d). As noted in Section 1, the courts have approved a similar scheme relating to nonroad engines.
[241] California v. Navy, 431 F.Supp. 1271, 1285 (N.D. Ca. 1977)(aff'd 624 F.2d 885 (9th Cir. 1980)).
[242] California v. Navy, (hereafter California v. Navy, 1980), 624 F.2d 885, 888 (9th Cir. 1980).
[243] Federal Aviation Administration, (hereafter FAA Memo), *Legality of Emission Based Airport Landing Fees*, Memo to EPA/FAA Stakeholder Process on June 22, 2000.

The Airline Deregulation Act

The only statute containing an express preemption provision is the ADA. That Act provides that the states may not enact or enforce any law or regulation "relating to rates, routes, or services of any air carrier." The Supreme Court first dealt with the scope of preemption in Morales v. Trans World Airlines, Inc.[244] Morales addressed the question of whether states could enforce the guidelines of the National Association of Attorneys General with respect to airline fare advertisements. The Court noted that the key to understanding the scope of ADA preemption was the phrase "relating to."[245] The Court found that "[s]tate enforcement actions having a connection with, or reference to, airline 'rates, routes, or services' are pre-empted . . ."[246] The Court made clear, however, that "some state actions may affect airline fares in too tenuous, remote, or peripheral a manner to have pre-emptive effect."[247] Finally, the Court noted that it was not determining where a line might be drawn between state actions that would or would not "relate to" airline rates.[248]

The Supreme Court addressed ADA preemption further in American Airlines, Inc. v. Wolens.[249] In Wolens, plaintiffs sued American Airlines, contending that the "frequent flyer program" modifications imposed by American violated Illinois law and were a breach of contract. The Illinois Supreme Court had found no preemption, because the frequent flyer programs were not "essential" to the airline and the plaintiffs' claims only "tenuously" related to rates, routes, and services. The U.S. Supreme Court reversed, finding first that the ADA made no distinction between "essential" and "unessential" matters.[250] Further, the Court found that the claims related to "'rates, i.e. American's charges in the form of mileage credits . . . and to 'services,' i.e. access to flights and class-of-service upgrades . . ."[251] The Court found that plaintiffs' claims under Illinois state law were preempted.[252] For reasons not relevant to this report, it also found that the ADA did not preempt a contract between private parties.[253]

In Federal Express Corp. v. California Public Utilities Comm'n, the Ninth Circuit Court of Appeals found that Federal Express was an "air carrier" and that trucks were "an essential component" of its system to deliver packages.[254] The Court held that the Public Utility Commission's regulation of "rates, of discounts and promotional pricing, of claims, of overcharges, of bills of lading and freight bills, and its imposition of fees enters the zone Congress has forbidden the states to enter."[255] Thus, the Court found such a regulation was preempted by the ADA. However, the Court pointed out that "it is

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[244] Morales v. Trans World Airlines, Inc., (hereafter Morales), 504 U.S. 374 (1992).
[245] Ibid at 382.
[246] Ibid at 384.
[247] Ibid at 390.
[248] Ibid.
[249] American Airlines, Inc. v. Wolens, (hereafter Wolens), 513 U.S. 219 (1995).
[250] Ibid at 226.
[251] Ibid.
[252]Ibid at 228.
[253] Ibid at 233.
[254] Federal Express Corp. v. California Public Utilities Comm'n., (hereafter Federal Express), 936 F.2d 1075 (9th Cir. 1991) at 1076-77.
[255] Ibid at 1078.

uncontested in this case that the general traffic laws of California and its safety requirements for trucks on its highways apply to Federal Express; only economic regulation is challenged."[256]

It would seem logical to conclude from these decisions that state regulation of ground-level airport operations would, as non-economic regulation, be held to be so tenuously connected to "rates, routes, and services" as to not be preempted under the ADA. A note of caution is appropriate in this analysis. A regulation that might be deemed related to "safety," such as a regulation requiring that aircraft be towed, rather than taxi, from the gate to the runway, might be preempted. This is because certain state courts have held that state laws restricting an airline's selection of an employee based on physical characteristics necessarily has a connection to airline services, since they affect the safety of those services.[257] These courts held, in essence, that any law affecting safety has a connection to services, and thus were preempted by the Act. The same logic could be applied to state regulation of ground-level operations, provided there was a basis for finding the regulations affected safety. With this caveat, it is probable that certain state regulations aimed a ground-level operation of aircraft would not be preempted under the ADA since they do not infringe on safety.

Section 40103

Section 40103 empowers the Administrator of the Federal Aviation Administration to regulate "airspace." Specifically, section 40103(b)(2) dictates that the Administrator "shall prescribe air traffic regulations on the flight of aircraft" (emphasis added). The FAA might argue that this provision results in field preemption of any state laws or regulations, including any regulation related to ground level operation of aircraft.[258]

The notion that preemption exists simply because a Federal Agency has issued regulations concerning an issue, even comprehensive regulations that leave no space for state regulation, is one that has been rejected by the Supreme Court. "To infer preemption whenever an agency deals with a problem comprehensively is virtually tantamount to saying that whenever a federal agency decides to step into a field, its regulations will be exclusive. Such a rule, of course, would be inconsistent with the federal-state balance embodied in our Supremacy Clause jurisprudence."[259] However, there is little to suggest that the courts would disagree with the view that the ADA preempts all local control of aircraft operations, including ground operations. Courts have, in fact, given expansive definition to the scope of the FAA's authority.[260] Because regulations mandating single or reduced engine taxiing or towing aircraft from the gate may fairly be seen as impinging on the safety of takeoffs and landings, it is likely that such regulations would be struck down. More likely to survive legal challenge would be

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[256] Ibid.
[257] See Wellons v. Northwest Airlines, Inc., 165 F.3d 493, 495 (6th Cir. 1999)(collecting cases).
[258] FAA Memo.
[259] Hillsborough County v. Automated Medical Laboratories, Inc., 471 U.S. 710, 713 (1985).
[260] See Burbank-Glendale-Pasadena Airport Authority v. City of Los Angeles, 979 F.3d 1338, 1341 (9th Cir. 1992) that stated: "The proper placement of taxiways and runways is critical to the safety of takeoffs and landings and essential to the efficient management of the surrounding airspace".

regulations that do not affect the movement of aircraft, such as requiring the installation and use of fixed-based power and pre-conditioned air.

Section 44715

Section 44715 is the re-codification of what was known as the Federal Noise Pollution Control Act. The FAA and the airlines have looked to decisions based on this statute to support arguments that the entire field of aircraft regulation is preempted. Specifically, the airlines and FAA have used the Supreme Court's decision in City of Burbank v. Lockheed Air Terminal, Inc in support of this preemption.[261] In Burbank, the City of Burbank promulgated a city ordinance forbidding any jet aircraft from taking off from Hollywood-Burbank Airport between 11:00 p.m. and 7:00 a.m., and forbidding the airport from permitting any such take-offs. While the case was pending in the lower courts, Congress passed the Noise Control Act of 1972, amending the Federal Aviation Act. The Court found that the Burbank ordinance was preempted, holding that "[i]t is the pervasive nature of the scheme of federal regulation of aircraft noise that leads us to conclude that there is pre-emption (emphasis added)."[262] The Court also found that if a significant number of communities followed the Burbank example, "it is obvious that fractionalized control of the timing of takeoffs and landings would severely limit the flexibility of the FAA in controlling air traffic flow. The difficulties of scheduling flights to avoid congestion and the concomitant decrease in safety would be compounded."[263]

Thus, the Supreme Court's holding does not rest exclusively on the provisions of the Noise Control Act, but largely so. The decision can be, and has been, interpreted to hold that state and local controls of noise by aircraft, even if those controls come in the form of such regulations as curfews, are pre-empted.[264] Certainly, it is not clear from the Supreme Court's decision that Congress intended to preempt any other area of regulation than noise, despite the decision's somewhat broad language regarding safety. Further, neither the airlines nor FAA have identified a court decision broadening the Burbank holding to show that the statutes preempt the entire field of aircraft regulation.

Ground regulations may still run afoul of the FAA regulations on *Notice of Approval of Airport Noise and Access Regulations* ("Part 161").[265] Even those regulations not intended to curtail or limit noise pollution fall under Part 161 if those regulations are ones "affecting access or noise that affects the operation of Stage 2 or Stage 3 aircraft…"[266] Under this Part, regulations which must be submitted to the FAA for approval are exempt, as are peak-usage pricing schemes. Further, "[o]ther noise abatement procedures, such as taxiing and engine runups, are not subject to this part unless the procedures imposed limit the total number of Stage 2 or Stage 3 aircraft operations, or limit the hours of Stage 2 or Stage 3 aircraft operations, at the airport."[267]

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[261] City of Burbank v. Lockheed Air Terminal, Inc., (hereafter Burbank), 411 U.S. 624 (1973).
[262] Ibid at 633.
[263] Ibid at 639.
[264] See Faux-Burhans v. County Comm'rs of Frederick County, 674 F.Supp. 1172, 1174 (D.Md. 1987)(interpreting Burbank as limited to preemption of noise regulations and upholding broad zoning regulations).
[265] 14 C.F.R. section 161.
[266] 14 C.F.R. section 161.5.
[267] Ibid.

Thus, so long as state regulations of ground-level aircraft operation are not intended to curtail noise pollution, and do not impinge on safety requirements nor on FAA regulations regarding such topics as takeoffs and landings, it is possible that states or political subdivisions would have the authority to impose such regulations. However, it is likely that the FAA would protest any such regulation, and that courts may be sympathetic to the FAA's claims that such regulation was preempted. Further, the FAA has defined safety broadly, and there are indications that the courts would agree. In at least one instance, an airport convinced environmental regulators that requiring towing of aircraft from the gate was beyond the authority of the airport to implement, since the FAA maintained "preemptory control" over "operating procedures."[268]

C.3 Regulations on the Number of Operations at Airports

States may not regulate either the number of takeoffs or landings at an airport nor limit the performance of ground operations. The Federal Aviation Act would almost certainly preempt regulating the number of takeoffs and landings.[269] State regulation limiting the performance of the number of operations would, with almost equal certainty, be found to violate the preemption provisions of the ADA, since they would be a state regulation of airline services. Thus, neither of these options is available to states.

C.4 Limiting Flight Procedures

States may not limit flight procedures by requiring, for example, reduced use of reverse thrust on landing or requiring derated takeoffs. Such procedures are clearly within the jurisdiction of the FAA, which regulates flight safety. Thus, the Federal Aviation Act would preempt such regulations. In addition, imposing such requirements and the court challenge they would provoke could result in unfavorable law, since the Courts have not to this point determined the breadth of preemption under the Federal Aviation Act.

C.5 Controls on Types of Planes Using the Airport

It is unlikely that states could control the types of planes using airports (for example, requiring that only certain planes known to have low emissions may use the airport), even at airports where they are proprietors. This was, in effect, the strategy used in Burbank, where the airport limited the times that certain planes could use the airport. Although its decision was limited to preemption because of noise regulation, the Court also noted that such a curfew would have deleterious effects on the FAA's control of traffic flow. Limiting planes on the basis of their emissions characteristics would appear to have the same effect, and thus would likely result in preemption.

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[268] Airports Council International - North America, (hereafter ACI-NA, 2001), *Environmental Regulations Impacting Airports*, available at: <http://www.aci-na.org/new_website/frame_publications.html>, 2001.

[269] See Burbank (finding regulation disallowing takeoffs or landings during certain hours invalid and noting that it would "severely limit the flexibility of the FAA in controlling traffic flow.").

C.6 State Petition

States may petition the EPA to set stricter standards for aircraft engine emissions, and the Agency's denial of such a petition would be reviewable by the U.S. Circuit Court (see above). If the EPA were to deny the petition, it would have to set forth its reasons for doing so, and the petitioner could then seek judicial review.[270] Oljato set a procedure where, when an Agency had promulgated a standard under the Clean Air Act and the period for appeal of that standard under section 307 had passed, an interested party could petition the Agency for revision of the standard. In order to do so, "[t]he person seeking revision of a standard of performance . . . should petition EPA to revise the standard in question. The petition should be submitted together with supporting materials, or references to supporting materials."[271]

These materials must include "new information" on which the petition for revision is based. Only material that became available after the promulgation of the standard and the review period had passed would be allowed. Failure to base the petition on new information would, essentially, be a challenge to the original promulgation of the standard. Such a challenge is not permitted after the review period set forth in section 307 has passed.

In the case of aircraft engine emissions, the states might consider petitioning not only the EPA, but also the DOT. While the DOT does not have the power to revise standards, EPA's ability to promulgate new standards without DOT cooperation would be limited, at best. Note that there is no explicit procedure for petitioning both agencies.

C.7 State Limits on Emissions from Ground Support Equipment (GSE)

States may be able to limit emissions of GSE, as part of the promulgation of their SIPs, so long as the limitations do not create an "emissions standard" for new, nonroad engines. However, decisions by the First and Second Circuits make such state regulations problematic. Also, in 2000, the Texas Natural Resource Conservation Commission (TNRCC) promulgated rules requiring emissions reductions, specifically of NO_X, by owners or operators of GSE at specified airports (see Chapter IV). The Air Transport Association sued, claiming that the regulations were preempted by section 209(e) of the CAA and by the Federal Aviation Act and ADA. The parties settled the suit out of court, and the claims of the ATA were never adjudicated. However, there is a reasonable chance that the TNRRC and similar plans would not be preempted.

The Clean Air Act

Section 209(e)(2) addresses nonroad equipment other than locomotives and construction and farm machinery. It does not expressly prohibit state regulation of other "new" nonroad equipment. Instead, it provides that EPA shall authorize California to adopt and enforce emissions standards for nonroad engines, and allows other states to adopt emissions standards identical to those promulgated by California. As discussed above, EPA issued regulations interpreting this section providing that "states are not precluded under section 209 from regulating the use and operation of nonroad engines,

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[270] Oljato at 666.
[271] Ibid.

such as regulations on hours and use, daily mass emission limits or sulfur limits on fuel."[272] This portion of the rules was upheld by the Court of Appeals for the D.C. Circuit. The Court also found that the implied preemption found in section 209(e)(2) extends to new and existing nonroad equipment. Thus, the states cannot promulgate "standards or other regulations" "relating to the control of emissions from nonroad equipment."

The question, then, is whether the TNRRC plan was a "standard" "relating to the control of emissions" or was an "in-use limit on operation." California v. Navy is again instructive, since the Ninth Circuit Court of Appeals held that "if the state pollution regulations can be met without affecting the design, structure, operation, or performance of the aircraft engine, then the state emission regulations are not preempted by section 233."[273] Note that operation of the engine and operation of the equipment in which the engine is installed are two different matters.

Several recent decisions are more problematic. In American Automobile Manufacturers Assoc. v. Cahill, the Second Circuit was faced with deciding whether New York State's requirement that a certain percentage of automobiles sold in that state be zero-emission vehicles ("ZEVs") was preempted under section 209(a) of the CAA. New York State claimed that the requirement was not a "standard relating to the control of emissions" and thus was not preempted. The Second Circuit disagreed, reasoning that:

> To be sure, the ZEV sales requirement does not impose precise overall quantitative limits on levels of emissions, as do the classification system and fleet averages. It mandates only that a specified percentage of the cars sold by a manufacturer in any model year be ZEVs. Nonetheless, the ZEV sales requirement must be considered a standard "relating to the control of emissions." ZEV, after all, stands for "zero-emission vehicle" and a requirement that a particular percentage of vehicle sales be ZEVs has no purpose other than to effect a general reduction in emissions.[274]

The First Circuit, in Association of Int'l. Automobile Manufacturers, Inc. v. Commissioner, agreed with the Second Circuit, finding that Massachusetts' imposition of ZEV mandates was a "standard relating to the control of emissions, and thus preempted. The Court noted that "[r]ather than simply monitoring or enforcing compliance with some distinct numerical emissions standard, the very purpose and effect of the ZEV mandates is to effect a quantitative reduction in emissions."[275] These decisions are, of course, controlling law in the First and Second Circuits, encompassing the northeast states. It is difficult to conclude that any regulation that is aimed specifically at reducing

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[272] 59 FR 31306.
[273] California v. Navy, 1980.
[274] American Automobile Manufacturers Assoc. v. Cahill, (hereafter Cahill), 152 F.2d 196, 200 (2d Cir. 1998).
[275] Association of Int'l. Automobile Manufacturers, Inc. v. Commissioner, (hereafter Commissioner), 208 F.3d 1, 7 (1st Cir. 2000).

emissions from GSE in these states will be upheld. However, there are recent developments in other parts of the country that indicate more flexibility.

A recent U.S. District Court decision gives more reason for optimism for the ability of states to regulate GSE emissions. In 2000, the South Coast Air Quality Management District (SCAQMD) promulgated rules mandating that, when certain operators of local fleets purchased or replaced fleet vehicles, they acquire only specific vehicles designated by SCAQMD. The Engine Manufacturers Association (EMA) filed suit, claiming that the fleet rules were preempted by section 209 of the CAA. The District Court disagreed, finding that "[t]he Rules impose no new emission requirements on manufacturers whatsoever, and therefore do not run afoul of Congress's purpose behind motor vehicle preemption: namely, the protection of manufacturers against having to build engines in compliance with a multiplicity of standards."[276] The Court also found that "[r]ather than impose any numerical control on new vehicles, the rules regulate the purchase of previously certified vehicles."[277] Thus, the court reasoned, this case was distinguishable from Cahill and Commissioner. Since the fleet rules did not regulate sales by manufacturers, but purchases, they were not "standards" within the meaning of section 209. Therefore, states were not preempted from introducing such requirements. It must be pointed out that the California Court did not address the ruling by the First Circuit that if the "purpose and effect" of the regulations is to achieve a "quantitative reduction in emissions" the rule is impermissible under section 209.

The EPA, in a "clarification" of comments to the rules proposed by the TNRCC, adopted a somewhat similar line of reasoning in concluding that the CAA did not preempt the rules. The EPA reasoned, without reference to any case law, that because the fleet operators had alternatives available that did not require them to make modifications to the equipment (including measures to restrict emissions by restricting the use or operation of the equipment), the rules were not "standards" within the meaning of the CAA.

Given the SCAQMD decision, a rule requiring operators of GSE fleets to purchase alternative fuel or electric vehicles might be upheld so long as such vehicles were elsewhere defined. Of course, a state that had not adopted the California standards for Super Ultra Low Emissions Vehicles (SULEVs) and Ultra Low Emissions Vehicles (ULEVs) could not dictate that owners of fleets of GSE purchase vehicles meeting those standards. That would presumably amount to imposing a new emissions limitation. Such states could still require that fleet owners purchase only alternative-fueled vehicles, without dictating specific emissions standards those vehicles would have to meet. In the Northeast, however, Cahill and Commissioner dictate that a regulation intended to achieve a quantitative reduction in emissions from GSE will be overturned as preemptive. Although an argument might be made that this subverts Congressional intent, the established law in these circuits is, for the moment, clear.

[276] Engine Manufacturers Association v. South Coast Air Quality Management District, (hereafter SCAQMD) CV 00-09065 FMC, (Slip Op. at 7)(C.D. Ca. August 21, 2001).
[277] Ibid.

The Airline Deregulation Act

It is doubtful that rules similar to those adopted by the TNRCC would be preempted under the ADA, although a valid argument could be constructed for the opposite point of view. Because the rules would not constitute an "economic regulation," they may well escape preemption as being too "tenuous, remote, or peripheral" to airline rates and services (see section B.2 above). Support might be found in the Ninth Circuit's opinion in Federal Express that California highway and safety regulations still applied to trucks operated by an airline. However, some could argue that GSE were necessary in order to provide airline service at all, and thus any regulation of GSE was a regulation of services. While it is unlikely that the ADA would be construed so broadly, it is difficult to be definitive about this interpretation in the absence of relevant case law.

Other Provisions of the Federal Aviation Act

An argument that other provisions of the Federal Aviation Act preempt regulation of GSE relies on a field preemption argument. The argument about whether there is preemption relies on the same discussion as the state regulation of ground-level operations of aircraft. Here the argument that there is no federal preemption is considerably stronger. The FAA does not closely regulate GSE, and no provision of the Federal Aviation Act discusses GSE. Hence, it does not appear that the Federal Aviation Act would preempt state regulation of GSE.

C.8 Regulation of Ground Access Vehicles

Some portion of the pollution at airports is caused by GAV including buses, taxis, and private automobiles (see Chapter II). Proposals for limiting emissions from GAV include requiring commercial GAV to be fueled by alternative fuels, setting emissions standards for GAV fleets, or imposing idle restrictions on GAV. Notably, there is nothing unique about GAV because they are associated with airports. States have the same freedom and limitations in regulating cars, buses and taxis as they would if they were not contributors to airport pollution. The exception to this is that states may have increased power as the proprietors of airports to restrict or otherwise regulate GAV.

In regulating GAV emissions, states are restricted to regulating the use of automobiles at airports (controlling traffic flow, prohibit idling, etc.).[278] Of course, a state could, as the proprietor of an airport, ban private automobiles, but such a step would be politically unpalatable, even if legally acceptable.

Alternative Fuels

As noted above, at least one federal court has upheld a California plan requiring fleet operators, when purchasing new or replacing retired fleet vehicles, to purchase only vehicles meeting the definition of alternative fuel vehicles (which includes a requirement that the vehicle attain at least ULEV standards).[279] It appears that states that have

[278] The states may seek to regulate traffic flow by including Transportation Control Measures in their SIP.

[279] "Alternative-fueled vehicle" is defined in the court decision as "a vehicle or engine that is not powered by gasoline or diesel fuel and emits hydrocarbon, carbon monoxide, or nitrogen oxides, on an individual basis at least equivalent to or lower than a ULEV based on [C]ARB's certification data." "Alternative-fuel heavy-duty vehicle" is defined as a heavy-duty vehicle or engine not powered by diesel fuel and meeting the emissions requirements of CARB's Urban Transit Bus Rule.

adopted the California standards for LEV, ULEV, and SULEV could promulgate similar rules with equal success.[280] In states that have not adopted the California standards, such rules could not specify a particular emissions limit, since that would likely be construed as a preempted emissions standard. It would seem that such states could define alternative-fueled vehicle, and require fleets to purchase those vehicles. The definition of alternative-fueled vehicle could not include an emissions standard that vehicles would have to meet; thus, such a regulation might only be effective if the alternative-fueled vehicles were inherently lower in emissions than the vehicles they replaced.

States that are proprietors of airports could impose requirements on fleets operating within the airport with impunity, even if they had not adopted the California standards. While such a rule could not be promulgated in a SIP, but would have to be issued by the airport authority itself, there does not appear to be a preemption problem, because the state would not be acting under authority of its police power.

Fleet Emissions Requirements

As discussed above in relation to GSE, it is possible that a fleet emission requirement could be established, so long as a fleet operator had options available to meet the requirement without modifying the engines in question. That same analysis applies to GAV. As a legal strategy, fleet emissions requirements are not without risk, since there are no legal decisions clearly establishing a state right to impose such requirements.

Idle Restrictions

There are no legal obstacles to imposing idle restrictions, since the CAA and other statutes do not impinge on states' historic powers to regulate traffic and safety. Although it has an environmental purpose, a statute restricting idling would likely be viewed as a traffic regulation and would survive legal challenge. Most states and localities have some form of idling restrictions.

C.9 Landing Fees

Two options have been suggested under the rubric of landing fees (see Chapter IV). In an "increased fee" system, landing fees would be increased to cover the cost of airport emissions reduction projects. The basis for the landing fee, however, would still be aircraft weight. In an "emissions-based fee" system, planes landing at the airport with greater emissions would pay a proportionally higher fee.

State Action

The Anti-Head Tax Act (AHTA) provides that:

> A State or political subdivision of a State may levy or collect a tax on or related to a flight of a commercial aircraft or an activity or service on the aircraft only if the

[280] This is different from the ULEV, SULEV, and LEV requirements in states that have adopted the California standards. It would require that these vehicles be purchased in a particular area (i.e., fleets serving an airport), whereas the ULEV, SULEV, and LEV requirements specify that the manufactures must sell a certain percentage of these vehicles in a given state.

> aircraft takes off or lands in the State or political subdivision as part of the flight.[281]

Because the statute discusses "taxes" and "fees," separately (see below), and because the statute explicitly permits states to charge landing fees on aircraft operators using airports owned or operated by the state, a landing fee would probably not be permissible as a "tax" under this section. Thus, landing fees charged by states are impermissible unless they are imposed on airports that the state (or a political subdivision) owns or operates.[282]

Actions as Owners or Proprietors of Airports

The AHTA provides that "[e]xcept as provided in subsection (d) of this section, a State or political subdivision of a State may levy or collect . . . reasonable . . . landing fees . . . from aircraft operators for using airport facilities of an airport owned or operated by that State or subdivision."[283] Subsection (d) does not permit states to "levy or collect a . . . fee . . . first taking effect after August 23, 1994, exclusively upon any business located at a commercial service airport or operating as a permittee of such an airport other than a . . . fee . . . wholly utilized for airport or aeronautical purposes."

Although this statute has not been interpreted in its new form, it would appear to allow a state operating an airport (or a political subdivision of a state operating an aircraft) to impose a landing fee so long as that fee was "reasonable" and so long as that fee was used wholly for "airport or aeronautical purposes."[284]

Reasonable Charges

What makes a fee "reasonable" has not been fully defined. The Supreme Court established a three-part test. In order to be reasonable, the fee must: (1) be based on some fair approximation of use of the facilities; (2) not be excessive in relation to the benefits conferred; and (3) not discriminate against interstate commerce.[285]

In 1994, Congress passed 49 U.S.C. § 47129, which required the Secretary of Transportation to publish standards that the DOT would use to determine whether a fee was reasonable. In 1996, the DOT published a "Final Policy Regarding Airport Rates and Charges."[286] The Air Transport Association and the City of Los Angeles both sought judicial review of the policy. The Court of Appeals for the District of Columbia vacated portions of the policy, finding it "much too rough to withstand judicial review . . ."[287]

That part of the policy left in place, however, included the DOT's policy regarding environmental costs. As stated in *Policy Statement* Paragraph 2.4.2:

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[281] 49 U.S.C. § 40116(c).

[282] For purposes of the Act, the definition of "state" includes "a political authority of at least 2 states." For example, the Port Authority of New York and New Jersey would be considered a state, whereas, the Massachusetts Port Authority, and similarly statute-created semi-public authorities, would be considered a "political subdivision" of the state.

[283] 49 U.S.C. § 40116(e)(2).

[284] There is some doubt whether an airline would be considered a "business located at a commercial service airport," but that statute is less than a model of clarity on this point.

[285] Northwest Airlines v. County of Kent, Michigan, 114 S.Ct. 855 (1994).

[286] 61 FR 31994.

[287] Air Transport Association of America v. Dep't of Transportation, 119 F.3d 38, 45 (D.C. Cir. 1997).

> Airport proprietors may include reasonable environmental costs in the rate base to the extent that the airport proprietor incurs a corresponding actual expense. All revenues received based on the inclusion of these costs in the rate base are subject to Federal requirements on the use of airport revenue. Reasonable environmental costs include, but are not necessarily limited to, the following:
>
> (a) the costs of investigating and remediating environmental contamination caused by airfield operations at the airport at least to the extent that such investigation or remediation is required by or consistent with local, state or federal environmental law, and to the extent such requirements are applied to other similarly situated enterprises.
>
> (b) the cost of mitigating the environmental impact of an airport development project (if the development project is one for which costs may be included in the rate base), at least to the extent that these costs are incurred in order to secure necessary approvals for such projects, including but not limited to approvals under the National Environmental Policy Act and similar state statutes;
>
> (c) the costs of aircraft noise abatement and mitigation measures, both on and off the airport, including but not limited to land acquisition and acoustical insulation expenses, to the extent that such measures are undertaken as part of a comprehensive and publicly-disclosed airport noise compatibility program; and
>
> (d) the costs of insuring against future liability for environmental contamination caused by current airfield activities. Under this provision, the costs of self-insurance may be included in the rate base only to the extent that they are incurred pursuant to a self-insurance program that conforms to applicable standards for self-insurance practices.

An argument could be made that emissions based landing fees are a “cost” of “remediating environmental contamination caused by airfield operations.” Although some may argue that ongoing pollution is not what is intended by “contamination,” reducing the pollution caused by aircraft use is certainly “consistent” with state and federal law. Further, the policy explicitly notes that reasonable environmental costs are not limited to those enumerated.

In the context of an airport expansion, it appears that the imposition of landing fees based on emissions would fit more comfortably under the guidelines, since it would be necessary for the airport to mitigate the effects of the expansion (including the increased emissions caused by more flights).

Other sections of the policy offer at least some guidance for what is considered reasonable. The policy explicitly states that a single approach is not required for rate setting. Fees may be set by any methodology, "as long as the methodology used is applied consistently to similarly situated aeronautical users and conforms with . . . this policy."[288] Although fees may not discriminate against aeronautical users, an airport proprietor may make "reasonable distinctions" between aeronautical users, and a "peak pricing system" would not be considered discriminatory.[289]

Thus, an emissions-based landing fee would not be considered unreasonable so long as it were properly structured and could be shown to be related to the costs of mitigating pollution caused by the airport.

Airport Purposes

In the absence of any authority interpreting whether an emissions based fee must be one that is "wholly used for airport services," there is reluctance to conclude that this language does not apply. However, it seems evident that the costs of mitigating pollution caused by the airport would be considered "wholly used for airport services." The fees extracted from the airlines would have to be used to remediate on-site pollution. For example, a landing fee applied to assist car rental agencies in purchasing LNG-powered buses would likely be permissible, since that is an "airport purpose." The use of such landing fees for assisting school bus operators to purchase LNG-powered buses would likely not be permissible, since the school bus was not used for "airport purposes". This raises the question of whether fees used to purchase off-site credits to offset on-site pollution would be considered "wholly used for airport services." There is a valid argument on both sides of the question. The airlines could argue that the fees imposed on them are not being used to mitigate airport pollution, but to subsidize pollution control at entirely remote sites. The airport could contend that the fees were being used for an airport purpose in that the pollution credits purchased were intended to mitigate on-site pollution. Both arguments have convincing aspects, and this issue may eventually reach the courts.

Prohibition by Part 191

As briefly discussed above in Section C.1, landing fees are subject to Part 161. Regulations subject to Part 161 include "a program of airport use charges that has the direct or indirect effect of controlling airport noise."[290] Since aircraft without advanced pollution control devices may also be without noise control devices, fees aimed at reducing air pollution may also control noise and thus be subject to Part 161. For restrictions of Stage 2 aircraft, Part 161 requires a notice of public comment period, as well as a detailed analysis of the proposed restriction.[291] For restrictions on Stage 3 aircraft, Part 161 requires the airport operator to reach an agreement with all aircraft operators that the fee is applied to, provides a notice and comment period, and requires FAA approval. Thus far, it does not appear that any restrictions have been approved by

[288] *Policy Statement* par. 2.1.
[289] Ibid, par. 3.1.1, 3.2.
[290] 14 C.F.R. section 161.5.
[291] 14 C.F.R. section 161.201 et seq.

the FAA under Part 161. Thus, although a more complete analysis is required, Part 161 appears to pose significant obstacle to the imposition of a landing fee system.

Preemption Under Other Statutes

Some have argued that emissions based landing fees would be preempted under current statutes. Because Congress has explicitly permitted states, as proprietors of airports, to impose fees in accordance with the law, other federal law cannot preempt such fees.

C.10 Regulation of "Airport Bubbles"

It has been proposed that the state could regulate total emissions from an airport by regulating an "airport bubble." That is, the state would consider all of the emissions arising from the airport, no matter what their source, and set a total cap on the emissions. The airport proprietor would then have to develop a plan to reduce emissions to levels no greater than the level of the cap.

This approach raises some issues regarding the source of the state authority to regulate an airport bubble. The CAA provides that stationary sources may be regulated using the "bubble" concept, but although the question has never been directly litigated, it is clear that airports are not stationary sources under the Act.[292] Further, at least one Circuit Court has held that a facility cannot be a stationary source and an indirect source.[293] According to this interpretation, airports could not be regulated as a stationary source.

It appears that the only source of authority is the state's power, under the CAA, to regulate "indirect sources" of pollution. As discussed above, airports likely qualify as "indirect sources" under the CAA. The decision "whether and how to regulate [indirect sources] is left largely to the states."[294] According to the CAA, the power of the states is limited to including "indirect source review programs" in a SIP. An "indirect source review program" is defined as the "facility-by-facility review of indirect sources of air pollution, including such measures as are necessary to assure, or assist in assuring, that a new or modified indirect source will not attract mobile sources of air pollution" so as to cause compliance problems. Thus, state power would be limited to "new or modified" airports. The relevant section of the CAA does not define what a "modified indirect source" is, and this issue does not appear to have been the subject of litigation. It would appear that any airport expansion projects involving, for example, the addition of a runway, would be a "modification" subject to review. The definition of an indirect source may vary slightly in the states that currently have indirect source reviews. Generally, states establish a *de minimus* threshold for indirect sources (e.g., activities that increase aircraft operations by 1,000). An indirect source permit could be required from the state for such projects.

[292] See Natural Resources Defense Council v. U.S. Environmental Protection Agency, 725 F.2d 761 (D.C. Cir. 1984). In this case EPA's original regulation of sources included airports.
[293] Larson.
[294] Sierra Club v. Larsen, (hereafter Larsen), 2 F.3d 462, 467 (1st Cir. 1993).

With the pressure for airport expansion, the limit of indirect source review to new or modified airports may not be as large a hurdle as it first appears. A number of airports throughout the nation are in the process of applying for expansion, or are expected to expand and could thereby provide an opportunity to utilize this provision. If the indirect source will cause compliance problems when modified (which may occur due to airport expansion), the state can require mitigation measures.[295] Such measures could include a limit on the total emissions of certain pollutants at the airport.

The "airport bubble" concept could be a powerful tool for states to reduce emissions from airports that seek to expand. Plans for expansion are being considered at a number of the largest airports in the country.[296] However, in the absence of airport efforts to expand, there does not appear to be a source of authority for states to impose emissions caps on airports. This question, however, certainly deserves further research.

C.11 Other Opportunities for State Involvement

States wield considerable power over airport improvement and expansion programs. Even given the recent severe downturn in the aviation industry, pressure on major metropolitan airports to expand is likely to remain considerable. Generally, airport expansion programs are subject to environmental review under state and federal law. This provides an opportunity for states and airport authorities to formulate "voluntary" and "cooperative" programs for environmental mitigation, including programs informed by the airport bubble concept. For instance, the Massachusetts Port Authority (Massport) recently instituted an "Air Quality Initiative" which, according to Massport, arose out of discussions with state environmental regulators. It is unclear whether a program similar to the AQI could have been imposed in the event Massport failed to voluntarily institute it. It seems clear that Massport was agreeable to the AQI because of its need for regulatory approval of a proposed airport expansion.

The certification process under the Airport and Airway Development Act is another area of potential state involvement. Under this Act, the Governor is responsible for issuing a certification stating that certain projects at an airport "…will be located, designed, constructed, and operated so as to comply with applicable air and water quality standards." Through this process there is opportunity to develop cooperative programs when airports seek certification for adding or extending runways. This approach has already been used at Sacramento International Airport.[297]

States also may have a number of opportunities to encourage the actions taken by decision makers. In developing the U.S. position for upcoming ICAO meetings, draft papers undergo consultations in the Interagency Group on International Aviation (IGIA) process, which includes representatives of federal government agencies and stakeholders (e.g., airlines, manufacturers, environmental organizations, and state organizations). During the course of ICAO meetings, IGIA participants are given updates on the meeting

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[295] Some analysis has shown that airport expansion can reduce emissions as a result of decreasing congestion.

[296] Evaluations are currently being undertaken at over 23 airports or regions where proposals have been made for airport modifications, expansions, or the potential development of new airports (DOT, 2001) In addition, a variety of airports are expected to undergo changes in the near-future.

[297] See discussion of Sacramento Airport in Chapter IV for greater detail on this program.

events and provided a forum to give further input on the U.S. position on specific issues that arise during the course of the meetings. Through the IGIA process, states can provide input into the U.S. position at ICAO meetings relevant to emissions. In addition, other opportunities for state input might arise during the course of the development of national legislation (e.g., budget authorizations and AIR-21 reauthorization).

D. Summary

This chapter broadly examined legal issues related to implementing a number of options to reduce aviation-related emissions. Consideration was given to whether a particular course of action by the states would be pre-empted by federal law. While pre-emption is the chief obstacle, it is by no means the only one for states to consider as they evaluate the feasibility and practicality of these options. For all the options considered, it is impossible to predict the success or failure of any particular regulation in the abstract. The drafting of that regulation is particularly important in determining whether it will withstand scrutiny. Based upon this cursory legal analysis, a number of options to reduce aviation-related emissions may be available to states, as follows:

D.1 Aircraft

Efforts are made to establish common international standards for aircraft engine emissions; however, these must be introduced individually by each nation. In addition, nations retain their national sovereignty and can therefore choose to establish more or less stringent standards. The U.S. could theoretically establish more stringent standards, but has typically conformed its standards to those developed by ICAO. Under various statutes, States are not allowed to establish emissions standards for aircraft engines, regulate the number of takeoffs or landings at an airport, limit flight procedures, and control the types of planes using airports. However, a number of other state policies to limit aircraft emissions might be legally permissible. State regulations of ground-level operation of aircraft that do not infringe on safety or affect the movement of aircraft could possibly withstand legal challenge. Claims that such regulation were preempted due to safety reasons may be upheld by the courts, thus making such an option unfeasible. In addition, states may petition the EPA to set stricter standards for aircraft engine emissions. States may want to consider petitioning DOT as well, since cooperation between EPA and DOT on aircraft standards is required.

D.2 Ground Service Equipment

Under the CAA, EPA has sole authority to establish engine emissions standards for GSE. However, EPA can authorize California to adopt and enforce emissions standards for GSE, and other states may adopt identical emissions standards. States can regulate the use and operation of GSE so long as fleet operators have options available that do not require modifications to the equipment. For example, states can establish regulations on hours of use and daily mass emissions limits. When operators of GSE fleets purchase replacement vehicles, recent court rulings suggest that states might be able to require that they purchase alternative fuel or electric vehicles, so long as such vehicles are elsewhere defined. Under these rulings, a state that had not adopted the

California standards as to SULEVs and ULEVs could require that fleet owners purchase only alternative-fueled vehicles, without dictating specific emissions standards those vehicles would have to meet. It would appear, however, that this option is not available to northeastern states (those in the First and Second Circuits) unless restrictive rulings by those Circuits are overturned.

D.3 Ground Access Vehicles

Emissions standards for private automobiles cannot be imposed by the states. Despite this preemption, an argument could be developed giving states authority to regulate GAV emissions in three ways. First, recent court rulings provide some indication that States that have adopted the California standards for LEV, ULEV, and SULEV could require fleets to purchase vehicles defined by the state as "alternative-fueled vehicles." This definition could not define an emissions standard that those vehicles would have to meet. Second, the airport authority could impose requirements on fleets operating within the airport, so long as a fleet operator had options available to meet the requirement without modifying the engines in question. Therefore, states that are proprietors of airports could require that certain commercial vehicles operating at the airport be alternatively fueled. Third, states can regulate the use of automobiles at airports (controlling traffic flow, prohibit idling, etc.).

D.4 Emissions-based Fees

ICAO recommends that emissions-based fees should not be used as a revenue-generating source for countries, and that the charge should be related to costs. The funds collected from such a charge should be used to mitigate the environmental impact of aircraft engine emissions. In the U.S., a state that acts as an owner or proprietor of an airport can levy a landing fee for using the airport facility, as long as the fee is "reasonable" and "wholly utilized for airport or aeronautical purposes." While an exact interpretation of these terms has not been articulated by the courts, examples of reasonable environmental costs provided by DOT include the costs of: investigating and remediating environmental contamination; mitigating the environmental impact of an airport development project; and insuring against future liability for environmental contamination. There is a strong argument that emissions based landing fees are a cost of "remediating environmental contamination." In the context of an airport expansion, it could be argued that the imposition of landing fees based on emissions would be necessary for the airport to mitigate the effects of the expansion, including the increased emissions caused by more flights. It may be that such fees are subject to the strictures of Part 161, which would make their imposition problematic.

D.5 Airport "Bubbles"

Under the CAA, an argument could be developed that states can regulate an airport "bubble" within their power to regulate "indirect sources" of pollution. Under this provision, states can include indirect source review programs in a SIP. This review could include measures to assure that a new or modified indirect source will not attract mobile sources of air pollution so as to cause compliance problems. Thus, a state may be able to require mitigation measures for "new or modified airports" if the project will cause compliance problems. Such mitigation measures could include a limit on the total emissions of certain pollutants at the airport. Furthermore, airport expansion programs are subject to environmental review under state and federal law, and this provides an opportunity for states and airport authorities to formulate “voluntary” and “cooperative” airport bubbles.

VI. Conclusions

A. Overview

As the relative importance of the airport source sector grows due to declining emissions in other sectors and continuing growth in air travel, it will be necessary to continue seeking opportunities to reduce emissions from aviation-related sources. Many localities are undertaking efforts to reduce emissions in order to comply with or maintain ambient pollution levels below national health-based standards. Under the more stringent ozone and particulate matter standards being introduced in coming years, significant further reductions in criteria pollutant are likely to be needed in many locations. To meet these standards, states and locales will require reductions from all types of emissions sources including airport-related ones. A concerted effort must be undertaken at the international, national, state, local, and airport levels to ensure that new, cleaner technologies and operational measures are introduced for all airport emissions sources. These initiatives must ensure that airport-related emissions decrease over time.

B. Emission Inventories

Aviation-related sources contribute a variety of emissions of concern, including NOx, hydrocarbons (HC), particulate matter, and air toxics. An inventory analysis conducted for this report showed that the total emissions contribution from three airports in the Northeast was already significant, relative to other major emissions sources in the area. Moreover, given the predicted increase in aircraft LTO over the next ten years at the three airports studied, and the relatively lax emission standards for aircraft and GSE, emissions are expected to increase at all three airports. At Logan Airport, total NOx emissions from aircraft, GSE, and APU were estimated at 3,102 tons in 1999 and predicted to increase to 3,923 tons in 2010[298]. At Manchester Airport, NOx emissions are estimated at 239 tons in 1999 and 350 tons in 2010. At Bradley Airport, NOx emissions are predicted to grow from 803 tons in 1999 to 1,149 tons in 2010. Aircraft emissions alone accounted for 85 percent to 95 percent of the total emissions inventory for aircraft, GSE, and APU at the three airports studied. Among types of aircraft, air carrier emissions (i.e. primarily from large commercial jets) dominated the NOx inventory. Given current growth rates and planned controls on existing stationary sources, airport-related NOx emissions will be greater than NOx emissions from the largest stationary sources (power plants) in the vicinity of the airports studied by 2010.

HC emissions are also projected to grow as activity at the airports increases. For example, HC emissions at Logan are expected to grow from 562 tons in 1999 to 567 tons in 2010. While air carriers dominate the aircraft NOx inventory, HC emissions from the air taxi category of aircraft (typically smaller, short-haul planes) comprise a larger percent of overall aircraft emissions than in the case of NOx. Thus any HC and toxic emission reduction strategy should not focus only on air carriers but must also address air taxi emissions. Estimated toxic emissions, such as benzene and

[298] This study commenced before the events of September 11, 2001. Forecasts reflecting these events were released by FAA in March, 2003 and have not been incorporated in this study.

formaldehyde, from aircraft operating at the three studied airports exceed those of the largest stationary sources in each of the three states where these airports are located.

State SIP inventories for airport-related NOx and HC differed significantly from the estimates developed as part of this report. In the case of aircraft NOx emissions, state estimates were 50 percent lower than the NESCAUM estimates. The same is true for HC with the exception of Manchester Airport, which reported higher HC emissions than this inventory.

The differences in the NESCAUM and state estimates are due to the incorporation of local data on mixing heights, new data on take-off time, and more exact assumptions about the aircraft/engine fleet mix. New versions of the widely used aircraft emissions model EDMS should incorporate these new data to improve state airport-related emissions inventories.

C. Technical and Operational Control Measures

Due to the variety of emissions sources at airports, policymakers must consider control strategies for various types of equipment, operations, and functions. Cost-effective technical and operational options are available to reduce emissions from all airport sources. Of course, some options are more cost effective and easier to implement than others. The cost-effectiveness and feasibility of the different measures can vary from airport to airport. To take one example, installing electrified gates can be done more easily at newer airports than at older airports. In addition, consideration needs to be given to potential trade-offs as some technologies can lead to decreases in one pollutant at the expense of another. These complexities need not stand in the way of action, but they do argue for a careful and comprehensive evaluation of all available options. Some technical opportunities to reduce aircraft and APU emissions include gate electrification, commercialization of composite, low-weight aircraft bodies, and commercialization of new, more aerodynamic wing design. Additionally, operational options are available to reduce aircraft emissions by, for example, improving airline operating efficiency, minimizing congestion, reducing power output, and minimizing taxi times. Similarly, a variety of options exist to reduce emissions from GSE. These include the use of alternative fuels, electric equipment, and emissions control retrofits. Options for reducing GAV emissions include using cleaner fuels or engines, increasing use of public transit alternatives, reducing employee-related trips, and limiting idling and congestion. Greater use of rail service can also play an important role in efforts to reduce airport-related emissions. Depending on the program, this option can lead to reductions in emissions from all sources.

Technical measures to reduce aircraft emissions hold the greatest potential emissions reduction benefit of all options examined in this report. Some of these measures, such as developing and commercializing new more aerodynamic aircraft may take several decades. However, technologies to reduce aircraft engine NOx emissions exist today (such as dual annular combustors and improved by-pass air ratio) and could be incorporated into further aircraft engine designs. Unfortunately, existing aircraft engine emission standards do not provide much impetus for the increased use of these technologies. Hence, a shift in the way the standards are structured is needed to further promote the application of these technologies. Operational measures to reduce aircraft engine emissions -- such as single engine taxi and reduce use of reverse thrust -- can generally be undertaken at little cost, though safety considerations, pilot training and airport design may affect the applicability of these measures in individual situations. Operational practices of this type are already encouraged by many airlines; hence the remaining potential to reduce emissions using operational strategies is uncertain.

Electrification holds the greatest promise to reduce GSE emissions and can produce cost savings over time. Of course, not all GSE can be replaced by electric equipment. Switching to natural gas and propane can also be effective at reducing GSE emissions, but is generally less promising than electrification for many types of GSE. Gate electrification and preconditioned air can also be extremely effective at reducing emissions and can result in cost savings to the operator. Installing these systems is most feasible at airports with sufficient power supply and room for new systems. Airports with limited power supply and with little room for system installation may not be ideal candidates for electrified gates and preconditioned air systems.

Improved intercity rail service also holds some promise for reducing airport-related emissions. Programs in Europe and the U.S. to increase rail travel and reduce aircraft traffic have been successful and could greatly reduce short airline trips (less than 350 miles) and related emissions. Investments in rail infrastructure are needed in order to make rail more competitive with air travel.

D. Policy Approaches

To effectively reduce airport emissions, policymakers should consider developing comprehensive policy approaches that encourage or require the utilization of both technological and operational measures. A number of policy approaches are available to state policymakers to promote the use of cleaner technologies and operations. These opportunities include source-specific programs, market-based approaches, and rail initiatives. Many of these programs have been undertaken at airports in the U.S. and abroad, as discussed in the case studies section of Chapter IV.

This report highlights a number of source-specific policy approaches that could be used on their own or in combination with other source-specific and market-based approaches. Emissions standards for both aircraft and GSE could be developed by national and international policymakers to push technology and to better account for the emissions performance of the aircraft as a whole, not just the engine. Activity limits represent a blunt, but potentially effective command-and-control type regulatory mechanism for limiting airport emissions. Use of this approach may be limited by political considerations and by the difficulty of conditioning activity limits on the differential emissions characteristics of different sources. Innovative approaches for GSE and GAV could be designed to promote or require the purchase of cleaner alternatives when fleet vehicles or equipment are replaced or added and could incorporate a declining fleet emissions target. Programs focused on reducing private vehicle trips to and from the airport should be developed as a means of reducing overall emissions in the community. Depending on available transit infrastructure, these efforts could include better connections to transit options and improvements in bus service and rail access.

Properly designed market-based approaches can utilize market forces to encourage the introduction of cleaner technology and the utilization of emissions reducing operational measures, while providing flexibility in how emissions are reduced and minimizing overall control costs. A fee-based program, similar to the Swiss and Swedish programs, can send a direct price signal to operators by making it more expensive to utilize higher emitting technologies and operations. Of course, the fee must be sufficiently high to encourage the desired emissions reductions. The use of a cap-and-trade, or "bubble" programs can provide an assurance of eventual environmental benefit and reduce the cost of compliance by allowing for flexibility in how and where emissions reductions occur. As in the Logan Airport program—where a cap is placed on total airport emissions and the cost of maintaining emissions below the cap is passed to airlines in the form of higher fees—emissions trading and fee-based programs can be combined.

Expanded high-speed rail could play an important role in future efforts to reduce aviation-related emissions by reducing the number of short-haul flights between certain cities. While the applicability of high-speed rail varies by location, it nonetheless should be considered when decision-makers develop short-term and long-term transportation plans.

E. Legal

While statutes and policies at both the international and federal levels provide some clear barriers to state and local level action, there is room for programs in many cases. In general, states have little or no authority to establish emissions standards for engines from aircraft, GSE, and GAV. Despite these barriers, states have a number of opportunities to develop programs that lead to emissions reductions from airport-related sources.

While current standards for aircraft engine emissions are generally set at the international level by ICAO, the U.S. could provide international leadership by promoting or introducing more stringent standards. Some state regulation of aircraft emissions could be permissible despite federal preemption of aircraft engine emissions standards, provided state regulations pertain to the ground-level operation of aircraft, do not infringe upon safety,and do not affect aircraft movements. Additionally, states may petition the EPA to set stricter standards for aircraft engine emissions. With the exception of California, states are preempted from establishing engine emissions standards for GSE. [299] However, they may be able to develop in-use limits on the operation of GSE so long as fleet operators have options available to them that do not require equipment modifications. Another option potentially available to states is to require that operators of GSE fleets purchase alternative fuel or electric vehicles.

Since states cannot establish emissions standards for automobiles, states options for reducing GAV emissions are limited to regulating the operation of automobiles at airports (e.g. controlling traffic flow, limiting idling, etc.). In some cases, states might also be able institute alternative-fueled vehicle requirements for commercial fleets serving the airport.

Within certain legal constraints, states may be able to introduce market-based measures, such as airport "bubbles" and fee-based programs. An emissions-based landing fee would be considered reasonable so long as it were properly structured and could be shown to be related to the costs of mitigating pollution caused by airport activities. States may also be permitted to set an absolute limit on airport emissions as a condition of issuing permits for airport modifications or expansion under the "indirect source review" provision of the Clean Air Act.

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[299] California has the authority under section 209 of the Clean Air Act to establish nonroad engine emission standards for engines with horsepower ratings larger than 175.

F. Recommendations

This report is intended to provide information and suggest options useful to policymakers as they face the challenge of reducing or limiting airport-related emissions. This report does not attempt to articulate concrete policy recommendations, rather it suggests a number of promising policy directions that should be considered in the development of programs to reduce emissions from airport-related sources. The policy context for each individual airport will depend on a variety of factors specific to the airport, locality, and state – these factors may include differing emissions needs, the feasibility of implementing different technological and operational options, and political considerations. The following general recommendations are made from the findings of this report.

- A detailed emissions inventory can provide useful information on the relative contribution of specific sources and serve as a sound basis for assessing those priority areas where emissions reducing programs should be focused. Such inventories should be developed using the most recent data and analysis tools as discussed in this report.

- Operators and policymakers should assess and seek means to integrate technology and operational measures that reduce emissions. A variety of cost-effective measures are available, but the applicability and cost of the measures will vary by airport. Therefore, consideration should be given to those measures that best fit the opportunities and constraints unique to each airport.

- Innovative or aggressive state programs could speed the introduction and development of lower emitting technologies such as new types of electric GSE which would otherwise not be introduced. The design of airport policies and programs must give serious consideration to legal barriers and opportunities. A properly designed program could be developed within the legal framework surrounding regulation of airport-related emissions sources.

- At the federal level, aircraft engine emission standards that encourage both fuel efficiency and reduced criteria pollutant emissions are needed. US EPA should adopt standards that encourage both. In addition, US EPA and FAA should adopt improvements to the EDMS model based on the modifications that were developed for the NESCAUM/EEA model used in this report.

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Appendix A: Airports Located in 1-hr and 8-hr Ozone Nonattainment and Maintenance Areas

A. Airports Located in 1-hr Ozone Nonattainment and Maintenance Areas

This section provides a summary of airports located in 1-hr ozone nonattainment and maintenance areas. Airports listed in Table A-1 had 10,000 or more aircraft operations in 1999.[300] The location of the airport was cross-referenced with the counties classified by US EPA as nonattainment and maintenance areas for the 1-hr ozone standard.[301]

Table A-1: Airports Located in 1-hr Ozone Nonattainment and Maintenance Areas

Airport[1]	State	Airport Code	County	Ozone Classification
Birmingham Intl	AL	BHM	Jefferson	Marginal Nonattainment
Phoenix Sky Harbor Intl	AZ	PHX	Maricopa	Serious Nonattainment
Scottsdale	AZ	SDL	Maricopa	Serious Nonattainment
Los Angeles	CA	LAX	Ventura	Extreme Nonattainment
Metropolitan Oakland Intl	CA	OAK	Sacramento	Other Nonattainment
Long Beach/Daugherty Field	CA	LGB	Sacramento	Extreme Nonattainment
John Wayne	CA	SNA	El Dorado	Extreme Nonattainment
San Francisco Intl	CA	SFO	San Diego	Other Nonattainment
San Jose Intl	CA	SJC	San Diego	Other Nonattainment
Mc Clellan-Palomar	CA	CRQ	Fresno	Serious Nonattainment
Montgomery Field	CA	MYF	San Diego	Serious Nonattainment
Fresno Yosemite Intl	CA	FAT	Kern	Serious Nonattainment
San Diego Intl	CA	SAN	Stanislaus	Serious Nonattainment
Meadows Field	CA	BFL	Santa Barbara	Serious Nonattainment
Burbank-Glendale-Pasadena	CA	BUR	Tulare	Extreme Nonattainment
Ontario Intl	CA	ONT	Imperial	Extreme Nonattainment
Sacramento Intl	CA	SMF	Butte	Severe-15 Nonattainment
Sonoma County	CA	STS	Alameda	Other Nonattainment
Monterey Pennisula	CA	MRY	San Mateo	Maintenance
Palm Springs Intl	CA	PSP	Santa Clara	Extreme Nonattainment
Oxnard	CA	OXR	Sonoma	Severe-15* Nonattainment
Modesto City-CO-Harry Sham	CA	MOD	Monterey	Serious Nonattainment
Imperial County	CA	IPL	Los Angeles	Section 185A
Santa Maria Pub	CA	SMX	Los Angeles	Serious Nonattainment
Chico Municipal	CA	CIC	Orange	Section 185A
Sacramento Mather	CA	MHR	Los Angeles	Severe-15 Nonattainment
Visalia Municipal	CA	VIS	San Bernadino	Serious Nonattainment
Lake Tahoe	CA	TVL	Riverside	Severe-15 Nonattainment
Denver Intl	CO	DEN	Denver	Section 185A
Bradley Intl	CT	BDL	Hartford	Serious Nonattainment
Groton-New London	CT	GON	New London	Serious Nonattainment
Tweed-New Haven	CT	HVN	New Haven	Serious Nonattainment
Fort Lauderdale/Hollywood Intl	FL	FLL	Duval	Moderate Maintenance

[300] See Federal Aviation Administration, T*erminal Area Forecast: Fiscal Years 2000-2015*, December 2000.
[301] Airport location was obtained from G.C.R. & Associates Inc., see <http://www.gcr1.com/5010WEB/default.htm>. County location for 1-hr ozone nonattainment and maintenance areas was obtained from US EPA, *Greenbook*, as of August 2, 2001.

Airport[1]	State	Airport Code	County	Ozone Classification
Miami International	FL	MIA	Broward	Moderate Maintenance
Palm Beach Intl	FL	PBI	Dade	Moderate Maintenance
Jacksonville Intl	FL	JAX	Palm Beach	Section 185A Maintenance
Tampa Intl	FL	TPA	Hillsborough	Marginal Maintenance
St. Petersburg/Clearwater Intl	FL	PIE	Pinellas	Marginal Maintenance
William B. Hartsfield Intl	GA	ATL	Fulton	Serious Nonattainment
Chicago O'Hare Intl	IL	ORD	Cook	Severe-17 Nonattainment
Chicago Midway	IL	MDW	Cook	Severe-17 Nonattainment
Merrill C. Meigs	IL	CGX	Cook	Severe-17 Nonattainment
Indianapolis Intl	IN	IND	Marion	Marginal Maintenance
Evansville Regional	IN	EVV	Vanderburgh	Marginal Maintenance
South Bend Regional	IN	SBN	St. Joseph	Marginal Maintenance
Louisville Intl	KY	SDF	Jefferson	Moderate Maintenance
Owensboro-Daviess County	KY	OWB	Daviess	Marginal Maintenance
Blue Grass	KY	LEX	Fayette	Marginal Maintenance
New Orleans Intl	LA	MSY	Jefferson	Serious Maintenance
Baton Rouge Metropolitan	LA	BTR	E.Baton Rouge Parish	Serious Nonattainment
Lafayette Regional	LA	LFT	Lafayette	Section 185A Maintenance
Lake Charles Regional	LA	LCH	Calcasieu Parish	Marginal Maintenance
Logan Intl	MA	BOS	Middlesex	Serious Nonattainment
Laurence G. Hanscom Field	MA	BED	Middlesex	Serious Nonattainment
Nantucket Memorial	MA	ACK	Nantucket	Serious Nonattainment
Provincetown Municipal	MA	PVC	Barnstable	Serious Nonattainment
Barnstable Muni-Boardman/Polan	MA	HYA	Barnstable	Serious Nonattainment
Marthas Vineyard	MA	MVY	Dukes	Serious Nonattainment
New Bedford Regional	MA	EWB	Bristol	Serious Nonattainment
Worcester Regional	MA	ORH	Worcester	Serious Nonattainment
Baltimore/Washington Intl	MD	BWI	Anne Arundel	Severe-15 Nonattainment
Portland Intl Jetport	ME	PWM	Knox	Moderate Nonattainment
Knox County Regional	ME	RKD	Cumberland	Moderate* Nonattainment
Hancock County-Bar Harbor	ME	BHB	Hancock	Marginal Maintenance
Detroit Metropolitan Wayne County	MI	DTW	Genesee	Moderate Maintenance
Detroit City	MI	DET	Wayne	Moderate Maintenance
Bishop Intl	MI	FNT	Wayne	Section 185A Maintenance
Gerald R. Ford Intl	MI	GRR	Kent	Moderate Maintenance
Muskegon County	MI	MKG	Muskegon	Moderate Maintenance
Willow Run	MI	YIP	Wayne	Moderate Maintenance
MBS Intl	MI	MBS	Saginaw	Incomplete Data Maintenance
Lambert-Saint Louis Intl	MO	STL	Platte	Moderate Nonattainment
Kansas City Intl	MO	MCI	St. Louis City	Other Maintenance
Spirit of St. Louis	MO	SUS	St. Louis	Moderate Nonattainment
Charlotte/Douglas Intl	NC	CLT	Mecklenburg	Moderate Maintenance
Raleigh-Durham Intl	NC	RDU	Wake	Moderate Maintenance
Piedmont Triad Intl	NC	GSO	Guilford	Moderate Maintenance
Manchester	NH	MHT	Hillsborough	Marginal Nonattainment
Newark Intl	NJ	EWR	Essex	Severe-17 Nonattainment
Teterboro	NJ	TEB	Bergen	Severe-17 Nonattainment
Trenton Mercer	NJ	TTN	Mercer	Severe-15 Nonattainment
Atlantic City Intl	NJ	ACY	Atlantic	Moderate Nonattainment

Airport[1]	State	Airport Code	County	Ozone Classification
Reno/Tahoe Intl	NV	RNO	Washoe	Marginal Nonattainment
La Guardia	NY	LGA	Queens	Severe-17 Nonattainment
JFK Intl	NY	JFK	Queens	Severe-17 Nonattainment
Stewart Intl	NY	SWF	Suffolk	Moderate Nonattainment
Buffalo Niagara Intl	NY	BUF	Orange	Marginal Nonattainment
Albany Intl	NY	ALB	Erie	Marginal Nonattainment
Long Island Mac Arthur	NY	ISP	Albany	Severe-17 Nonattainment
Cleveland-Hopkins Intl	OH	CLE	Cuyahoga	Moderate Maintenance
Port Columbus Intl	OH	CMH	Montgomery	Marginal Maintenance
James M. Cox	OH	DAY	Summit	Moderate Maintenance
Akron-Canton Regional	OH	CAK	Lucas	Moderate Maintenance
Toledo Express	OH	TOL	Franklin	Moderate Maintenance
Rickenbacker Intl	OH	LCK	Franklin	Marginal Maintenance
Portland Intl	OR	PDX	Multnomah	Marginal Maintenance
Philadelphia Intl	PA	PHL	Delaware	Severe-15 Nonattainment
Pittsburgh Intl	PA	PIT	Allegheny	Moderate Maintenance
Lehigh Valley Intl	PA	ABE	Westmoreland	Marginal Nonattainment
Lancaster	PA	LNS	Lehigh	Marginal Nonattainment
Wilkes-Barre/Scranton Intl	PA	AVP	Lancaster	Marginal Nonattainment
Harrisburg Intl	PA	MDT	Luzerne	Marginal Nonattainment
Erie Intl	PA	ERI	Dauphin	Marginal Nonattainment
Arnold Palmer Regional	PA	LBE	Erie	Moderate Maintenance
Johnstown-Cambria County	PA	JST	Cambria	Marginal Nonattainment
Altoona-Blair County	PA	AOO	Blair	Marginal Nonattainment
Theodore Francis Green State	RI	PVD	Kent	Serious Nonattainment
Block Island State	RI	BID	Washington	Serious Nonattainment
Westerly State	RI	WST	Washington	Serious Nonattainment
Memphis Intl	TN	MEM	Davidson	Marginal* Maintenance
Nashville Intl	TN	BNA	Shelby	Moderate Maintenance
Dallas/Fort Worth Intl	TX	DFW	Harris	Serious Nonattainment
George Bush Intercontinental	TX	IAH	Harris	Severe-17 Nonattainment
William P Hobby	TX	HOU	Harris	Severe-17 Nonattainment
Dallas Love Field	TX	DAL	Tarrant	Serious Nonattainment
Fort Worth Alliance	TX	AFW	Dallas	Serious Nonattainment
El Paso Intl	TX	ELP	Tarrant	Serious Nonattainment
Ellington Field	TX	EFD	El Paso	Severe-17 Nonattainment
Victoria Regional	TX	VCT	Jefferson	Incomplete Data Maintenance
Southeast Texas Regional	TX	BPT	Victoria	Moderate Nonattainment
Salt Lake City Intl	UT	SLC	Salt Lake	Moderate Maintenance
Washington Dulles Intl	VA	IAD	Loudoun	Serious Nonattainment
Ronald Reagan Washington Natl	VA	DCA	Arlington	Serious Nonattainment
Newport News/Williamsburg Intl	VA	PHF	Henrico	Marginal Maintenance
Norfolk Intl	VA	ORF	Newport News	Marginal Maintenance
Richmond Intl	VA	RIC	Norfolk	Moderate Maintenance
Seattle-Tacoma Intl	WA	SEA	King	Marginal Maintenance
Boeing Field/King County Intl	WA	BFI	King	Marginal Maintenance
Kenmore Air Harbor Inc	WA	S60	King	Marginal Maintenance
General Mitchell Intl	WI	MKE	Milwaukee	Severe-17 Nonattainment
Yeager	WV	CRW	Wayne	Moderate Maintenance

Airport[1]	State	Airport Code	County	Ozone Classification
Tri-State/Milton J. Ferguson	WV	HTS	Kanawha	Moderate Maintenance
Greenbrier Valley	WV	LWB	Greenbier	Marginal Maintenance
1) Airports listed have over 10,000 aircraft operations per year in 1999.				

Sources: Listing of ozone nonattainment areas from U.S. EPA, Greenbook, as of November 4, 2002, see: <www.epa.gov/oar/oaqps/greenbk/oindex.html#List1>. Locations based upon G.C.R. & Associates Inc., see: <http://www.gcr1.com/5010WEB/default.htm>.

B. Airports Located in Potential 8-hr Ozone Nonattainment Areas

This section provides a summary of airports located in potential 8-hr ozone nonattainment areas. Nonattainment areas for the 8-hr ozone standard have not been finalized; however, in testing over a three-year period, several counties were found to have ambient air quality levels above the 8-hr standard.[302] The final list of 8-hr ozone nonattainment areas could include more counties than those where monitors exceeded the 8-hr ozone standard. Airports listed in Table A-2 had 10,000 or more aircraft operations in 1999[303], based upon FAA… The location of the airport was cross-referenced with the counties where monitors exceeded the 8-hr ozone standard.[304]

Table A-2: Airports Located in Potential 8-hr Ozone Nonattainment Areas

Airport	State	Airport Code	County
Birmingham Intl	AL	BHM	Jefferson
Mobile Regional	AL	MOB	Mobile
Huntsville Intl	AL	HSV	Madison
Mobile Downtown	AL	BFM	Mobile
Phoenix Sky Harbor Intl	AZ	PHX	Maricopa
Scottsdale	AZ	SDL	Maricopa
Los Angeles	CA	LAX	Los Angeles
Metropolitan Oakland Intl	CA	OAK	Alameda
Long Beach/Daugherty Field	CA	LGB	Los Angeles
Mc Clellan-Palomar	CA	CRQ	San Diego
Montgomery Field	CA	MYF	San Diego
Fresno Yosemite Intl	CA	FAT	Fresno
San Diego Intl	CA	SAN	San Diego
Meadows Field	CA	BFL	Kern
Burbank-Glendale-Pasadena	CA	BUR	Los Angeles
Ontario Intl	CA	ONT	San Bernadino
Sacramento Intl	CA	SMF	Sacramento
Palm Springs Intl	CA	PSP	Riverside
Oxnard	CA	OXR	Ventura
Redding Municipal	CA	RDD	Shasta

[302] For a listing of the counties where tests exceeded the 8-hr standard, see: U.S. EPA, *1997-1999 8-Hour Ozone County Design Values,* at <www.epa.gov/ttn/rto/areas/state/aq/aq99cnty.htm>.
[303] See Federal Aviation Administration, T*erminal Area Forecast: Fiscal Years 2000-2015*, December 2000.
[304] Airport location was obtained from G.C.R. & Associates Inc., see <http://www.gcr1.com/5010WEB/default.htm>.

Airport	State	Airport Code	County
Modesto City-CO-Harry Sham	CA	MOD	Stanislaus
Imperial County	CA	IPL	Imperial
Sacramento Mather	CA	MHR	Sacramento
Visalia Municipal	CA	VIS	Tulare
Lake Tahoe	CA	TVL	El Dorado
Bradley Intl	CT	BDL	Hartford
Groton-New London	CT	GON	New London
Tweed-New Haven	CT	HVN	New Haven
Fort Lauderdale/Hollywood Intl	FL	FLL	Broward
Tampa Intl	FL	TPA	Hillsborough
William B. Hartsfield Intl	GA	ATL	Fulton
Columbus Metropolitan	GA	CSG	Muscogee
Augusta Regional	GA	AGS	Richmond
Middle Georgia Regional	GA	MCN	Bibb
Glynco Jetport	GA	BQK	Glynn
Chicago O'Hare Intl	IL	ORD	Cook
Chicago Midway	IL	MDW	Cook
Merrill C. Meigs	IL	CGX	Cook
Indianapolis Intl	IN	IND	Marion
Fort Wayne Intl	IN	FWA	Allen
Evansville Regional	IN	EVV	Vanderburgh
South Bend Regional	IN	SBN	St. Joseph
Cincinatti/Northern Kentucky Intl	KY	CVG	Boone
Louisville Intl	KY	SDF	Jefferson
Blue Grass	KY	LEX	Fayette
Owensboro-Daviess County	KY	OWB	Daviess
Barkley Regional	KY	PAH	McCraken
New Orleans Intl	LA	MSY	Jefferson Parish
Baton Rouge Metropolitan	LA	BTR	E.Baton Rouge Parish
Shreveport Regional	LA	SHV	Caddo Parish
Lake Charles Regional	LA	LCH	Calcasieu Parish
Logan Intl	MA	BOS	Middlesex
Laurence G. Hanscom Field	MA	BED	Middlesex
Provincetown Municipal	MA	PVC	Barnstable
Barnstable Muni-Boardman/Polan	MA	HYA	Barnstable
New Bedford Regional	MA	EWB	Bristol
Worcester Regional	MA	ORH	Worcester
Baltimore/Washington Intl	MD	BWI	Anne Arundel
Portland Intl Jetport	ME	PWM	Cumberland
Hancock County-Bar Harbor	ME	BHB	Hancock
Detroit Metropolitan Wayne County	MI	DTW	Wayne
Detroit City	MI	DET	Wayne
Bishop Intl	MI	FNT	Genesee
Gerald R. Ford Intl	MI	GRR	Kent
Kalamazoo/Battle Creek Intl	MI	AZO	Kalamazoo
Muskegon County	MI	MKG	Muskegon
Willow Run	MI	YIP	Wayne
Lambert-St. Louis Intl	MO	STL	St. Louis City
Kansas City Intl	MO	MCI	Platte
Spirit of St. Louis	MO	SUS	St. Louis

Airport	State	Airport Code	County
Charlotte/Douglas Intl	NC	CLT	Mecklenburg
Raleigh-Durham Intl	NC	RDU	Wake
Piedmont Triad Intl	NC	GSO	Guilford
Fayetville Regional	NC	FAY	Cumberland
Pitt-Greenville	NC	PGV	Pitt
Kinston RGNL Jetport*	NC	ISO	Lenoir
Manchester	NH	MHT	Hillsborough
Newark Intl	NJ	EWR	Essex
Trenton Mercer	NJ	TTN	Mercer
Atlantic City Intl	NJ	ACY	Atlantic
Mc Carran Intl*	NV	LAS	Clark
North Las Vegas*	NV	VGT	Clark
Henderson*	NV	L15	Clark
La Guardia*	NY	LGA	Queens
John F Kennedy Intl*	NY	JFK	Queens
Westchester County	NY	HPN	Westchester
Stewart Intl	NY	SWF	Orange
Buffalo Niagara Intl	NY	BUF	Erie
Long Island Mac Arthur	NY	ISP	Suffolk
Chautauqua County/Jamestown	NY	JHW	Chautauqua
Cleveland-Hopkins Intl	OH	CLE	Cuyahoga
Port Columbus Intl	OH	CMH	Franklin
James M. Cox	OH	DAY	Montgomery
Akron-Canton Regional	OH	CAK	Summit
Toledo Express	OH	TOL	Lucas
Youngstown-Warren Regional	OH	YNG	Trumbull
Rickenbacker Intl	OH	LCK	Franklin
Tulsa Intl	OK	TUL	Tulsa
Will Rogers World	OK	OKC	Oklahoma
Philadelphia Intl	PA	PHL	Delaware
Pittsburgh Intl	PA	PIT	Allegheny
Lehigh Valley Intl	PA	ABE	Lehigh
Reading Regional/Carl A Spaatz	PA	RDG	Berks
Lancaster	PA	LNS	Lancaster
Wilkes-Barre/Scranton Intl	PA	AVP	Luzerne
Harrisburg Intl	PA	MDT	Dauphin
University Park	PA	UNV	Centre
Erie Intl	PA	ERI	Erie
Arnold Palmer Regional	PA	LBE	Westmoreland
Johnstown-Cambria County	PA	JST	Cambria
Altoona-Blair county	PA	AOO	Blair
Theodore Francis Green State	RI	PVD	Kent
Block Island State	RI	BID	Washington
Westerly State	RI	WST	Washington
Memphis Intl	TN	MEM	Shelby
Nashville Intl	TN	BNA	Davidson
MC Ghee Tyson	TN	TYS	Blount
Lovell Field	TN	CHA	Hamilton
Tri-Cities Regional TN/VA	TN	TRI	Sullivan
Dallas-Fort Worth Intl	TX	DFW	Tarrant

Airport	State	Airport Code	County
George Bush Intercontinental	TX	IAH	Fort Bend
William P Hobby	TX	HOU	Harris
San Antonio Intl	TX	SAT	Bexar
Dallas Love Field	TX	DAL	Dallas
Fort Worth Alliance	TX	AFW	Tarrant
Austin-Bergstrom Intl	TX	AUS	Travis
Ellington Field	TX	EFD	Harris
Tyler Pounds Field	TX	TYR	Smith
Gregg County	TX	GGG	Gregg
Washington Dulles Intl	VA	IAD	Loudoun
Ronald Reagan Washington	VA	DCA	Arlington
Richmond Intl	VA	RIC	Henrico
Roanoke Regional/Woodrum Field	VA	ROA	Roanoke
General Mitchell Intl	WI	MKE	Milwaukee
Yeager	WV	CRW	Kanawha
Wood County Airport Gill Robb	WV	PKB	Wood
Greenbrier Valley	WV	LWB	Greenbrier
* Indicates county has a "potential to violate" based on two years of data.			

Sources: For counties exceeding the 8-hr standard, *U.S. EPA 1997-1999 8-Hour Ozone County Design Values* at <www.epa.gov/ttn/rto/areas/state/aq/aq99cnty.htm>. For airport locations, G.C.R. & Associates Inc., see <http://www.gcr1.com/5010WEB/default.htm>.

Appendix B: Emissions Calculations

A. Aircraft Emissions Methodology

Aircraft emissions estimates are based on a number of factors, including aircraft and engine fleet mix, engine emission factors, the number of landings and takeoffs (LTOs), and the time spent in each phase of the LTO cycle. Commercial aircraft and air taxi emissions were calculated using weighted averages for each aircraft type owned by each airline (i.e., Continental Boeing 727-200, Continental Boeing 737-300, American Airbus 32-200, etc.), with emission factors from the ICAO Aircraft Engine Exhaust Emissions Data Bank, LTO data from FAA, and time-in-mode data calculated from EPA mixing height data. The detailed calculation for estimating aircraft emissions is described below. The development of data for these calculations for the baseline and forecast years follows.

A.1 Aircraft Emission Calculation

The emissions from one engine for each phase of the LTO cycle are calculated by

$$E_{phase} = \frac{Emissions\ (lb)}{Fuel\ \ flow\ (lb)} * \frac{Fuel\ use\ (lb)}{(min)} * Time\ in\ mode\ (min) \qquad (1)$$

where E_{phase} is the total emissions for that phase, *Emissions/Fuel flow* and *Fuel use/min* are engine emission factors from various sources,[1,2] and *Time in mode* is the duration of the phase (as described in Section A.2 below).

The emissions for the entire LTO cycle are determined by

$$E_{cycle} = \sum_{phases} E_{phase} \qquad (2)$$

where E_{cycle} is the total emissions for the LTO cycle and the *phases* are approach, reverse thrust, taxi/idle, take-off, and climbout.

E_{cycle} is the emissions from one engine, so the emissions from an aircraft, $E_{aircraft}$ are given by

$$E_{aircraft} = E_{cycle} * N_{engines} \qquad (3)$$

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[1] Emission factors for CO, HC, and NOx come from the ICAO Aircraft Engine Exhaust Emissions Data Bank. Emission factors for SO_2 come from EPA jet fuel sampling data. Emission factors for toxics come from "Documentation for the 1996 Base Year National Toxics Inventory for Aircraft Sources" and are calculated in an additional step.

[2] The CO_2 emission factor is calculated by assuming that all carbon in the fuel is emitted as CO_2, and that carbon emissions as CO or HC are negligible. (Comparing the numbers in Tables II-5 (HC emissions), B-6 (CO emissions), and B-7 (CO_2 emissions) shows that this assumption is reasonable.) CO_2 emissions can then be calculated as the weight fraction of carbon in fuel divided by the weight fraction of carbon in CO_2. Jet fuel has a C:H ratio of about 1:2; recalling that carbon has an atomic mass of 12 and hydrogen has an atomic mass of 1, jet fuel has a carbon mass fraction of about 12/(12+2). The carbon mass fraction of CO_2 is 12/(12+2*16). The mass of CO_2 emitted per pound of fuel is then equal to (12 lb C/14 lb fuel)*(44 lb CO_2/12 lb C) = 3.14 lb CO_2/lb fuel.

where $N_{engines}$ is the number of engines on the plane.

This calculation is performed for all aircraft/engine combinations. Because LTOs are reported by air carrier and aircraft-type (i.e., Continental Boeing 727-200), but not with the engine-type of each plane (Continental's nine 727-200s have three different engine models), we take a weighted average of the emissions from each type of engine in the air carrier's fleet, or

$$\overline{E_{aircraft}} = \frac{\sum_{engine\ types} E_{aircraft}}{Number\ of\ engine\ types} \qquad (4)$$

where $\overline{E_{aircraft}}$ is the weighted average from one model of aircraft and *Number of engine types* is the number of different engines for that aircraft model owned by the air carrier, from Jet Information Services' World Aircraft Inventory.

The emissions for each airline/aircraft type is multiplied by its associated LTOs, and the results totaled to find the total emissions for the airport, given by

$$E_{airport} = \sum_{aircraft,\, airline} (\overline{E_{aircraft}} * LTO_{aircraft}) \qquad (5)$$

where $E_{airport}$ is the total emissions at the airport and $LTO_{aircraft}$ is the number of LTOs flown by each aircraft owned by each airline, from US DOT's annual Airport Activity Statistics of Certificated Air Carriers.

A.2 Data Preparation for 1999 Analysis

The robustness of the NESCAUM analysis is based on the development of detailed data for input to the emissions model. Data was used at the finest level of resolution that was reasonable for calculations. Several sets of inputs were available with daily or monthly data, so data was aggregated into monthly averages and monthly emissions were calculated. This section describes the process for developing input data for the 1999 emissions estimates. The following section describes how the input data were developed for the 2010 emissions estimates.

Fleet Mix

The fleet mix for commercial aircraft was compiled from Jet Information Service's World Aircraft Inventory. This Inventory included the aircraft owners, the makes and models of aircraft in their fleets, and the engine models on those aircraft. When airline/aircraft combinations were included in the LTO tables but not in the World Aircraft Inventory, the aircraft was assigned the engine most commonly used on that aircraft.

No aircraft-specific LTO figures were available for air taxi or general aviation aircraft; therefore engines and the fraction of single- and multi-engine aircraft were assigned from a national registry. Emissions were calculated using weighted averages of the engines in the national registry.

LTOs

Table 7 of US DOT's "Airport Activity Statistics of Certificated Air Carriers, Twelve Months Ending December 31, 1999" provides LTOs by airline/aircraft combination on an annual basis. In order to calculate monthly emissions, the Table 7 data was augmented with monthly operations data from the FAA Air Traffic Activity Query System. These operations numbers were converted to monthly LTO fractions (calculated as the month's operations divided by total annual operations). Monthly airline/aircraft LTOs were then calculated by multiplying annual LTOs for each airline/aircraft combination by the monthly LTO fraction. This calculation assumes that the fleet mix provided in the LTO data is constant through the year.

LTOs for air taxi and general aviation aircraft we also obtained from the FAA Air Traffic Activity Query System. LTOs were not available for specific models of aircraft, so aggregate LTO figures were used. Monthly LTOs were obtained from the database to calculate monthly emissions.

Time-in-Mode

The duration of each phase of the LTO cycle is important in the first step of estimating emissions (Equation 1, above). Emissions during each phase are directly related to the time spent in that mode. Reviewing the LTO cycle in Figure II-2, we see that the duration of the each phase is influenced by several factors (Table B-1). Aircraft speed is a factor when aircraft are in the air, and it differs for each mode. The mixing height changes during the day and across the year, and directly influences the height considered for approach and climbout. The altitude to which takeoff extends affects both climbout and takeoff. The only factor effecting taxi/idle time is ground time.

Table B-1: Influences on the Time-in-Mode for Phases of the LTO Cycle

	Aircraft Speed	Mixing Height	Takeoff Altitude	Ground Time
Approach	Y	Y		
Takeoff	Y		Y	
Climbout	Y	Y	Y	
Taxi/Idle				Y

CAEP has set the times-in-mode (TIM) for a standard LTO cycle for commercial air carriers based on estimated air speeds, a mixing height of 3000 feet, a takeoff altitude of 500 feet, and a generic taxi/idle time. EPA developed TIMs for other aircraft types; the TIM for the CAEP and EPA standard LTO cycles are shown in Table II-2. These times are often used to estimate emissions at airports, but they are not based on any actual airport. In order to increase the accuracy of the emissions estimates it was necessary to adjust the standard TIMs. The standard method for adjusting TIM assumes that aircraft speed is not changed, but incorporates additional data about mixing height, takeoff altitude, and taxi/idle time, as they are available. In order to estimate emissions at the three airports of study, we have collected airport-specific data and used it to adjust the standard TIM.

The equations necessary to adjust the CAEP TIMs are shown in Table B-2; EPA TIMs are adjusted with the same equations, substituting the appropriate estimated TIM for each phase of the LTO cycle.

Table B-2: Calculating Adjusted Time-in-Mode for Commercial Aircraft Based on the Standard LTO Cycle

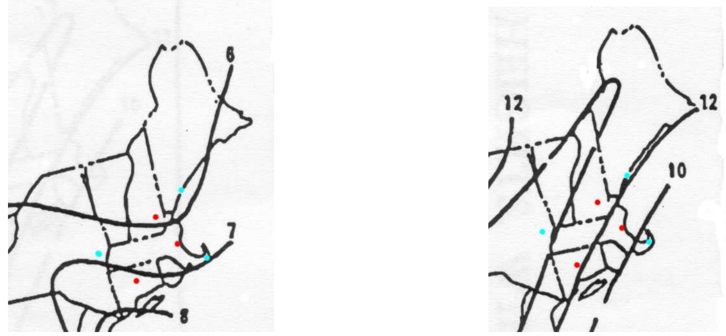
Phase of the LTO Cycle	CAEP Estimated Time-in-Mode (min)	Calculating Time-in-Mode
Approach	4.0	$TIM = 4.0\min \times \frac{MixingHeight(ft)}{3000 ft}$
Takeoff	0.7	$TIM = 0.7\min \times \frac{TakeoffHeight}{500 ft}$
Climbout	2.2	$TIM = 2.2\min \times \frac{(MixingHeight - TakeoffHeight)}{2500 ft}$

Mixing Height

Mixing height data is available from the EPA SCRAM (Support Center for Regulatory Air Models) database for limited number of sites in the United States. Measurements were not taken directly at Logan, Manchester, or Bradley airports, so it was necessary to choose alternate mixing height stations near these airports. There are only six mixing height stations in the NESCAUM region, located at: Caribou, ME; Portland, ME; Chatham, MA; Albany, NY; Buffalo, NY; and Atlantic City, NJ. The stations at Caribou, ME; Buffalo, NY; and Atlantic City, NJ were eliminated as too far from the airports of study. Assignments of mixing heights to the three airports were made with consideration for previous EPA mixing height studies and for differences in coastal and inland climates.

EPA's 1972 mixing height study estimated mean annual morning and afternoon mixing heights at stations across the country, and provided maps of isopleths of mixing heights. Figure B-1 shows the contours for New England, with the airports of study marked in red and the mixing height stations marked in blue. An airport and mixing height station between isopleths are generally considered to have similar climatic features, which is desirable for estimating mixing height at the airports. The figure shows that Manchester International Airport in NH and the mixing height station at Portland, ME are between the same isopleths in both the morning and afternoon. This is not the case for any of the stations with respect to Logan International Airport in MA or Bradley International Airport in CT. If one draws the "half" or "odd" isopleths between those presented in Figure B-1, Logan falls within the same isopleths as Portland, ME or Chatham, MA. Bradley still has no obvious choice for a mixing height station.

Figure B-1: Morning and Afternoon Mixing Heights



(a) Morning Mixing Height (b) Afternoon Mixing Height

Isopleths (m x 10^2) of mean mixing heights. Airports of study (Manchester, NH; Logan, MA; and Bradley, CT) are shown in red. Mixing height stations (Portland, ME; Albany, NY; and Chatham, MA) are shown in blue.

Source: adapted from US EPA. “Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Continuous United States”. Figures 1 and 6, pp. 26 and 31.

In order to assign mixing height stations for Logan and Bradley, a second factor, coastal vs. inland climate, must be considered. Coastal and inland climates differ in temperature and precipitation. Coastal climates are often more moderate than inland climates, with lower temperatures and lower mixing heights. It is therefore best to assign inland mixing height stations to inland airports and coastal mixing height stations to coastal locations. As can be seen from Figure B-1, Albany is quite far inland, while both Portsmouth and Chatham are coastal sites, with Chatham mostly surrounded by water.

Assigning Logan and Bradley to mixing height stations is difficult because there is no clear choice that meets the criteria of not crossing isopleths and matching coastal climates between airports and mixing height stations. Mixing height stations were assigned as shown in Table B-3.

Table B-3: Mixing Height Stations for the Three Airports

Airport	Mixing Height Station
Logan	Portland, ME
Bradley	Albany, NY
Manchester	Portland, ME

Logan was assigned to Portland, ME. The coastal characteristics of Portland are more similar to Logan than is Chatham, which is surrounded by water and is considered to have a very mild climate. Manchester should have an inland mixing height station, but because Albany is much further away than Portland, Portland was assigned to Manchester. Finally, Bradley requires an inland station, and although Albany is far away, it is the closest of the available inland stations.

The SCRAM mixing height data consists of two daily measurements of mixing height and other meteorological data. The measurements are taken at noon and midnight and labeled as "morning" and "afternoon," respectively. From these twice-daily measurements and additional meteorological data available from EPA SCRAM, hourly estimates of mixing height were calculated with EPA's PCRAMMET model. The average mixing heights for the airports of study were calculated as the average of all mixing heights greater than 10 meters[3] between 6am and midnight, averaged for each month. The hours between 6am and midnight were chosen because most airport LTOs take place between these hours.

Takeoff Height

Takeoff profile information obtained from the Air Transport Association as part of the EPA/FAA Stakeholder Process indicates that takeoff may last well past 500 feet, and perhaps as high as 1000 feet. The equations in Table B-2 incorporate alternate takeoff heights in the calculation of times-in-mode.

Taxi Time

Monthly taxi-in and taxi-out statistics for each of the airports were available from DOT's Bureau of Transportation Statistics. These statistics include airline-specific taxi times for large carriers as well as an airport average taxi time. The airport averages of taxi-in and taxi-out times were used, and total taxi/idle time was the sum of the taxi-in and taxi-out times.

Average mixing heights and the resulting times-in-mode for climbout and approach were calculated for each month at each of the mixing height stations. The heights and times-in-mode are shown in Table B-4. These calculations incorporate a takeoff height of 1000 feet; takeoff time was always 1.4 minutes.

A.3 Data Preparation for 2010 Emissions Estimates

Data for the 2010 emissions estimate was prepared in a similar manner to the data to 1999; however, making the projection required adjustments to the methods for developing some factors. This section describes how fleet mix, LTOs, and time-in-mode were calculated for 2010.

Fleet Mix

The fleet mix for commercial aircraft was mostly unchanged from the 1999 estimates. Scrappage in airline fleets was accomplished through adjusting LTOs, as described in the next section. The primary assumption made in this analysis was that as planes are phased out of service, their engine types are phased out in equal proportions. Engines for new aircraft are assigned based on contract press releases and similar information obtained from aircraft manufacturers. In instances where multiple contracts have been initiated, each engine is assigned to an equal share of aircraft activity. Finally, for engines that are not yet in production, emission factors for similar current engines (based on thrust) have been substituted.

The fleet mix for air taxi and general aviation aircraft were not changed from the 1999 estimates.

[3] The lower limit of 10 meters was selected because the PCRAMMNET program prints a warning when calculated mixing heights are below this height.

Table B-4: Monthly Average Mixing Heights and Associated Times-in-Mode for Commercial Aircraft

Takeoff altitude is assumed to be 1000 feet.

	Logan and Manchester			Logan	Manchester	Bradley			
	Mixing Height (feet)	Climbout Time (min)	Approach Time (min)	Taxi Time (min)	Taxi Time (min)	Mixing Height (feet)	Climbout Time (min)	Approach Time (min)	Taxi Time (min)
January	1932.4	0.82	2.58	28.8	16.1	2167.9	1.03	2.89	21.8
February	2317.0	1.16	3.09	25.7	14.6	2605.2	1.42	3.49	17.6
March	2971.3	1.73	3.96	26.5	14.8	3450.2	2.16	4.60	17.4
April	3112.8	1.86	4.15	24.5	14.3	4366.5	2.96	5.82	16.9
May	2895.0	1.67	3.86	25.9	14.9	4473.0	3.06	5.96	17.9
June	3340.6	2.06	4.45	28.5	14.9	4506.0	3.09	6.01	17.7
July	3281.1	2.01	4.37	31.7	15.3	4388.1	2.98	5.85	18.9
August	2938.8	1.71	3.92	28.2	14.9	3995.7	2.64	5.33	17.8
September	2773.7	1.56	3.70	28.4	15.0	3503.5	2.20	4.67	18.0
October	2413.3	1.24	3.22	29.0	15.6	2872.8	1.65	3.83	18.8
November	2247.0	1.10	3.00	26.7	15.1	2696.1	1.49	3.59	17.2
December	2016.6	0.89	2.69	26.0	14.8	2317.4	1.16	3.09	17.6

LTOs

2010 LTO activity by air carrier and aircraft type was forecasted using baseline (1999) FAA LTO data, total airport-specific LTO activity forecasts prepared by the FAA, and industry aircraft forecasts prepared by Boeing and Airbus[4]. Both Boeing and Airbus produce forecasts by aircraft class (which can loosely be defined in terms of seating capacity). The fundamental methodology used to forecast activity growth can be viewed as a two step process, controlled (or constrained) by the overall airport-specific activity forecasts produced by the FAA. In effect, a "free market" forecast, that is both airline and aircraft specific, is prepared using industry forecast data. The total LTO activity arising from this forecast is then compared to the total LTO activity at each airport as forecasted by the FAA and normalized as necessary to equilibrate the two independent methodologies.

This equilibration step should be viewed as necessary to include airport-specific constraints into the forecast process. The free market forecast considers only industry-wide influences, in effect "smoothing out" airport-specific influences so that local distinctions are lost. The equilibration step "recaptures" these local distinctions. Nevertheless, the differential between the FAA forecasted LTO activity and the pre-normalized industry-forecasted LTO activity can still be viewed as a measure of the relative consistency of the two forecasting methods. Differentials for airports that are growing under average conditions would be expected to be near unity, while airports growing at either above or below average rates would be expected to exhibit corresponding differentials. For this work, the FAA-to-free market forecast differentials are 1.02 for Bradley, 0.66 for Logan, and

[4] Airbus Industrie, *Global Market Forecast 2000-2019*; July 2000 and Boeing Commercial Airplanes, *Current Market Outlook 2001*; June 2001.

1.11 for Manchester. These are quite consistent with expectations, with Manchester growing at a faster than average rate, Bradley growing at a near average rate, and Logan growing at a less than free market rate due to existing airport capacity constraints.

Industry forecasts were converted in airline and airport-specific activity forecasts as follows. It should first be recognized that in combining LTO and aircraft growth data, it was necessarily assumed that the growth in LTO activity would occur at the same rate as growth in aircraft ownership. With this assumption, the initial processing step consists of estimating that fraction of aircraft that will be scrapped between 1999 and 2010 (which corresponds to the expected reduction in associated LTOs). This estimate was produced using an aircraft-specific scrappage model presented in the Airbus forecast. The Airbus scrappage estimate was for 2009-to-1999 and was extrapolated to 2010 for this work. Using the scrappage estimate, the 1999 FAA LTO data for each airport was proportionally adjusted to produce an estimate of the 2010 LTO activity associated with the same airlines and aircraft observed in 1999 (in effect, an estimate of how much LTO activity is associated with the "non scrapped" portion of the aircraft fleet). Generally, the use of continuing aircraft accounts for 35-40 percent of forecasted 2010 LTOs.

The second step in the free market forecast utilizes the Boeing and Airbus forecast data to calculate aircraft class-specific 1999-2010 growth rates. These growth rates were then applied to the observed 1999 LTO data for each airport to derive total expected 2010 LTO activity. The difference between this forecasted activity and that associated with the non-scrapped fleet (as calculated during the initial processing step previously described) is the LTO activity associated with new and replacement aircraft. It is important to recognize that at this point the relationship between specific airlines and aircraft (based on 1999 FAA observations) ceases. There is no requirement that replacement aircraft be of the same class as scrapped aircraft or that the fleet grow proportionally across classes. In fact, market trends such as the shift toward smaller regional-scale jets dictates that proportionality will not occur. It is, therefore, necessary to develop a probability-type function that distributes replacement aircraft across various classes.

Such a function was developed from the industry forecasts by comparing the class-specific growth rates to the overall aircraft growth rate and assuming that differentials are accounted for by movement between each class and its nearest larger and smaller neighbors. Under this approach, a class growing at a greater than average rate will satisfy both within class replacement aircraft demand and a portion of replacement demand in the neighboring classes. Neighboring class demand fractions are assumed to be split in proportion to the difference between neighboring class and average aircraft growth. Conversely, for classes growing at less than average growth rates, all replacement aircraft are assumed to be within class aircraft.

Combining the replacement aircraft activity estimates and probability functions results in estimates of total class-specific LTO estimates. These class-specific estimates are then distributed across component aircraft in accordance with the distribution of current new aircraft orders within each class. The resulting aircraft LTOs are not assigned to any specific airline, but rather modeled as a distinct "replacement aircraft" category.

Time-in-Mode

Time-in-mode for the forecast year was calculated similarly to 1999 TIMs. The same mixing heights (and therefore the same takeoff, climbout, and approach times) were used for the base year and the forecast year. Taxi time was adjusted based on factors found in airport planning documents.

Logan Airport calculated taxi times for the forecast year based on the "no action" alternative in its *Logan Airside Improvements Planning Project*.[5] Taxiway delay is projected to increase by 6 minutes per LTO in 2010 if the airport serves 37.5 million passengers.[6] The 2010 TIM for Logan was calculated as the 1999 TIM plus six minutes.

No forecast information for taxi/idle time was available for Manchester or Bradley airports. Forecast emissions were therefore calculated with the 1999 TIMs.

A.4 Additional Results

Tables B-5 through B-7 present the calculated inventories for SO_2, CO, and CO_2 emissions from aircraft at the three airports for 1999 and 2010.

Table B-5: 1999 and 2010 SO_2 Inventories

Airport	1999 SO_2 Emissions (tons/year)	2010 SO_2 Emissions (tons/year)	Percent Change
Logan	230.6	293.1	27.1%
Bradley	55.3	69.7	26.0%
Manchester	16.4	22.2	35.4%

Table B-6: 1999 and 2010 CO Inventories

Airport	1999 CO Emissions (tons/year)	2010 CO Emissions (tons/year)	Percent Change
Logan	1799.6	2972.2	65.2%
Bradley	316.0	499.2	58.0%
Manchester	105.4	164.6	56.2%

[5] *Logan Airside Improvements Planning Project* is part of the Draft Environmental Impact Statement and Report for new runways proposed at Logan Airport. Three alternatives plans for runway development are presented, as well as "Alternate 4", representing airport conditions if no action is taken to build a new runway.
[6] Logan has revised its passenger forecast since the publication of *Logan Airside Improvements Planning Project*. Logan now expects to serve 37.5 million passengers in 2015 instead of 2010. No adjustments to the taxiway delay figures are available, however, so the 2010 figure from the planning document was used.

Table B-7: 1999 and 2010 CO_2 Inventories

Airport	1999 CO_2 Emissions (tons/year)	2010 CO_2 Emissions (tons/year)	Percent Change
Logan	579,267	736,267	27%
Bradley	138,914	175,086	26%
Manchester	41,197	55,766	35%

B. Auxiliary Power Unit (APU) Emissions Methodology

B.1 Calculation Methodology

Because of the similarity between APUs and aircraft engines, APU emissions are calculated in the same manner as aircraft engine emissions. APUs operate only during the idle portion of the LTO cycle, however, so the equations are simplified to calculate one phase. Emissions during use are calculated by

$$E_{APU-use} = \frac{Emissions\ (lb)}{Fuel\ \ flow\ (lb)} * \frac{Fuel\ use\ (lb)}{(min)} * Time\ in\ mode\ (min) \qquad (6)$$

where $E_{APU\text{-}use}$ is the total emissions during one use of the APU, *Emissions/Fuel flow* and *Fuel use/min* are engine emission factors from varying sources,[7] and *Time in mode* is the duration of the use of the engine (as calculated below in this section).

Because APUs are only used during one phase of the LTO, the step to sum the phases is omitted. There is only one APU per aircraft, so the multiplicative factor for number of engines is also omitted. However, as with aircraft, different models of APUs may be used in a specific aircraft, so we again take a weighted average of emissions from APUs assigned to aircraft types, using the equation

$$\overline{E_{APU-aircraft}} = \frac{\sum_{APU\ types} E_{APU-use}}{Number\ of\ \ APU\ types} \qquad (7)$$

where $\overline{E_{APU\text{-}aircraft}}$ is the average emissions from the models of APU used on a specific type of aircraft. Then, as with aircraft, total APU emissions are calculated for the number of LTOs made by each type of aircraft owned by each airline, using the equation

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[7] APU emission factors for CO, HC, and NOx come from AP-42, EEA-95, and EDMS v3.1. Emission factors for SO_2 come from EPA jet fuel sampling data, and CO_2 emission factors are calculated as for aircraft (see Footnote 2 of this appendix).

$$E_{APU} = \sum_{aircraft,airline} (\overline{E_{APU-per-aircraft}} * LTO_{aircraft}) \quad (8)$$

where E_{APU} is the total emissions from APU at the airport and the other terms are the same as described in Section AI.B.

B.2 Time-in-Use Calculation for APU Emissions Estimates

Several factors influence APU time in use. APUs are generally used to provide power and conditioned air to an aircraft while it is at the gate, though these functions can be provided instead by ground power units (GPUs) or air starts. (GPUs and air starts are types of ground service equipment and are described in Table II-14.) Some airport gates can provide power and/or pre-conditioned air, reducing the need for APU use. This variety of power sources complicates the estimation of APU time-in-use.

In order to estimate APU times-in-use at the airports of study, we first calculated gate turnaround times from airport schedules to estimate maximum times-in-use, then obtained information about the number and distribution of powered gates at the airports of study to estimate the fraction of LTOs that use their APUs.

Gate turnaround times were calculated from monthly airport schedules. Schedules contained arrival or departure times for flights, destination or origin city, airline, aircraft make (and sometimes model), and the number of stops on the flight. Schedules for arriving and departing planes were matched based on airline and aircraft, with the base assumption that departures must follow arrivals. Gate time was calculated as the difference between departure and arrival times. Gate time was not calculated for aircraft that remain at the airport overnight. Time-in-use was calculated as the average gate time of flights arriving and departing the same day, calculated for airline/aircraft combinations. Calculations were made from the October 2000 flight schedule for Manchester airport and the January and December 1999 flight schedules for Bradley International Airport. A flight schedule of sufficient detail was not available from Logan for domestic airlines; however, international flight schedules from August 2000 were used to calculate time-in-use for international airlines.

APU time-in-use data is entered into the emissions model similarly to the aircraft LTO data, by airline/aircraft combination, with separate calculations for domestic and international carriers. The flight schedules did not contain all of the airline/aircraft combinations included in the FAA LTO data, so substitutions were necessary. Time-in-use data and substitutions were entered in the following order:

1. For airline/aircraft combinations found in the airport schedule, enter calculated time-in-use.

2. For aircraft listed in the LTO table but not found in the schedule by their airline, enter the airport-average time-in-use for that aircraft.

3. For aircraft listed in the LTO table and not found in the schedule for that airport, but found in the schedule at another airport, enter the airport-average time-in-use for that aircraft from the alternate airport.

4. For aircraft not listed in the schedule for domestic airlines, make substitutions as shown in Table B-8.

Table B-8: Domestic Airline Aircraft Substitutions for APU Time-in-Use

<table>
<tr><th>Aircraft in LTO Table</th><th>Substituted Aircraft</th><th>Aircraft in LTO Table</th><th>Substituted Aircraft</th></tr>
<tr><td>ATR-72</td><td>ATR-42</td><td rowspan="5">A-300-600
B-747
B-747-200
B-767-200
B-767-300
B-777
DC-10-10
DC-10-30
DC-10-40
L-1011/100/20
L-1011-500
MD-11</td><td rowspan="5">International widebody substitution[8]</td></tr>
<tr><td>B-737-800/900</td><td>B-737-400</td></tr>
<tr><td>DC-9-40</td><td>DC-9-30</td></tr>
<tr><td>Embraer-120
Embraer-135</td><td>Embraer-145</td></tr>
<tr><td colspan="2"></td></tr>
</table>

5. For aircraft not listed in the schedule for international airlines, make substitutions as shown in Table B-9.

Table B-9: Domestic Airline Aircraft Substitutions for APU Time-in-Use

<table>
<tr><th>Aircraft in LTO Schedule</th><th>Substituted Aircraft</th><th>Aircraft in LTO Schedule</th><th>Substituted Aircraft</th></tr>
<tr><td rowspan="3">B-727-100
B-727-200/231A
MD-80</td><td rowspan="3">B-737</td><td>A310-300</td><td>B-767-200</td></tr>
<tr><td>L-1011-1/100/200</td><td>B-747</td></tr>
<tr><td>MD-11</td><td>DC-10</td></tr>
<tr><td>BA Concorde</td><td>JFK Turnaround[9]</td><td colspan="2"></td></tr>
</table>

Because a detailed flight schedule for domestic airlines was not available for Logan Airport, only steps 2 and 3 were applied, using the data calculated at Bradley Airport.

[8] No widebody aircraft were included in the domestic schedules. All APU times-in-mode for domestic widebody aircraft were replaced with the shortest international widebody aircraft turnaround time (Alitalia B-767-300).

[9] The single Concorde LTO at Logan in 1999 was an unusual occurrence. The scheduled turnaround time at JFK airport was used for this aircraft.

APU times-in-use were calculated similarly for cargo flights, but turnaround times were only available at Manchester Airport for three aircraft. Airborne Express (ABX) and Federal Express (FedEx) both turned around in approximately 35 minutes, while UPS flights had turnaround times of over two hours. This was the case for multiple flights for each airline, and we attribute the difference between the carriers to the number and size of packages that each carries. In order to apply the APU times-in-use to other carriers and other airports, we applied the UPS time only to UPS flights, and the average of the ABX and FedEx times to all other cargo aircraft.

In the forecast year, APU time-in-use was assumed to grow in proportion to airport congestion, for which the best measure was increase in taxi times. Because adjusted taxi times were only available for Logan airport, only Logan's APU times were adjusted. For 1999 aircraft operating in 2010, APU times were entered as for 1999, with Logan times being multiplied by 1.6, the average of the monthly increase in taxi time.

For new aircraft, no calculations of turnaround times were available, so APU time-in-use substitutions were made as shown in Table B-10, applying the factor of 1.6 for aircraft at Logan.

Table B-10: Aircraft Substitutions for Projection Year Time-in-Use

<table>
<tr><th>Aircraft in LTO Schedule</th><th>Substituted Aircraft</th><th>Aircraft in LTO Schedule</th><th>Substituted Aircraft</th></tr>
<tr><td>Avro RJX70
Bomb CRJ700
Emb ERJ170
F/Do 728JET</td><td>Emb-145</td><td rowspan="4">B767-200ER
A310-300
B767-300
B767-300ER
B767-400ER
A330-200
B777-200ER
A330-300
A340-300
A340-500
B777-200
B747-400
B777-300
A340-600
MD-11
A380</td><td rowspan="4">International Widebody Substitution</td></tr>
<tr><td>A318-100
Avro RJX85
Avro RJX100
Bomb CRJ900
Emb ERJ190
F/Do 928JET</td><td>F-100</td></tr>
<tr><td>B717-200
MD-90
Tu-154</td><td>MD-80</td></tr>
<tr><td>B737-600
B737-700</td><td>B-737</td></tr>
<tr><td>B737-800
B737-900</td><td>B-737-400</td><td>A321-100
A321-200</td><td>A-320</td></tr>
</table>

It was not possible to obtain sufficient information about the number of powered gates or the fraction of LTOs that utilize gate electricity or preconditioned air. Therefore this analysis assumed that APUs were used 100% of the time. This assumption will lead to an overestimation of actual APU emissions, but will estimate the maximum possible emissions from APUs.

B.3 Additional Results

Tables B-11 through B-13 present the calculated inventories for SO_2, CO, and CO_2 emissions from APUs at the three airports for 1999 and 2010.

Table B-11: 1999 and 2010 SO_2 Inventories

Airport	1999 SO_2 Emissions (tons/year)	2010 SO_2 Emissions (tons/year)	Percent Change
Logan	25.1	43.5	73.3%
Bradley	5.8	14.5	150%
Manchester	1.5	2.6	73.3%

Table B-12: 1999 and 2010 CO Inventories

Airport	1999 CO Emissions (tons/year)	2010 CO Emissions (tons/year)	Percent Change
Logan	197.3	206.0	4.4%
Bradley	59.6	70.7	18.6%
Manchester	14.9	12.1	-18.8%

Table B-13: 1999 and 2010 CO_2 Inventories

Airport	1999 CO_2 Emissions (tons/year)	2010 CO_2 Emissions (tons/year)	Percent Change
Logan	63,051	109,272	73%
Bradley	14,570	36,424	150%
Manchester	3,768	6,531.2	73%

Appendix C: "Airlines Feel Pressure of Europe's Fast Trains."
New York Times, August 12, 2001

www.nytimes.com
The New York Times ON THE WEB

August 12, 2001

TRAVEL ADVISORY: CORRESPONDENT'S REPORT; Airlines Feel Pressure Of Europe's Fast Trains

By JOHN TAGLIABUE

EVEN Bernard Chaffange freely owns up. ''Whenever I go to Paris,'' he said recently in a telephone interview, ''I take the TGV.'' That might not seem a surprise, since Mr. Chaffange lives in Lyon, which has been connected to Paris by high-speed train since 1981, when the French national railway introduced the 185-mile-an-hour Trains à Grande Vitesse.

Except that Mr. Chaffange is director of Lyon-Saint-Exupéry Airport, which lost 85 percent of its traffic with Paris in the first years after 1981. This year, he said, 730,000 passengers will fly between Lyon and Paris, half the number that did so before the arrival of the TGV.

Mr. Chaffange's attitude is similar to that of a growing number of Europeans. As the network of high-speed trains grows, airlines find themselves under pressure from the fast and comfortable rail system.

In some cases, the airlines are seeking to compete. When the French national railway inaugurated a three-hour train service on the 490-mile route from Paris to Marseille in May, Air France cut round-trip fares on the route to as little as $70, versus $84 for a second-class round-trip ticket on the TGV. Elsewhere the airlines have thrown in the towel. When Germany introduced its high-speed ICE trains in 1991, Lufthansa shut down its Hanover-to-Frankfurt route. Earlier this year, Air France discontinued flights from Paris to Brussels, crushed by competition from the new Thalys train.

Increasingly, the airlines are exploring ways to cooperate with the trains. British Airways, for instance, has an equity stake in Eurostar, the company that runs trains through the Channel Tunnel. Lufthansa is experimenting with ways to mesh its schedules with those of trains, and in a licensing agreement with the German railways, the Deutsche Bahn, has launched a high-speed train that makes the trip from the Stuttgart rail terminal to Frankfurt Airport in about an hour and a half. Passengers can check their bags in Stuttgart and connect with flights at Frankfurt, Germany's biggest hub. Airports in France, including Paris and Lyon, have built stations for high-speed trains into their infrastructure.

The reasoning is simple: for journeys of up to three hours, the airlines find it difficult to compete with trains. The advantages of incorporating trains into the airlines' hub-and-spoke systems means increased passenger volumes for the railways. For the airlines, the arrangement enables them to focus more on high-yield international routes that can be comfortably fed by the trains, while freeing up valuable slots at crowded hubs by shifting feeder traffic to the rails.

''Competition? In principle, yes,'' said Wolfgang Weinert, project manager for intermodal transport at Lufthansa. Lufthansa pioneered the use of trains to feed its hubs in the 1980's, after it introduced the Airport Express, a train that linked Düsseldorf and Cologne with the Frankfurt airport. Passengers could check their bags on the train through to their final destinations, and the train schedules dovetailed with Lufthansa departure times. But the trains were low-speed and were later discontinued. Now the airline is test-marketing the concept with the high-speed Stuttgart-Frankfurt train.

Transportation experts say the airlines distinguish increasingly between point-to-point travel, when passengers begin a trip in, say, Paris, and end it in Lyon, and feeder-to-hub travel, when passengers set out, for example, in Lyon to travel via Paris to a third city like Los Angeles or Tokyo.

On point-to-point trips, Mr. Chaffange said, ''the cutoff point is usually between two and three hours.'' Under that time, passengers will choose the train; for longer trips, they take the plane. Of course leisure passengers often prefer the train while business travelers choose the plane. The high-speed train trip from Lyon to Lille, Mr. Chaffange said, takes three hours, versus 50 minutes for the flight, but the airlines have maintained a 90 percent lock on the route because most passengers are business travelers. Air France estimates it will lose about 20 percent of its traffic to the TGV on the Paris-Marseille route.

Other factors complicate the choice. Business travelers often prefer high-speed trains because it enables them to work along the way. ''We try to take Eurostar,'' said Christopher Logan, an analyst with Goldman, Sachs's transportation team in London. A flight to Paris involves a trip to Heathrow Airport in London, a wait for the plane, a brief 50-minute flight and another trip from the airport into town. On the train, that time can be spent working.

Airline experts say the competition between train and plane to feed airline hubs is decided by a different yardstick, which they refer to as ''total elapsed travel time.'' Mr. Weinert of Lufthansa said that if the time between a passenger's departure from, say, Stuttgart to travel via Frankfurt to Los Angeles were lengthened by taking the Stuttgart-to-Frankfurt train, passengers would probably choose a feeder flight. To reduce the total elapsed time, passengers must be able to check their luggage at the train station through to their final destination, and trains must be scheduled to fit departures at the hub airport.

From Lyon to Paris, where the train time is 2 hours 10 minutes, Air France continues to operate 10 flights a day, mainly to feed its hub at Charles de Gaulle Airport; on the Brussels-to-Paris route, which takes 80 minutes by train, it canceled the last of its connecting flights in April.