United States
Environmental Protection
Agency

Air and Radiation

EPA420-R-99-007
May 1999

Technical Support for Development of Airport Ground Support Equipment Emission Reductions

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Prepared by:
Sierra Research, Inc. for the
Office of Mobile Sources
U.S. Environmental Protection Agency
Contract No. 68-C7-0051

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Report No. SR98-12-05

Airport Ground Support Equipment Emissions

prepared for:

U.S. Environmental Protection Agency

December 31, 1998

prepared by:

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Table of Contents

INTRODUCTION

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Background

The significance of air pollution emissions from airports is growing as airports expand to meet increasing demand for air travel and as the relative contribution of other sources declines under the pressure of progressively more stringent emission control programs. As a result, airports are being targeted for more aggressive emission control programs. Aircraft ground support equipment (GSE) represents one of three groups of mobile emission sources at airports. Together with aircraft and ground access vehicles, GSE contribute a small but significant share of the hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulate matter (PM) emitted in metropolitan areas. Today, total emissions from these three source categories comprise on the order of 2-3 percent of total manmade emissions in a typical metropolitan area, but this share is expected to increase as air travel continues to grow while emissions from other, non-airport sources are subject to increasingly stringent controls.

Since airports represent a growing source of emissions, EPA issued a work assignment to gather information and develop methodologies that can be used to develop a protocol on how to obtain State Implementation Plan (SIP) credit for emission reductions associated with the retrofit/replacement of airport ground support equipment by third parties, or governmental entities. This project is in support of the U.S. EPA Office of Mobile Sources Transportation and Market Incentives Group's (TMIG) efforts to develop protocols for quantifying voluntary mobile source emissions programs (VMEPs). Voluntary Measure Protocols are stand-alone guidance documents that describe the steps and methodology necessary for states and/or third parties to quantify emission reductions for SIP credit under EPA's Voluntary Measures Policy. Steps include requirements for quantifying emission benefits and estimating uncertainties in emission reductions and compliance, as well as administrative requirements for record keeping and/or SIP submission.

Project Scope

The purpose of this work assignment was to examine the control measures available to reduce emissions from one component of airport emissions, ground support equipment, and to recommend methodologies to quantify the reductions associated with implementing those control measures. This effort included the following key tasks:

- Literature/Data Search
- List of Equipment and Control Strategies
- Description of Individual Control Strategies
- Summary of Available Control Strategies
- Methods for Estimating Ground Support Equipment Activity
- Preparation of a Spreadsheet to Quantify Ground Support Emissions

This report presents a compendium of the work products produced under each task. To aid the reader in identifying products of interest, a brief summary of the contents of each section of this report is presented below.

Literature/Data Search - An extensive review of the literature was conducted to identify additional reports and bodies of information that provide insight into GSE emission rates, activity levels and available technologies to reduce emissions. The results are summarized in a series of tables addressing the following:

- General reports;
- Journal articles;
- Airport reports; and
- GSE manufacturer product information.

List of Equipment Control Strategies - Based upon a review of the available literature, a series of tables were constructed to list the control strategies available for each category of ground support equipment. Separate tables were prepared for each pollutant (i.e., HC, CO, NOx, PM, and carbon dioxide [CO_2]). Each table is organized by GSE type (e.g., airport pushback tractor, forklift, etc.), engine type, estimated U.S. population, fraction of total GSE population, fraction of emissions, and percent emission reduction potential for each control strategy.

Basis for GSE Population Estimates - Since there are no registration requirements for GSE or any other national organization charged with tracking GSE activity, there is no reliable database from which accurate GSE populations can be determined. To provide a reliable estimate of national GSE population, a detailed statistical regression analysis of the available data was conducted. This section presents the results of that review by airline classification and by equipment and engine type.

GSE Emissions and Activity Estimates - Accurately characterizing the emissions performance of a particular GSE requires detailed knowledge in two specific areas: (1) the rate of equipment emissions per unit of activity, and (2) the amount of activity performed during the period of interest. Generally, the unit activity emission rate can be either measured directly or estimated from previous measurements taken for similar equipment or engines. Because emission rates typically vary with engine speed and load (a measure of how “hard” the engine is being worked), emission rates for GSE-type equipment are commonly measured over a broad series of constant speed and load operating modes that, when weighted in accordance with the amount of time the engine spends in each mode, can describe the average emission rate of the equipment. This section presents a methodology for estimating equipment specific activity and related emission levels.

LPG and CNG Control Strategies - The majority of conventionally powered GSE can be converted to either liquefied petroleum gas (LPG) or compressed natural gas (CNG) fueling or replaced with a specially manufactured LPG- or CNG-powered counterpart. The basic issues surrounding the use of LPG or CNG as a GSE fuel are quite similar and, therefore, both fueling strategies can be treated together. Generally, non-methane hydrocarbon (NMHC), CO, NO_x, PM, and CO_2 emissions from LPG or CNG GSE are all reduced relative to emissions from gasoline-powered GSE. Relative to diesel GSE, emissions of NO_x and PM are reduced, emissions of HC and CO are increased, and emissions of CO_2 can be either slightly increased or decreased depending on equipment size. This section presents a review of important issues in determining the viability of either conversion or replacement strategies.

Electric GSE - The majority of conventionally powered GSE can be either converted to electric power or replaced with specially manufactured electrically powered counterparts. Although there is an increase in offsite power generating station emissions resulting from the increased electrical demand required to recharge electric GSE, conversion to electric power or replacement with electric GSE can be a very effective emission reduction strategy. Even when the increased emissions from power generating stations are considered, electric GSE usually emit[*] significantly less HC, CO, NO_x, PM, and CO_2 emissions than their fossil-fueled (i.e., gasoline, diesel, CNG, and LPG) counterparts. This section reviews issues for consideration in determining the viability of either conversion or replacement strategies.

Emissions Aftertreatment - The majority of GSE continue to emit pollutants at essentially uncontrolled rates. Certain emission species such as HC, CO, and, in some cases, NO_x can be substantially reduced by the installation of a catalytic converter in the equipment exhaust system. Exhaust system traps (or filters) can perform similar reduction functions for PM. Catalyst technology has been well proven in on-road vehicle applications and particulate trap technology has advanced considerably over the last several years. Both systems are commercially available for equipment in the off-road sector, but long-term reliability and effectiveness have not been proven. This section presents a review of the systems designed for application on gasoline, diesel, CNG, and LPG engines.

Fixed Gate Support - While the majority of conventionally powered GSE can be either converted to or replaced by GSE powered by alternative fuels such as LPG, CNG, or electricity, a significant fraction of GSE can be eliminated entirely by incorporating fixed point-of-use support equipment into aircraft gate design. Such design not only eliminates all energy demands associated with moving displaced mobile GSE between aircraft gates and maintenance/storage facilitates, but also facilitates the use of "hard-wired" electrical power connections, thereby eliminating the need for a recharging infrastructure and scheduling plan. Although, as with electrically powered GSE, there is an increase in offsite power generating station emissions due to the increased demand for electrical power, fixed equipment is likely to consume less power than equivalent mobile GSE due to the elimination of the motive aspect of GSE operation. Even when the increased emissions from power generating stations are considered, fixed electrically powered support equipment usually emit significantly less HC, CO, NO_x, PM, and CO_2 emissions

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[*] Technically, electrically powered GSE do not emit any pollutants. The term emit, as used here, ascribes to the electric GSE, the offsite increase in power generating station emissions due to increased airport electrical power to support electric GSE recharging. In essence, the electrically powered GSE are treated as if they "emitted" the increased power generating station emissions associated with their use.

than their mobile fossil-fueled (i.e., gasoline, diesel, CNG, and LPG) counterparts. This section reviews issues related to the capital and operating cost and reliability of fixed gate-based equipment.

GSE Control Strategy Summary - An evaluation of GSE and associated service demands indicates that there are several control strategies that offer the potential to reduce emissions over both the long and the short term. Such strategies include both demonstrated and innovative technologies. All have associated issues that must be considered prior to implementation, but a generalized classification includes the following:

- The development of new engine emission standards for all currently unregulated equipment;

- The replacement or conversion of gasoline or diesel powered GSE to LPG or CNG fueling;

- The replacement or conversion of gasoline, diesel, LPG, or CNG powered GSE to electric power;

- The replacement of mobile GSE with electrically powered fixed gate-based equipment;

- The retrofit of existing GSE with catalytic converters or particulate traps; and

- The preferential replacement of existing two-stroke gasoline engines.

As might be expected, both the feasibility and cost effectiveness of emission reductions vary considerably across the potential control strategies. This section provides an overview of the major issues associated with each strategy and, where possible, provides an estimate of associated emissions reduction and cost effectiveness.

Estimating GSE Activity - Knowledge of the activity levels of airport GSE is critical to accurately determining emissions performance. This is true regardless of whether one considers the baseline emissions performance of today's GSE fleet or the potential emission reductions that can be derived through the implementation of various control measures. Either assessment requires the detailed characterization of equipment population and/or usage rates to derive accurate emission or emission reduction estimates. This section presents a review of the basic GSE emissions calculation methodology and methods available to prepare population estimates.

GSEModel Instructions - GSEModel is a personal computer spreadsheet-based analysis tool that has been developed to quantify emission benefits and calculate the cost-effectiveness of converting existing airport GSE to cleaner-burning fuels and engine technologies. The model has been developed as a planning tool for use by metropolitan planning organizations (MPOs), airports, and other agencies interested in evaluating potential emission benefits and cost savings resulting from available GSE emission control technologies. It has been designed with a mouse-enabled graphical user interface to make it simple and easy to use.

The GSEModel tool is based upon the “best practice” methodologies and information presented in the body of this report. It has been designed to utilize local (i.e., airport-specific) GSE usage and cost information coupled with best-available emission factor data to perform the following functions <u>using a consistent methodology</u>:

- Estimate current and alternative technology GSE emissions by individual equipment category (e.g., aircraft pushback tractors, baggage tugs, cargo loaders, etc.);

- Compute the emission benefits of the available alternative technologies;

- Quantify the incremental capital, operating, and life-cycle costs of converting GSE units to these alternative technologies; and

- Calculate and compare the cost-effectiveness (cost per unit emissions reduced, e.g., $/ton) of these alternative technologies for each equipment category under airport-specific operating and usage conditions.

A description of the model and operating instructions are presented in this section.

This project was conducted by Sierra Research, Inc. (Sierra) and Energy & Environmental Analysis, Inc. (EEA) under Work Assignment 0-05 of U.S. Environmental Protection Agency (EPA) contract #68-C7-0051. Sierra served in an oversight capacity and had primary responsibility for preparing the spreadsheet model for quantifying GSE model and related documentation. EEA had the lead responsibility for preparing all of the other sections presented in this report.

AVAILABLE INFORMATION SOURCES

TABLE 1. GENERAL REPORTS

TITLE	DATE	SPONSOR	DESCRIPTION	INCLUDES REFERENCES?
Airline Industry Talking Points on South Coast/Sacramento FIPs	Nov-93	Air Transport Association	Presents arguments from the airline industry regarding South Coast/Sacramento FIPs. Airlines should be able to achieve greater GSE emission reductions than estimated by EPA.	no
Manual Calculation Methods for Air Pollution Inventories	May-88	Guy T. Fagin, Capt., USAF, BSC, USAF Occupational and Environmental Health Laboratory, Human Systems Division, Brooks AFB, Texas 78235-5501	The purpose of this report was to provide guidelines for engineers on how to perform Air Emission Inventories. This report provided example calculations, emission factors, and an example inventory.	no
Air Pollution Mitigation Measures for Airports and Associated Activity	May-94	California Air Resources Board, Sacramento, California	Provides a reference guide to emission mitigation techniques that can be applied to ground support equipment. Each measure is described along with guidelines for its use and constraints that may limit its effectiveness.	yes
Electric Vehicles at Boston's Logan Airport (IN-102438)	1994	Layla Sandell, Electric Power Research Institute, Palo Alto, California	No abstract available	
Airport Electrification Project: Consolidated Results and Analysis (TR-109041)	1997	Layla Sandell, Electric Power Research Institute, Palo Alto, California	Studied electrification opportunities at seven airports and found that 96% of all inventoried IC vehicles and equipment could be converted (directly or indirectly) to similar electric powered models.	
Power Quality Guidelines for Airport (TC-108418)	1997	Layla Sandell, Electric Power Research Institute, Palo Alto, California	No abstract available	
Document Control List	not dated	Environmental Protection Agency	List of all documents used by EEA to perform tasks related to Airport Emissions Control Regulatory Support, all work which was conducted under an E.H. Pechan State Assistance Contract.	
Methodology to Estimate Off-Road Equipment Populations	May-91	Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI	Discusses method used to estimate airport equipment population, based on aircraft departures as an activity indicator. Also collected population data from airlines to compare to estimates.	no
Nonroad Engine and Vehicle Emission Study Report	Nov-91	Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI	Quantifies the contribution of nonroad sources to ozone and carbon monoxide air pollution and to other pollutants. Includes inventory and emissions estimates of Airport Service Equipment.	no
Airport Emission Inventories for FIP Areas	May-93	Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI	Mobile source airport emissions inventory data for various nonattainment areas in CA. Report discusses data availability, recommendations for further data collection, a review of control strategies, and a forecast of aircraft fleet make up and activity.	yes
Technical Support Document Civil and Military Aviation, California FIP NPRM	Mar-94	Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI	This document discusses technical information used by EPA during its development of the proposed FIP control strategy for aircraft operations. Includes operations and emissions data for various types of GSE.	yes

TABLE 1. GENERAL REPORTS (CONTINUED)

TITLE	DATE	SPONSOR	DESCRIPTION	INCLUDES REFERENCES?
GSE Population Data	Sep-93	Air Transport Association	Individual GSE population submissions from several ATA member airlines as part of California FIP development process	no
Analysis of GSE Emissions Associated with Airport Operations in the South Coast Air Basin	Jul-94	Environmental Protection Agency	Provides explanation of the analytical methodology used by EEA to calculate air emissions from GSE in the California South Coast area. Describes data sources, calculations, and results.	no
Memo - FIP Emission and Cost Forecasts for Aviation Sources: Controlled and Uncontrolled	May-95	Environmental Protection Agency	Documents the final methodology used for evaluating the cost and benefit of the California FIP after revisions were made. Includes a final summary of uncontrolled and controlled emissions and cost-impact forecasts for APUs and GSE in the FIP areas.	no
Memo - Refinement of FIP Ground Support Equipment Calculations		Environmental Protection Agency	Summarizes the calculation methodology of the refined GSE emission estimates presented in the previous referenced memo (May 1995).	no
Technical Support Document Aircraft/Airports, California FIP Draft IFR	Feb-95	Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI	This document discusses technical information used by EPA during its development of the interim final FIP control strategy for aircraft operations. Includes operations and emissions data for various types of GSE and emission control measures.	yes
Technical Data to Support FAA's Advisory Circular on Reducing Emissions from Commercial Aviation - Draft Final Report	Sep-95	Rich Wilcox - Environmental Protection Agency; Bill Albee - Federal Aviation Administration	Presents technical data to support FAA's advisory Circular on Reducing Emissions from Commercial Aviation. Data was collected and compiled in four main areas, including GSE.	yes
Analysis of Techniques to Reduce Air Emissions at Airports	Jun-97	Environmental Protection Agency, Washington, DC	Examines control strategies to reduce air emissions from mobile sources at airports, as well as the potential for application of controls at four specific airports. Detailed emission inventories are constructed for the four airports examined.	no
Airport Vehicle Fleets	n/a	Gas Research Institute	Currently not available. According to synopsis, presents the results of a survey of vehicle fleets at airports in the United States and Canada. Information collected indicates a growing NGV population at some of the busiest airports.	
Flying Off Course	Oct-96	National Resources Defense Council Washington, DC 20005	Determines the most important environmental issues connected with airports and the best management techniques airports are using to mitigate them.	yes
Airport Impact Mitigation and Management Study	Jul-90	South California Association of Governments Los Angeles, California	Outlines possible emission control measures that could be taken at 5 airports in the Southern California area. GSEs are not explored in depth.	no

TABLE 2. JOURNAL ARTICLES

TITLE	DATE	SOURCE	DESCRIPTION
airport rEVolution	Oct-94	EPRI Journal	Air Quality regulations are encouraging the use of electric vehicles at urban airports across the US. Airports are ideal for EVs, given the short distances and predictable routes that airport vehicles typically travel.
Preparing for Takeoff Newsletter - Volume 1, Number 2	1997	EPRI	Discusses electrification projects at various airports, focusing specifically on Southwest Airlines at Phoenix Sky Harbor Int'l airport, who is replacing diesel-powered tugs and conveyor belt loaders with their electric counterparts.
The Evolution of Preconditioned Air and 400 Hz Central Systems	Feb-94	GSE Today	Discusses why usage of preconditioned air (PCA) and 400 Hz central systems has come about. Use of PCA and 400 Hz offers the aircraft users opportunities to reduce costs, fuel usage, noise, and air pollution.
Selecting & Paying for Fixed Ground Support Systems	Oct-96	GSE Today	Discusses benefits of fixed power over APUs and presents a cost analysis.
Why Use a Gas Turbine as a Main Power Source for Air Start Units?	Jun-97	GSE Today	New generation gas turbine engines are less complex than diesel engines and more straightforward. Other benefits include lower maintenance costs, lower fuel and oil costs, longer life span, lower emissions, and take up less space.
California Clean Air Initiatives Bog Down	Sep-97	GSE Today	Discusses California's effort to reduce airport emissions in Southern California. Problem with figuring out what agency would have authority for GSE. Discusses different approaches that could be taken to reduce emissions from GSE.
Clean Air Update: A Draft MOU for Clean Air in California's SCAQMD	Apr-98	GSE Today	Discusses draft MOU prepared by ATA to develop a system of voluntary compliance to reduce emissions from GSE in SCAQMD. Still have to figure out baseline emissions, where funds should come from, and getting an accurate GSE operations inventory.
Cleared for Landing: NGVs Find a Niche at Nation's Airports	Jun-95	Natural Gas Fuels	Airports are ideal locations for NGVs due to the relatively restricted travel range. Discusses the potential for alternative fueled vehicles at airports with a spotlight on Denver International Airport and it's natural gas vehicle fleet.
Airports: Models of Opportunity	Sep-96	Natural Gas Fuels	Discusses airports that have begun converting vehicles to natural gas as well as funding opportunities available to airports to assist with conversions.
In Plane Sight / A Flight Plan for the Airport Market	Jan-98	Natural Gas Fuels	Natural gas is gaining a solid reputation for its performance in airport applications. NGVs account for the largest share of the increasing airport AFV population. However, GSE conversions are not as popular for several reasons.
Ground Support Goes Electric	Dec-95	Jane's Airport Review	The market potential for electric GSE depends on legislative requirements, perceived benefits, and the feasibility of converting. Outlines the potential advantages or disadvantages of conversion to electric GSE.
US Moves Closer to Towbarless Concept	Dec-96	Jane's Airport Review	Benefits of towbarless tractors (TLT) and possibilities of establishing a market in the US.
Jane's Airports, Equipment and Services 1996-97, ATOS 3-R Towbarless Tractor	1996-1997	Jane's Internet Web Site	The idea of using the TLT for operational or dispatch towing to save fuel seems to have disappeared and now these tractors are used for push-back operations. It is likely TLTs will start replacing conventional tow-tractors at a faster rate in the future.

TABLE 3. AIRPORT REPORTS

TITLE	DATE	SOURCE	DESCRIPTION
Sacramento International Airport, 1995 Annual Air Quality Report	Apr-96	Jim Humphries, Air Quality Coordinator, Sacramento International Airport, Sacramento, CA 95837	Includes emission estimates, mitigation measures, and associated reductions.
Sacramento International Airport, Annual Air Quality Report - Fiscal Year 1992/1993	Sep-93	Jim Humphries, Air Quality Coordinator, Sacramento International Airport, Sacramento, CA 95837	Includes emission estimates, mitigation measures, and associated reductions.
Baltimore-Washington International (BWI) Airport, Air Quality Plan	Sept. 94	Barbara Grey Manager, Programming and Environmental Services, Maryland Aviation Administration, BWI Baltimore, MD 21240	Explores primary sources of air emissions, inventory methods, emissions estimates, projections for future emissions, and possible mitigation measures. BWI noted that GSE are a leading source of emissions and could increase in future years.
Final Environmental Impact Statement - San Diego International Airport, Lindbergh Field Facilities Improvements	Feb-94	William Johnstone, Federal Aviation Administration, Los Angeles, CA 90009	Includes emission estimates and mitigation measures.
Phoenix Sky Harbor International Airport, Air Pollution Reduction Measures 1991-1994	Aug-95	City of Phoenix Aviation Department, Environmental Programs	Overview of emission reduction measures that have been initiated at Sky Harbor - includes conversion of airport fleet vehicles to CNG.
Maricopa Association of Governments, Aviation Air Quality Study	Nov-96	Maricopa Association of Governments, Phoenix, AZ 85007	Purpose of this study is to develop an aviation emissions preprocessor. Also summarizes and evaluates emissions results obtained and discusses further enhancement recommendations.
Washington National Airport, New Terminal and Related Facilities Project - 400 Hertz Power System Study	Oct-91	Metropolitan Washington Airports Authority, Washington, DC	The purpose is to compare the use of APU vs. various other methods for providing required power, while considering installation, operating and fuel costs to determine payback periods.
San Francisco International Airport Master Plan - Final EIR	May-92	City of San Francisco, Department of City Planning, San Francisco, CA	Includes emissions estimates for GSE in the aggregate.
Preconditioned Air and 400 HZ Study for San Francisco International Airport, New Concourses "A" and "G"	Dec-94	Aviation Systems, Inc. for Hellmuth, Obata, and Kassabaum	Purpose of this study was to analyze, based on life cycle cost, preconditioned air and 400 Hz systems using either central or point of use systems. Includes cost analysis.
LAX Energy Study for Future Preconditioned Air, 400 Hz, and Battery Powered GSE Equipment	Aug-95	Aviation Systems, Inc. for LAX	Determine the increase in electrical power as a result of adding PCA and 400 Hz systems to those gates which do not currently have them, and in addition, the power required if all or most of the GSE was changed to battery power
Environmental Studies - Boston-Logan International Airport	1994 and 1995	Massport, Boston, MA	Includes emissions estimates for GSE, mitigation measures, and emission projections.

TABLE 4. GSE MANUFACTURER PRODUCT INFORMATION

MANUFACTURER AND GSE TYPE	DESCRIPTION	INFORMATION INCLUDED
Various	"Advanced Transportation Vehicle Catalog" internet website: www.calstart.org/cgi-bin/catalog.cgi	The CALSTART website provides specifications for electric and alternative fuel GSE.
Krauss-Maffei - Towbarless Tractor	Report - "The Super Tug Advantage"	Includes technology information, emissions analysis at LAX, and environmental aspects (fuel savings, noise reduction, and exhaust gas reduction).
Krauss-Maffei - Towbarless Tractor	Extract from a presentation of a paper concerning "Towbarless Towing by Nose Gear Clamping"	Includes net fuel savings, advantages of towbarless towing, fuel consumption comparisons, and emissions savings.
Krauss-Maffei - Towbarless Tractor	Product Brochure	Includes technology information.
Krauss-Maffei - Towbarless Tractor	Product Brochure	Includes technology information, specifications, user experience.
FMT - Aircraft Gate Support Equipment	Product Brochure	Technology information, time savings.
FMT - Aircraft Gate Support Equipment	Product Presentation Material	Includes advantages of vehicle free gate, products offered by FMT, and cost comparisons.
Hobart - Ground Power Units	Product Brochure	Technology information.
FMC Jet Way Systems - PC Air and 400 Hz	Report "400 Hz and PC Air Point of Use Systems"	Includes two case studies done by Aviation Systems, Inc. for LAX regarding feasibility of PC Air and 400 Hz systems. Also includes customer comments, specifications, and cost comparisons.
FMC Jet Way Systems - PCA, 400 Hz, potable water	Product Brochure	Capital costs, operating estimates, and approximate payback time.

POTENTIAL CONTROL STRATEGIES

TABLE 1. POTENTIAL HC REDUCTION STRATEGIES FOR AIRPORT GSE

						Potential HC Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE HC	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Aircraft Pushback Tractor	Diesel	2113	4.7%	76.6%	3.4%	n/a	n/a	up 135	up 55	96	50	20	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	489	1.1%	17.7%	2.2%	50	65	50	65	99+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	63	0.1%	2.3%	0.1%	n/a	35	n/a	35	98	70	n/a	n/a	n/a
	Electric	94	0.2%	3.4%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2759	6.1%		5.8%									
Baggage Tug	Diesel	4399	9.8%	41.9%	4.6%	n/a	n/a	up 105	up 35	97	50	20	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	4863	10.8%	46.3%	26.6%	50	65	50	65	99+	90	n/a	99+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	973	2.2%	9.3%	2.7%	n/a	35	n/a	35	99	70	n/a	99	n/a
	Electric	270	0.6%	2.6%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	10505	23.3%		33.8%									
Belt Loader	Diesel	2429	5.4%	47.1%	1.7%	n/a	n/a	up 45	up 5	98	50	20	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2317	5.1%	45.0%	6.4%	50	65	50	65	99+	90	n/a	99+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	314	0.7%	6.1%	0.4%	n/a	35	n/a	35	99	70	n/a	99	n/a
	Electric	94	0.2%	1.8%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	5154	11.4%		8.5%									
Carts Tool & Lavatory	Diesel	31	0.1%	1.4%	0.0%	n/a	n/a	up 375	up 215	98	50	20	n/a	n/a
	2-str Gas	612	1.4%	28.3%	2.0%	97	98	97	98	99.9+	80	n/a	n/a	94
	4-str Gas	610	1.4%	28.2%	0.1%	45	65	45	65	99+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	910	2.0%	42.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2163	4.8%		2.1%									
Forklift	Diesel	146	0.3%	4.4%	0.0%	n/a	n/a	up 105	up 35	98	50	20	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	873	1.9%	26.1%	1.5%	65	75	65	75	99+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	1583	3.5%	47.4%	1.0%	n/a	35	n/a	35	99	70	n/a	n/a	n/a
	Electric	737	1.6%	22.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	3339	7.4%		2.5%									

TABLE 1. POTENTIAL HC REDUCTION STRATEGIES FOR AIRPORT GSE

(Continued)

						Potential HC Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE HC	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Ground Power Unit	Diesel	2504	5.6%	82.0%	3.7%	n/a	n/a	up 135	up 55	96	50	20	96	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	94	0.2%	3.1%	0.7%	50	65	50	65	99+	90	n/a	99+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	455	1.0%	14.9%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	3053	6.8%		4.3%									
Service Trucks Fuel, Food, Lavatory, Water, & Other	Diesel	409	0.9%	11.5%	0.2%	n/a	n/a	up 155	up 70	96	50	20	96	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2905	6.4%	81.5%	8.4%	50	65	50	65	99+	90	n/a	99+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	251	0.6%	7.0%	0.4%	n/a	35	n/a	35	98	70	n/a	99	n/a
	Electric	0	0.0%	0.0%	0.0%									
	All	3565	7.9%		9.0%									
Aggregate		30538	67.8%		66.1%									

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[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent).

[2] Emission reductions due to replacement with EV equipment can vary with the emissions performance of local power generating stations. The tabulated values represent "typical" or "average" power generating station emission rates. For HC, the range of emissions variability across U.S. power generating stations is not dramatic and the tabulated emission reduction percentages will be affected by only a few percentage points regardless of local conditions.

[3] In addition to the potential for direct replacement of some GSE services, fixed, gate-based systems such as electrical power and conditioned air also potentially reduce aircraft auxiliary power unit (APU) emissions by 70-90 percent and emissions from (non-tabulated) GSE-based air conditioning service equipment by nearly 100 percent. Of the tabulated GSE, ground power unit (GPU) replacement is most feasible, with baggage tug and belt loader replacement quite difficult in retrofit applications.

TABLE 2. POTENTIAL CO REDUCTION STRATEGIES FOR AIRPORT GSE

						Potential CO Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE CO	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Aircraft Pushback Tractor	Diesel	2113	4.7%	76.6%	0.4%	n/a	n/a	up 4000	up 4000	98	90	0	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	489	1.1%	17.7%	4.1%	40	40	40	40	99.9+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	63	0.1%	2.3%	0.3%	n/a	0	n/a	0	99.9+	90	n/a	n/a	n/a
	Electric	94	0.2%	3.4%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2759	6.1%		4.9%									
Baggage Tug	Diesel	4399	9.8%	41.9%	0.4%	n/a	n/a	up 4000	up 4000	98	90	0	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	4863	10.8%	46.3%	37.9%	40	40	40	40	99.9+	90	n/a	99.9+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	973	2.2%	9.3%	4.7%	n/a	0	n/a	0	99.9+	90	n/a	99.9+	n/a
	Electric	270	0.6%	2.6%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	10505	23.3%		43.0%									
Belt Loader	Diesel	2429	5.4%	47.1%	0.1%	n/a	n/a	up 3500	up 3500	98	90	0	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2317	5.1%	45.0%	9.1%	40	40	40	40	99.9+	90	n/a	99.9+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	314	0.7%	6.1%	0.8%	n/a	0	n/a	0	99.9+	90	n/a	99.9+	n/a
	Electric	94	0.2%	1.8%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	5154	11.4%		10.0%									
Carts Tool & Lavatory	Diesel	31	0.1%	1.4%	0.0%	n/a	n/a	up 5000	up 5000	98	90	0	n/a	n/a
	2-str Gas	612	1.4%	28.3%	0.1%	20	20	20	20	99.9+	90	n/a	n/a	up 30
	4-str Gas	610	1.4%	28.2%	0.1%	40	40	40	40	99.9+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	910	2.0%	42.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2163	4.8%		0.2%									
Forklift	Diesel	146	0.3%	4.4%	0.0%	n/a	n/a	up 4000	up 4000	98	90	0	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	873	1.9%	26.1%	2.0%	55	55	55	55	99.9+	90	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	1583	3.5%	47.4%	1.7%	n/a	0	n/a	0	99.9+	90	n/a	n/a	n/a
	Electric	737	1.6%	22.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	3339	7.4%		3.8%									

TABLE 2. POTENTIAL CO REDUCTION STRATEGIES FOR AIRPORT GSE
(Continued)

						Potential CO Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE CO	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Ground Power Unit	Diesel	2504	5.6%	82.0%	0.5%	n/a	n/a	up 4000	up 4000	98	90	0	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	94	0.2%	3.1%	1.2%	40	40	40	40	99.9+	90	n/a	99.9+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	455	1.0%	14.9%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	3053	6.8%		1.7%									
Service Trucks Fuel, Food, Lavatory, Water, & Other	Diesel	409	0.9%	11.5%	0.0%	n/a	n/a	up 4500	up 4500	98	90	0	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2905	6.4%	81.5%	15.3%	40	40	40	40	99.9+	90	n/a	99.9+	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	251	0.6%	7.0%	1.0%	n/a	0	n/a	0	99.9+	90	n/a	99.9+	n/a
	Electric	0	0.0%	0.0%	0.0%									
	All	3565	7.9%		16.4%									
Aggregate		30538	67.8%		79.9%									

[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent).

[2] Emission reductions due to replacement with EV equipment can vary with the emissions performance of local power generating stations. The tabulated values represent "typical" or "average" power generating station emission rates. For CO, the range of emissions variability across U.S. power generating stations is not dramatic and the tabulated emission reduction percentages will be affected by only a few percentage points regardless of local conditions.

[3] In addition to the potential for direct replacement of some GSE services, fixed, gate-based systems such as electrical power and conditioned air also potentially reduce aircraft auxiliary power unit (APU) emissions by 70-90 percent and emissions from (non-tabulated) GSE-based air conditioning service equipment by nearly 100 percent. Of the tabulated GSE, ground power unit (GPU) replacement is most feasible, with baggage tug and belt loader replacement quite difficult in retrofit applications.

TABLE 3. POTENTIAL NO_x REDUCTION STRATEGIES FOR AIRPORT GSE

						Potential NO_x Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE NO_x	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Aircraft Pushback Tractor	Diesel	2113	4.7%	76.6%	19.4%	n/a	n/a	75	75	97	0	0	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	489	1.1%	17.7%	1.0%	25	25	25	25	90	0	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	63	0.1%	2.3%	0.1%	n/a	0	n/a	0	90	0	n/a	n/a	n/a
	Electric	94	0.2%	3.4%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2759	6.1%		20.5%									
Baggage Tug	Diesel	4399	9.8%	41.9%	18.8%	n/a	n/a	80	80	97	0	0	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	4863	10.8%	46.3%	7.9%	25	25	25	25	90	0	n/a	90	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	973	2.2%	9.3%	1.2%	n/a	0	n/a	0	90	0	n/a	90	n/a
	Electric	270	0.6%	2.6%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	10505	23.3%		28.0%									
Belt Loader	Diesel	2429	5.4%	47.1%	2.6%	n/a	n/a	55	55	95	0	0	95	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2317	5.1%	45.0%	1.9%	25	25	25	25	90	0	n/a	90	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	314	0.7%	6.1%	0.2%	n/a	0	n/a	0	90	0	n/a	90	n/a
	Electric	94	0.2%	1.8%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	5154	11.4%		4.7%									
Carts Tool & Lavatory	Diesel	31	0.1%	1.4%	0.0%	n/a	n/a	80	80	96	0	0	n/a	n/a
	2-str Gas	612	1.4%	28.3%	0.0%	up 135	up 135	up 135	up 135	55	0	n/a	n/a	up 360
	4-str Gas	610	1.4%	28.2%	0.0%	50	50	50	50	90	0	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	910	2.0%	42.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2163	4.8%		0.0%									
Forklift	Diesel	146	0.3%	4.4%	0.2%	n/a	n/a	80	80	97	0	0	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	873	1.9%	26.1%	0.3%	20	20	20	20	90	0	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	1583	3.5%	47.4%	0.4%	n/a	0	n/a	0	90	0	n/a	n/a	n/a
	Electric	737	1.6%	22.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	3339	7.4%		1.0%									

TABLE 3. POTENTIAL NO_x REDUCTION STRATEGIES FOR AIRPORT GSE

(Continued)

						Potential NO_x Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE NO_x	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed “At Gate” Equipment	Replace with 4-Str Gasoline Equipment
Ground Power Unit	Diesel	2504	5.6%	82.0%	20.9%	n/a	n/a	75	75	97	0	0	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	94	0.2%	3.1%	0.3%	25	25	25	25	90	0	n/a	90	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	455	1.0%	14.9%	0.1%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	3053	6.8%		21.3%									
Service Trucks Fuel, Food, Lavatory, Water, & Other	Diesel	409	0.9%	11.5%	1.4%	n/a	n/a	70	70	97	0	0	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2905	6.4%	81.5%	3.7%	25	25	25	25	90	0	n/a	90	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	251	0.6%	7.0%	0.3%	n/a	0	n/a	0	90	0	n/a	90	n/a
	Electric	0	0.0%	0.0%	0.0%									
	All	3565	7.9%		5.3%									
Aggregate		30538	67.8%		80.8%									

[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier “up” signify emission increases (in percent).

[2] Emission reductions due to replacement with EV equipment can vary with the emissions performance of local power generating stations. The tabulated values represent “typical” or “average” power generating station emission rates. For NO_x, the range of emissions variability across U.S. power generating stations is dramatic and emission reduction percentages can range, depending on local conditions, from: a 182 percent increase through a 91 percent reduction relative to 2-stroke gasoline emissions; a 40-90 percent reduction relative to 4-stroke gasoline emissions; a 20-97 percent reduction relative to LPG emissions; or a 60-99+ percent reduction relative to diesel emissions.

[3] In addition to the potential for direct replacement of some GSE services, fixed, gate-based systems such as electrical power and conditioned air also potentially reduce aircraft auxiliary power unit (APU) emissions by 70-90 percent and emissions from (non-tabulated) GSE-based air conditioning service equipment by nearly 100 percent. Of the tabulated GSE, ground power unit (GPU) replacement is most feasible, with baggage tug and belt loader replacement quite difficult in retrofit applications.

TABLE 4. POTENTIAL PM REDUCTION STRATEGIES FOR AIRPORT GSE

						Potential PM Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE PM	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Aircraft Pushback Tractor	Diesel	2113	4.7%	76.6%	21.6%	n/a	n/a	97	97	97	30	90	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	489	1.1%	17.7%	0.1%	15	15	15	15	20	10	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	63	0.1%	2.3%	0.0%	n/a	0	n/a	0	5	10	n/a	n/a	n/a
	Electric	94	0.2%	3.4%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2759	6.1%		21.7%									
Baggage Tug	Diesel	4399	9.8%	41.9%	26.8%	n/a	n/a	96	96	98	30	90	98	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	4863	10.8%	46.3%	1.6%	15	15	15	15	45	10	n/a	45	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	973	2.2%	9.3%	0.3%	n/a	0	n/a	0	35	10	n/a	35	n/a
	Electric	270	0.6%	2.6%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	10505	23.3%		28.8%									
Belt Loader	Diesel	2429	5.4%	47.1%	6.2%	n/a	n/a	96	96	97	30	90	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2317	5.1%	45.0%	0.4%	15	15	15	15	45	10	n/a	45	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	314	0.7%	6.1%	0.0%	n/a	0	n/a	0	35	10	n/a	35	n/a
	Electric	94	0.2%	1.8%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	5154	11.4%		6.6%									
Carts Tool & Lavatory	Diesel	31	0.1%	1.4%	0.0%	n/a	n/a	85	85	98	30	90	n/a	n/a
	2-str Gas	612	1.4%	28.3%	0.6%	98	98	98	98	99+	10	n/a	n/a	96
	4-str Gas	610	1.4%	28.2%	0.0%	35	35	35	35	90	10	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	910	2.0%	42.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2163	4.8%		0.6%									
Forklift	Diesel	146	0.3%	4.4%	0.3%	n/a	n/a	96	96	98	30	90	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	873	1.9%	26.1%	0.1%	35	35	35	35	55	10	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	1583	3.5%	47.4%	0.1%	n/a	0	n/a	0	30	10	n/a	n/a	n/a
	Electric	737	1.6%	22.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	3339	7.4%		0.5%									

TABLE 4. POTENTIAL PM REDUCTION STRATEGIES FOR AIRPORT GSE

(Continued)

						Potential PM Emission Reduction (Percent Reduction[1]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE PM	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[2] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[3] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Ground Power Unit	Diesel	2504	5.6%	82.0%	23.0%	n/a	n/a	96	96	97	30	90	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	94	0.2%	3.1%	0.0%	15	15	15	15	20	10	n/a	20	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	455	1.0%	14.9%	0.1%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	3053	6.8%		23.2%									
Service Trucks Fuel, Food, Lavatory, Water, & Other	Diesel	409	0.9%	11.5%	1.5%	n/a	n/a	96	96	97	30	90	97	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2905	6.4%	81.5%	0.5%	15	15	15	15	20	10	n/a	20	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	251	0.6%	7.0%	0.0%	n/a	0	n/a	0	5	10	n/a	5	n/a
	Electric	0	0.0%	0.0%	0.0%									
	All	3565	7.9%		2.0%									
Aggregate		30538	67.8%		83.4%									

[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent).

[2] Emission reductions due to replacement with EV equipment can vary with the emissions performance of local power generating stations. The tabulated values represent "typical" or "average" power generating station emission rates. For PM, the range of emissions variability across U.S. power generating stations is dramatic and emission reduction percentages can range, depending on local conditions, from: an 80-99+ percent reduction relative to 2-stroke gasoline emissions; a 5000 percent increase through a 98 percent reduction relative to 4-stroke gasoline emissions; a 6000 percent increase through a 98 percent reduction relative to LPG emissions; or a 100 percent increase through a 99+ percent reduction relative to diesel emissions.

[3] In addition to the potential for direct replacement of some GSE services, fixed, gate-based systems such as electrical power and conditioned air also potentially reduce aircraft auxiliary power unit (APU) emissions by 70-90 percent and emissions from (non-tabulated) GSE-based air conditioning service equipment by nearly 100 percent. Of the tabulated GSE, ground power unit (GPU) replacement is most feasible, with baggage tug and belt loader replacement quite difficult in retrofit applications.

TABLE 5. POTENTIAL CO_2 REDUCTION STRATEGIES FOR AIRPORT GSE[1]

						Potential CO_2 Emission Reduction (Percent Reduction[2]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE CO_2	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[3] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[4] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Aircraft Pushback Tractor	Diesel	2113	4.7%	76.6%	10.2%	n/a	n/a	up 5	0	45	up 3	up 2	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	489	1.1%	17.7%	1.8%	15	20	15	20	55	up 55	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	63	0.1%	2.3%	0.2%	n/a	5	n/a	5	50	up 45	n/a	n/a	n/a
	Electric	94	0.2%	3.4%	0.2%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2759	6.1%		12.4%									
Baggage Tug	Diesel	4399	9.8%	41.9%	9.5%	n/a	n/a	5	10	50	up 3	up 2	50	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	4863	10.8%	46.3%	15.2%	15	20	15	20	55	up 65	n/a	55	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	973	2.2%	9.3%	2.5%	n/a	5	n/a	5	50	up 45	n/a	50	n/a
	Electric	270	0.6%	2.6%	0.4%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	10505	23.3%		27.6%									
Belt Loader	Diesel	2429	5.4%	47.1%	2.8%	n/a	n/a	up 10	up 2	55	up 3	up 2	55	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2317	5.1%	45.0%	3.6%	15	20	15	20	55	up 60	n/a	55	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	314	0.7%	6.1%	0.4%	n/a	5	n/a	5	50	up 45	n/a	50	n/a
	Electric	94	0.2%	1.8%	0.1%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	5154	11.4%		6.9%									
Carts Tool & Lavatory	Diesel	31	0.1%	1.4%	0.0%	n/a	n/a	up 15	up 10	65	up 3	up 2	n/a	n/a
	2-str Gas	612	1.4%	28.3%	0.1%	40	45	40	45	80	up 25	n/a	n/a	30
	4-str Gas	610	1.4%	28.2%	0.1%	15	20	15	20	75	up 45	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	910	2.0%	42.1%	0.0%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	2163	4.8%		0.2%									
Forklift	Diesel	146	0.3%	4.4%	0.1%	n/a	n/a	5	10	50	up 3	up 2	n/a	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	873	1.9%	26.1%	0.8%	15	20	15	20	65	up 65	n/a	n/a	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	1583	3.5%	47.4%	1.2%	n/a	5	n/a	5	60	up 35	n/a	n/a	n/a
	Electric	737	1.6%	22.1%	0.2%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	All	3339	7.4%		2.3%									

TABLE 5. POTENTIAL CO_2 REDUCTION STRATEGIES FOR AIRPORT GSE[1]

(Continued)

						Potential CO_2 Emission Reduction (Percent Reduction[2]) if:								
GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE CO_2	Convert to LPG Fueling	Convert to CNG Fueling	Replace with LPG Equipment	Replace with CNG Equipment	Replace[3] with EV Equipment	Retrofit with Oxy Catalyst	Retrofit with PM Trap	Replace[4] with Fixed "At Gate" Equipment	Replace with 4-Str Gasoline Equipment
Ground Power Unit	Diesel	2504	5.6%	82.0%	11.2%	n/a	n/a	up 5	2	45	up 3	up 2	45	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	94	0.2%	3.1%	0.5%	15	20	15	20	55	up 55	n/a	55	n/a
	CNG	0	0.0%	0.0%	0.0%									
	LPG	0	0.0%	0.0%	0.0%									
	Electric	455	1.0%	14.9%	1.2%	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a
	All	3053	6.8%		12.9%									
Service Trucks	Diesel	409	0.9%	11.5%	0.7%	n/a	n/a	up 10	up 6	45	up 3	up 2	45	n/a
	2-str Gas	0	0.0%	0.0%	0.0%									
	4-str Gas	2905	6.4%	81.5%	6.8%	15	20	15	20	55	up 55	n/a	55	n/a
Fuel, Food, Lavatory, Water, & Other	CNG	0	0.0%	0.0%	0.0%									
	LPG	251	0.6%	7.0%	0.6%	n/a	5	n/a	5	50	up 45	n/a	50	n/a
	Electric	0	0.0%	0.0%	0.0%									
	All	3565	7.9%		8.1%									
Aggregate		30538	67.8%		70.4%									

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[1] Tabulated CO_2 emissions and emission reductions are based on brake-specific fuel consumption estimates and are not adjusted for the relatively high CO emission rates of engines used in GSE. The table, therefore, reflects a scenario in which CO emissions are already controlled to a level that is minor relative to CO_2. The one exception is for oxidation catalyst installation, where the tabulated increases in CO_2 are primarily associated with the oxidation of large amounts of CO to CO_2 (although an increase in exhaust system backpressure also contributes a small share of the observed CO_2 increases). Adjusting baseline GSE CO_2 emission rates downward due to inherently high CO would negatively influence (by a substantial margin) the CO_2 impact of switching to fuels with inherently low CO emissions. For example, correcting baseline 4-stroke gasoline CO_2 emissions for high CO would alter the tabulated 15 percent CO_2 emission reduction due to conversion or replacement with LPG equipment to a 15-30 percent CO_2 emissions increase.

[2] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent).

[3] Emission reductions due to replacement with EV equipment can vary with the emissions performance of local power generating stations. The tabulated values represent "typical" or "average" power generating station emission rates. For CO_2, the range of emissions variability across U.S. power generating stations is dramatic and emission reduction percentages can range, depending on local conditions, from: a 75-90 percent reduction relative to 2-stroke gasoline emissions; a 40-85 percent reduction relative to 4-stroke gasoline emissions; a 30-85 percent reduction relative to LPG emissions; or a 25-80 percent reduction relative to diesel emissions.

[4] In addition to the potential for direct replacement of some GSE services, fixed, gate-based systems such as electrical power and conditioned air also potentially reduce aircraft auxiliary power unit (APU) emissions by 70-90 percent and emissions from (non-tabulated) GSE-based air conditioning service equipment by nearly 100 percent. Of the tabulated GSE, ground power unit (GPU) replacement is most feasible, with baggage tug and belt loader replacement quite difficult in retrofit applications.

TABLE 6. ADDITIONAL GSE AND ASSOCIATED EMISSION IMPACT ESTIMATES

GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE HC	Estimated Fraction of All GSE CO	Estimated Fraction of All GSE NO$_x$	Estimated Fraction of All GSE PM	Estimated Fraction of All GSE CO$_2$
Conditioned Air Unit	Diesel	376	0.8%	78.5%	0.0%	0.0%	0.2%	0.2%	0.1%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	41	0.1%	8.6%	0.0%	0.0%	0.0%	0.0%	0.0%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	31	0.1%	6.5%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	31	0.1%	6.5%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	479	1.1%		0.0%	0.0%	0.2%	0.2%	0.1%
Air Start Unit	Diesel	771	1.7%	87.5%	1.0%	0.1%	5.6%	6.3%	2.8%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	63	0.1%	7.2%	0.1%	0.1%	0.0%	0.0%	0.1%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	16	0.0%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%
	Turbine	31	0.1%	3.5%	0.0%	0.0%	0.2%	0.3%	0.1%
	All	881	2.0%		1.1%	0.3%	5.9%	6.6%	3.0%
Bobtail	Diesel	157	0.3%	15.9%	0.2%	0.0%	0.9%	1.2%	0.4%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	815	1.8%	82.5%	4.5%	6.3%	1.3%	0.3%	2.5%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	16	0.0%	1.6%	0.0%	0.1%	0.0%	0.0%	0.0%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	988	2.2%		4.7%	6.4%	2.2%	1.5%	3.0%
Cargo Loader	Diesel	1129	2.5%	77.4%	0.9%	0.1%	3.5%	5.0%	1.8%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	220	0.5%	15.1%	0.6%	0.9%	0.2%	0.0%	0.4%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	110	0.2%	7.5%	0.2%	0.3%	0.1%	0.0%	0.2%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	1459	3.2%		1.6%	1.3%	3.8%	5.1%	2.3%
Deicer	Diesel	31	0.1%	6.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	475	1.1%	93.9%	0.1%	0.1%	0.0%	0.0%	0.1%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	506	1.1%		0.1%	0.1%	0.0%	0.0%	0.1%
Lift	Diesel	47	0.1%	2.9%	0.0%	0.0%	0.1%	0.1%	0.1%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	951	2.1%	58.1%	2.0%	2.9%	0.6%	0.1%	1.2%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	324	0.7%	19.8%	0.3%	0.6%	0.2%	0.0%	0.3%
	Electric	314	0.7%	19.2%	0.0%	0.0%	0.0%	0.0%	0.2%
	All	1636	3.6%		2.4%	3.5%	0.9%	0.3%	1.7%
Maintenance Truck	Diesel	16	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	1259	2.8%	97.5%	2.9%	5.4%	1.3%	0.2%	2.4%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	16	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	1291	2.9%		3.0%	5.4%	1.3%	0.2%	2.4%

TABLE 6. ADDITIONAL GSE AND ASSOCIATED EMISSION IMPACT ESTIMATES
(Continued)

GSE Type	Engine Type	Estimated U.S. Population	Fraction of All GSE	Fraction of Type Specific GSE	Estimated Fraction of All GSE HC	Estimated Fraction of All GSE CO	Estimated Fraction of All GSE NO_x	Estimated Fraction of All GSE PM	Estimated Fraction of All GSE CO_2
“Other” GSE	Diesel	376	0.8%	21.6%	0.1%	0.0%	0.1%	0.2%	0.1%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	1195	2.7%	68.6%	0.9%	1.2%	0.2%	0.0%	0.4%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	141	0.3%	8.1%	0.0%	0.1%	0.0%	0.0%	0.0%
	Electric	31	0.1%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	1743	3.9%		1.0%	1.2%	0.3%	0.3%	0.6%
Bus	Diesel	115	0.3%	39.9%	0.1%	0.0%	0.1%	0.6%	0.3%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	173	0.4%	60.1%	0.6%	0.1%	0.1%	0.1%	0.5%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	288	0.6%		0.8%	0.1%	0.3%	0.7%	0.8%
Car	Diesel	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	580	1.3%	100.0%	0.6%	0.0%	0.1%	0.0%	1.8%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	580	1.3%		0.6%	0.0%	0.1%	0.0%	1.8%
Pickup Truck	Diesel	41	0.1%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	2595	5.8%	93.4%	10.0%	0.9%	2.2%	0.9%	7.8%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	141	0.3%	5.1%	0.3%	0.0%	0.1%	0.0%	0.4%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	2777	6.2%		10.3%	0.9%	2.3%	1.0%	8.2%
Van	Diesel	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	2-str Gas	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	4-str Gas	1842	4.1%	96.7%	8.2%	0.7%	1.8%	0.8%	5.6%
	CNG	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	LPG	63	0.1%	3.3%	0.1%	0.0%	0.0%	0.0%	0.2%
	Electric	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	All	1905	4.2%		8.3%	0.8%	1.9%	0.8%	5.7%
Aggregate		14533	32.2%		33.9%	20.1%	19.2%	16.6%	29.6%

BASIS FOR GSE POPULATION ESTIMATES

BASIS FOR GSE POPULATION ESTIMATES

Background: Airport ground support equipment (GSE) comprise a diverse range of vehicles and equipment necessary to service aircraft during passenger and cargo loading and unloading, maintenance, and other ground-based operations. The wide range of activities associated with aircraft ground operations lead to an equally wide ranging fleet of GSE. For example, activities undertaken during a typical aircraft gate period include: cargo loading and unloading, passenger loading and unloading, potable water storage, lavatory waste tank drainage, aircraft refueling, engine and fuselage examination and maintenance, and food and beverage catering. Airlines employ specially designed GSE to support all these operations. Moreover, electrical power and conditioned air are generally required throughout gate operational periods for both passenger and crew comfort and safety, and many times these services are also provided by GSE.

Emissions Impact: The majority of GSE engines continue to be "uncontrolled" from an emissions perspective. Although an increasing number of the larger vehicles used for GSE operations such as water, fuel, lavatory, and aircraft maintenance services are powered by emissions-certified on-road engines, a majority of similar older GSE and nearly all specially-designed GSE continue to utilize engines that have not been designed for low emissions. As a result, GSE do contribute significantly to the emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), and carbon dioxide (CO_2) associated with airports. A recent U.S. EPA-commissioned study of four major U.S. airports indicates that GSE are responsible for 15-20 percent of airport-related NO_x and 10-15 percent of airport-related HC. Moreover, studies have shown that the availability of alternative fueled and electric powered GSE as well as the availability of alternative means of providing, in some cases, equivalent aircraft support services can lead to substantial reductions in GSE emissions from current levels. This GSE information series is designed to provide both an overview of these available emission reduction strategies and an estimate of the magnitude of associated emission reductions.

GSE Population: Since there are no registration requirements for GSE or any national organization charged with tracking GSE activity, there currently is no reliable database from which accurate GSE populations can be determined. Numerous estimates of the national GSE population have been made over the last several years using various statistical procedures, with total population estimates ranging from as low as 10,000 units to 100,000 units or more.[*]

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[*] Examples include the following: (1) a 1994 California ARB report entitled *Air Pollution Mitigation Measures for Airports and Associated Activity* estimated 2,500 GSE in California, implying a national population of about 26,000 units; (2) a 1995 ARB report entitled *Documentation of Input Factors for the New Off-Road Mobile Source Emissions Factor Model* estimated 12,000 California GSE, implying a national population of about 125,000 units; (3) a 1995 U.S. EPA report entitled *Technical Support Document: Aircraft/Airports* estimated 2,500 GSE in California FIP areas, implying a national population of about 34,000 units; (4) a 1998 GRI report entitled *Survey of Airport Fleet Vehicles* estimated a GSE population of between 24,000 and 34,000 at the top 48 airports, implying a national population of 33,000-47,000 units; (5) a 1991 U.S. EPA report entitled *Nonroad Engine and Vehicle Emissions Study - Report* estimated a national GSE population of just under 85,000 units.

Available data on GSE is certainly sufficient to narrow this range considerably and, therefore, it is likely that additional factors such as inconsistencies in considered equipment contribute to the magnitude of the observed differential between previous national GSE population estimates.

Detailed data on GSE populations at specific airports were collected in support of two U.S. EPA- and one California Air Resources Board-commissioned studies on airport emissions. As indicated Table 1, these studies included the collection of detailed GSE inventories from 35 individual airlines at 10 U.S. airports, 6 of which are among the top 50 national airports in terms of aircraft landing and take-off (LTO) cycles. In total, over 3,000 individual GSE were represented in the reported inventory data and together they provide support for about 9 percent of national annual LTO cycles. A simple extrapolation of this reported GSE population to total national LTO activity readily indicates the inherent inaccuracy in national GSE population estimates as low as 10,000 units and as high as 100,000 units.

Airport	Airlines Providing Detailed GSE Data
Baltimore-Washington International	Delta, Southwest, U.S. Airways
Boston Logan	Business Express, Flagship, Northwest, Spirit, U.S. Airways
Burbank	Delta, Southwest, United
Long Beach	Delta, United
Los Angeles International	Alaska Air, American, America West, Continental, Delta, Northwest, Skywest, Southwest, TransWorld, United, U.S. Airways
Ontario	Delta, Southwest, United
Orange County	Delta, United
Palm Springs	Delta, United
Phoenix Sky Harbor	America West, Southwest
Sacramento	Delta, Southwest

Table 1. Airports and Airlines Providing Detailed GSE Population Data

To provide a reliable estimate of national GSE population, a detailed statistical regression analysis of the reported data was conducted. Examinations of scatter diagrams of airline- and airport-specific GSE population by annual airline- and airport-specific LTO cycles as well as preliminary regression statistics reveals distinct differences in the GSE inventory characteristics of airlines along three major classifications. First, the GSE inventories of all major airlines except Southwest (e.g., Delta, Northwest, United) show similar characteristics. Second, regional carriers (e.g., Business Express, Skywest) show similar characteristics amongst themselves, but (not surprisingly) these characteristics are quite different than those of the major carriers. Finally, Southwest Airlines exhibits characteristics unique from those of both the regional and other major carriers.

Stratifying the reported GSE population data in accordance with the three-level classification scheme (i.e., major airlines other than Southwest, Southwest, and regional airlines) and conducting detailed classification-specific regression analysis of GSE by annual LTO cycles yields promising statistics, but a final adjustment for the major airlines (other than Southwest) is required to obtain optimum results. Major airlines (especially those with international service) operate both wide- and narrow-body aircraft, which possess significantly different demands in terms of both the number of GSE required for gate support and the length of time those GSE are required. Therefore, major airlines with a larger wide-body aircraft fleet and more frequent wide-body LTO cycles tend to operate more GSE than major airlines with few wide-body LTO cycles. Once this criteria is included in the regression analysis, satisfactory GSE statistics for all three airline classifications are obtained. Table 2 presents the applicable statistical relationships.

Airline Classification	Regression Equation (GSE Population =)	Correlation Coefficient
Major Airlines (other than Southwest)	0.0226 (LTO_{wb}) + 0.0054 (LTO_{nb}) [t=5.2] [t=4.1]	0.79
Southwest Airlines	0.0022 (LTO) [t=5.5]	0.83
Regional Airlines	0.0008 (LTO) [t=4.0]	0.75

LTO indicates the total number of annual LTO cycles, LTO_{wb} indicates the number of annual wide-body LTO cycles, and LTO_{nb} indicates the number of annual narrow-body LTO cycles.

Table 2. GSE Population Regression Statistics

As indicated by the correlation coefficients, none of the regression equations are excellent predictors of the GSE population for a specific airline at a specific airport. However, all provide reasonable airline- and airport-specific predictions and (since the t statistics are all significant at over 99 percent confidence) highly significant representations of *aggregate* GSE population across several airlines or several airports. Therefore, an evaluation of the three regressions using national LTO data should provide for a good approximation of the national population of GSE. Such an evaluation yields a population estimate of just over 45,000 pieces of equipment (approximately the midpoint of the range of previous population estimates).

A measure of the relative GSE “demand” of the various airline classifications can also be obtained from the derived regression coefficients. A single GSE is required for every 44 wide-body aircraft LTO cycles versus every 185 narrow-body LTO cycles for major airlines other than Southwest. Southwest Airlines and regional carriers utilize substantially less GSE at the ratio of a single GSE for every 455 and every 1,250 LTO cycles respectively. Major narrow-body carriers utilize GSE at about 2.5 times the rate of Southwest Airlines, while wide-body aircraft impose approximately 4 times the GSE demand of narrow-body aircraft.

GSE Population by Equipment and Engine Type: The same detailed airline- and airport-specific data that was used to support the overall national GSE population estimate can be used to disaggregate the estimate into its various type-specific components. As mentioned above, over 3,000 individual GSE units are reflected in these data, representing approximately 7 percent of the estimated national GSE population. By aggregating the individual GSE type-specific populations across the 35 airlines and 10 airports for which detailed GSE data is available, an estimate of the national population type-specific equipment distribution can be derived. Since the regression analysis described above indicated significant differences between major airlines other than Southwest, Southwest, and regional airlines, this level of distinction should be maintained in determining national GSE type distributions. The distribution of national regional carrier GSE is developed by aggregating the data for the 5 regional carriers for which detailed GSE population data was available. Similarly, the GSE type-specific equipment distribution for national Southwest Airline GSE is based on the aggregation of data for the 6 airports for which detailed Southwest GSE populations were available and that of other major airlines is based on data aggregated across the 24 available detailed populations. Table 3 presents the resulting type-specific national GSE population estimates.

Clearly, although GSE comprise myriad equipment types, several specific types are estimated to dominate the overall population. In fact, baggage tugs and belt loaders constitute an estimated 35 percent of all GSE. Aircraft pushback tractors, forklifts, carts, ground power units, service trucks, and pickup trucks constitute another 36 percent. Gasoline is estimated to be the dominant engine type, powering an estimated 51 percent of GSE, while diesel engines are estimated to power another 33 percent. The remaining 16 percent of GSE is powered in approximately equal proportions by LPG and electricity.

References:

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2. *Air Pollution Mitigation Measures for Airports and Associated Activity*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, May 1994.

3. *Technical Support Document for Civil and Military Aviation*, prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency in support of the Notice of Proposed Rulemaking for the Federal Implementation Plan for California, March 1994.

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Analysis, Inc. for the U.S. Environmental Protection Agency in support of the Interim Final Rulemaking for the Federal Implementation Plan for California, February 9, 1995

5. GSE population data sheets submitted by member companies of the Air Transport Association as part of the U.S. Environmental Protection Agency's Federal Implementation Plan development process for California, September 1993.

6. *Documentation of Input Factors for the New Off-Road Mobile Source Emissions Factor Model*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, August 1995.

7. *Survey of Airport Fleet Vehicles*, Final Report, prepared by Edwards and Kelsey, Inc. for the Gas Research Institute, April 1998.

8. *Nonroad Engine and Vehicle Emissions Study - Report*, 21A-2001, U.S. Environmental Protection Agency, November 1991.

Equipment Type	Engine Type	Major[1] Airlines Split	Southwest Airlines Split	Regional Airlines Split	Major[1] Airlines Population	Southwest Airlines Population	Regional Airlines Population	All Carrier Population	All Carrier Split
Aircraft Pushback Tractor	Diesel	4.47%	12.94%	3.24%	1,914	169	30	2,113	4.69%
	Gasoline	1.06%	2.60%	0.00%	455	34	0	489	1.08%
	Electric	0.22%	0.00%	0.00%	94	0	0	94	0.21%
	LPG/CNG	0.15%	0.00%	0.00%	63	0	0	63	0.14%
	All Engines	5.90%	15.54%	3.24%	2,526	203	30	2,759	6.12%
Conditioned Air Unit	Diesel	0.88%	0.00%	0.00%	376	0	0	376	0.83%
	Gasoline	0.07%	0.00%	1.08%	31	0	10	41	0.09%
	Electric	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	LPG/CNG	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	All Engines	1.09%	0.00%	1.08%	469	0	10	479	1.06%
Air Start Unit	Diesel	1.72%	2.60%	0.00%	737	34	0	771	1.71%
	Gasoline	0.15%	0.00%	0.00%	63	0	0	63	0.14%
	Electric	0.04%	0.00%	0.00%	16	0	0	16	0.04%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Turbine	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	All Engines	1.98%	2.60%	0.00%	847	34	0	881	1.95%
Baggage Tug	Diesel	9.34%	20.67%	13.95%	4,000	270	129	4,399	9.76%
	Gasoline	10.62%	11.10%	18.27%	4,549	145	169	4,863	10.79%
	Electric	0.59%	1.45%	0.00%	251	19	0	270	0.60%
	LPG/CNG	2.27%	0.00%	0.00%	973	0	0	973	2.16%
	All Engines	22.81%	33.23%	32.22%	9,773	434	298	10,505	23.31%
Belt Loader	Diesel	5.16%	16.62%	0.00%	2,212	217	0	2,429	5.39%
	Gasoline	5.09%	6.66%	5.41%	2,180	87	50	2,317	5.14%
	Electric	0.22%	0.00%	0.00%	94	0	0	94	0.21%
	LPG/CNG	0.73%	0.00%	0.00%	314	0	0	314	0.70%
	All Engines	11.20%	23.28%	5.41%	4,800	304	50	5,154	11.44%

[1] Excluding Southwest Airlines.

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Table 3a. Estimated National GSE Populations

Equipment Type	Engine Type	Major[1] Airlines Split	Southwest Airlines Split	Regional Airlines Split	Major[1] Airlines Population	Southwest Airlines Population	Regional Airlines Population	All Carrier Population	All Carrier Split
Bobtail	Diesel	0.37%	0.00%	0.00%	157	0	0	157	0.35%
	Gasoline	1.87%	0.38%	1.08%	800	5	10	815	1.81%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.04%	0.00%	0.00%	16	0	0	16	0.04%
	All Engines	2.27%	0.38%	1.08%	973	5	10	988	2.19%
Cargo Loader	Diesel	2.64%	0.00%	0.00%	1,129	0	0	1,129	2.50%
	Gasoline	0.51%	0.00%	0.00%	220	0	0	220	0.49%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.26%	0.00%	0.00%	110	0	0	110	0.24%
	All Engines	3.41%	0.00%	0.00%	1,459	0	0	1,459	3.24%
Cart	Diesel	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	Gasoline	2.49%	0.77%	5.41%	1,067	10	50	1,127	2.50%
	Electric	2.12%	0.00%	0.00%	910	0	0	910	2.02%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	4.69%	0.77%	5.41%	2,008	10	50	2,068	4.59%
Deicer	Diesel	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	Gasoline	1.06%	0.77%	1.08%	455	10	10	475	1.05%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	1.13%	0.77%	1.08%	486	10	10	506	1.12%
Forklift	Diesel	0.33%	0.38%	0.00%	141	5	0	146	0.32%
	Gasoline	2.01%	0.77%	0.00%	863	10	0	873	1.94%
	Electric	1.72%	0.00%	0.00%	737	0	0	737	1.64%
	LPG/CNG	3.66%	1.07%	0.00%	1,569	14	0	1,583	3.51%
	All Engines	7.73%	2.22%	0.00%	3,310	29	0	3,339	7.41%
Fuel Truck	Diesel	0.18%	0.00%	1.08%	78	0	10	88	0.20%
	Gasoline	0.92%	0.00%	0.00%	392	0	0	392	0.87%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.04%	0.00%	0.00%	16	0	0	16	0.04%
	All Engines	1.13%	0.00%	1.08%	486	0	10	496	1.10%
Ground Power Unit	Diesel	5.24%	4.06%	22.49%	2,243	53	208	2,504	5.56%
	Gasoline	0.22%	0.00%	0.00%	94	0	0	94	0.21%
	Electric	1.06%	0.00%	0.00%	455	0	0	455	1.01%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	6.52%	4.06%	22.49%	2,792	53	208	3,053	6.77%
Lavatory Cart	Diesel	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Gasoline	0.04%	2.22%	5.41%	16	29	50	95	0.21%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	0.04%	2.22%	5.41%	16	29	50	95	0.21%
Lavatory Truck	Diesel	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Gasoline	1.58%	1.84%	1.08%	675	24	10	709	1.57%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	1.58%	1.84%	1.08%	675	24	10	709	1.57%
Lift	Diesel	0.11%	0.00%	0.00%	47	0	0	47	0.10%
	Gasoline	2.20%	0.00%	1.08%	941	0	10	951	2.11%
	Electric	0.73%	0.00%	0.00%	314	0	0	314	0.70%
	LPG/CNG	0.73%	0.77%	0.00%	314	10	0	324	0.72%
	All Engines	3.77%	0.77%	1.08%	1,616	10	10	1,636	3.63%

[1] Excluding Southwest Airlines.

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Table 3b. Estimated National GSE Populations

Equipment Type	Engine Type	Major[1] Airlines Split	Southwest Airlines Split	Regional Airlines Split	Major[1] Airlines Population	Southwest Airlines Population	Regional Airlines Population	All Carrier Population	Al Carrier Split
Maintenance Truck	Diesel	0.04%	0.00%	0.00%	16	0	0	16	0.04%
	Gasoline	2.89%	0.00%	2.16%	1,239	0	20	1,259	2.79%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.04%	0.00%	0.00%	16	0	0	16	0.04%
	All Engines	2.97%	0.00%	2.16%	1,271	0	20	1,291	2.86%
Other GSE	Diesel	0.88%	0.00%	0.00%	376	0	0	376	0.83%
	Gasoline	2.71%	2.60%	0.00%	1,161	34	0	1,195	2.65%
	Electric	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	LPG/CNG	0.33%	0.00%	0.00%	141	0	0	141	0.31%
	All Engines	3.99%	2.60%	0.00%	1,709	34	0	1,743	3.87%
Service Truck	Diesel	0.66%	2.99%	0.00%	282	39	0	321	0.71%
	Gasoline	3.55%	2.99%	4.32%	1,522	39	40	1,601	3.55%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.55%	0.00%	0.00%	235	0	0	235	0.52%
	All Engines	4.76%	5.97%	4.32%	2,039	78	40	2,157	4.79%
Bus	Diesel	0.26%	0.38%	0.00%	110	5	0	115	0.26%
	Gasoline	0.40%	0.00%	0.00%	173	0	0	173	0.38%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	0.66%	0.38%	0.00%	283	5	0	288	0.64%
Car	Diesel	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Gasoline	1.32%	0.38%	1.08%	565	5	10	580	1.29%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	1.32%	0.38%	1.08%	565	5	10	580	1.29%
Pickup Truck	Diesel	0.07%	0.77%	0.00%	31	10	0	41	0.09%
	Gasoline	5.93%	1.84%	3.24%	2,541	24	30	2,595	5.76%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.33%	0.00%	0.00%	141	0	0	141	0.31%
	All Engines	6.33%	2.60%	3.24%	2,713	34	30	2,777	6.16%
Van	Diesel	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Gasoline	4.14%	0.00%	7.46%	1,773	0	69	1,842	4.09%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.15%	0.00%	0.00%	63	0	0	63	0.14%
	All Engines	4.29%	0.00%	7.46%	1,836	0	69	1,905	4.23%
Water Truck	Diesel	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	Gasoline	0.44%	0.38%	1.08%	188	5	10	203	0.45%
	Electric	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	LPG/CNG	0.00%	0.00%	0.00%	0	0	0	0	0.00%
	All Engines	0.44%	0.38%	1.08%	188	5	10	203	0.45%
All GSE Types	Diesel	32.47%	40.76%	61.41%	13,911	377	802	15,090	33.48%
	Gasoline	51.27%	59.24%	35.30%	21,963	548	461	22,972	50.97%
	Electric	6.85%	0.00%	1.45%	2,933	0	19	2,952	6.55%
	LPG/CNG	9.34%	0.00%	1.84%	4,002	0	24	4,026	8.93%
	Turbine	0.07%	0.00%	0.00%	31	0	0	31	0.07%
	All Engines	100.00%	100.00%	100.00%	42,840	925	1,306	45,071	100.00%

[1] Excluding Southwest Airlines.

Table 3c. Estimated National GSE Populations

GSE EMISSIONS AND ACTIVITY ESTIMATES

GSE EMISSIONS AND ACTIVITY ESTIMATES

Background: Airport ground support equipment (GSE) comprise a diverse range of vehicles and equipment necessary to service aircraft during passenger and cargo loading and unloading, maintenance, and other ground-based operations. The wide range of activities associated with aircraft ground operations lead to an equally diverse fleet of GSE, each component of which has its own emissions performance and activity characteristics. For example, activities undertaken during a typical aircraft gate period include: cargo loading and unloading, passenger loading and unloading, potable water storage, lavatory waste tank drainage, aircraft refueling, engine and fuselage examination and maintenance, and food and beverage catering. Airlines employ specially designed GSE to support all these operations. Moreover, electrical power and conditioned air are generally required throughout gate operational periods for both passenger comfort and safety, and many times these services are also provided by GSE.

The Necessity for Proper Activity Characterization: Accurately characterizing the emissions performance of a particular GSE requires detailed knowledge in two specific areas: (1) the rate of equipment emissions per unit of activity and (2) the amount of activity performed during the period of interest. Generally, the unit activity emission rate can be either measured directly or estimated from previous measurements taken for similar equipment or engines. Because emission rates typically vary with engine speed and load (a measure of how “hard” the engine is being worked), emission rates for GSE-type equipment are commonly measured over a broad series of constant speed and load operating modes that, when weighted in accordance with the amount of time the engine spends in each mode, can describe the average emission rate of the equipment.[*] Two standard emission tests of this type are commonly employed for GSE-type equipment. Engines rated at 25 horsepower (hp) or less are usually tested over the Society of Automotive Engineers’ J1088 test cycle, while larger engines are tested over what is commonly referred to as the “8 mode” test. Differences in the various test modes to which the engines are subjected can be best defined through the amount of useful work that is performed by the engine when operating in each mode and, therefore, emission measurements for GSE-type equipment are usually measured in terms of grams of emissions per brake horsepower-hour of work performed (g/bhp-hr).

Since GSE-type emission factors are measured in terms of work performed, a measurement of the amount of work performed over the time period of interest is integral to the proper emissions

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[*] This differs from the measurement of emissions from on-road vehicles such as passenger cars and light trucks where the vehicle engine is exercised over a well defined, but continuously changing (or transient) driving cycle that includes a wide range of engine speed and load conditions. Such a test is more representative of the performance of such vehicles since they undergo a wide range of continuously varying speed and load combinations in actual use. GSE, however, generally do not undergo either frequent speed or load changes, instead operating within relatively narrow speed/load ranges for extended periods. Accordingly, the emissions performance of GSE can be accurately measured by testing the equipment (or engine) over an appropriate series of such “steady state” conditions.

assessment of a piece of equipment. For short, single operating mode periods, this measurement can be derived directly from the speed and load conditions placed on the engine during the operating mode. However, over longer periods, equipment operations usually encompass a series of differing operating conditions (e.g., extended idle, between gate transit) and the amount of work performed is usually defined as a fraction of total possible work that can be performed during the period. Commonly referred to as the load factor, this fraction is equal to the ratio of actual work performed to work which could have been performed if the engine was operated throughout the period at its manufacturer-rated speed and horsepower (those conditions over which engine work output is a maximum). For example, the load factor for the aggregated J1088 emissions test is 0.39 (i.e., the derived emission rate over the J1088 cycle reflects an aggregated series of test conditions in which 39 percent of maximum engine work is performed), while that of the "8 mode" test for larger engines is 0.56.

Once a load factor has been established for a typical operating period, emissions performance over that or any period of similar engine operation can be calculated from measured unit-work emission rates. The amount of work performed over the period of interest is calculated by multiplying the engine manufacturer-rated engine output (hp) by the total number of hours of engine operation over the period to determine maximum possible time period work, and then multiplying this maximum possible work by the representative load factor. The product of the unit-work emission rate and work performed over the period of interest represents the overall emissions estimate for the period of interest. Expressed algebraically, the generalized GSE emissions calculation methodology is:

$$\frac{\text{GSE emissions}}{\text{time period of interest}} = \frac{\text{g}}{\text{bhp - hr}} \times \text{rated hp} \times \frac{\text{hours of operation}}{\text{time period of interest}} \times \text{load factor}$$

While conceptually simple, each of the components of the GSE emissions calculation equation has inherent uncertainty with the exception of the rated engine horsepower (which is an element of engine design). The unit-work emission rate is typically based on a standardized test with a load factor of either 0.39 ($\leq$ 25 hp engines) or 0.56 (> 25 hp engines). Equipment operated at load factors substantially different than those of the test cycle may exhibit substantially different emission rates. Experience has shown that emission rates over a load factor range of about ±0.2 of the test cycle load factor are fairly well represented. The hours of operation for the time period of interest is certainly conceptually simple and for a single piece of equipment, relatively easily tracked. But defining a "typical" hours per day operating rate over extended time periods, across multiple units, across airlines, or across airports is inherently uncertain. The load factor is perhaps the most uncertain element of the calculation. Although GSE-specific load factors have been developed over the last several years, there is considerable uncertainty in these estimates across units, airlines, and airports. For example, equipment idle time can vary considerably and in extreme cases, where idle emissions are applicable for all or most of the time period of interest, the GSE emissions calculation methodology "falls apart" as the load factor approaches zero while the actual emission rate per unit work performed approaches infinity. Clearly each of the factors upon which the generalized GSE emissions calculation methodology is dependent must be accurately quantified to determine emissions with any degree of certainty.

Emission Rate Data: Numerous studies over the last decade or so have attempted to compile available emissions rate data on engines such as those used on GSE. Although the size of the database continues to be relatively small, it is comprehensive in that engines of all applicable sizes and configurations are represented. In many aspects, the state of the off-road engine emissions database is comparable to that of on-road vehicles in the mid-1970's. Interest in off-road engine emissions became significant only in the late-1980's and early 1990's with the advent of U.S. Environmental Protection Agency (EPA) and California Air Resources Board (ARB) regulatory program development efforts. Emissions data collection has accelerated in response to these efforts, but given the wide range of engine sizes and configurations found in the off-road sector, the number of emission tests performed on most engine categories continues to be limited. There are some exceptions, such as small lawn mower-type utility engines which have been the focus of early regulatory attention and are thus fairly well represented, but in general much data collection activity remains to be performed. To date, no comprehensive, detailed GSE-specific emissions rate data collection program has been undertaken. This is clearly an area where the development of a structured test program could not only improve the quantity and quality of data collected, but also provide an indication of the degree of uncertainty associated with current GSE emissions test data.

In the mid-1990's, the ARB began development of an off-road emission factor model. A key component of this development work was the collection and analysis of available emissions test data for all types of off-road engines, including GSE. This emissions test data development activity was performed at a very disaggregated level-of-detail and continues to represent the "state-of-the-art" emissions rate "database" for GSE. Data was analyzed over relatively narrow horsepower ranges as well as by fuel type (i.e., gasoline, diesel, etc.), valve configuration (i.e., overhead valve versus side valve), engine cooling design (i.e., air versus water cooled), fueling system type (i.e., carburetion, indirect injection, direct injection), and air intake type (i.e., naturally aspirated versus turbocharged). In addition to emissions rate data, the ARB model development efforts also included detailed reviews of available off-road engine (including GSE) population (for California), load factor, and usage rate data (for California). In recognition of its comprehensive nature, all data presented in this GSE information series, with relatively minor exceptions where noted, are derived from the resulting model database.

Although all equipment are represented by the ARB data, it should be recognized that a targeted GSE emissions data collection program would be invaluable in not only in augmenting and quality assuring the existing database, but in also providing an important measure of emissions variability. Moreover, any program based on the issuance of credits for GSE retirement or conversion should be based on actual emission measurements for the specific equipment involved. Only after sufficient data have been collected to provide a reasonable measure of emissions rate uncertainty can surrogate engine data be expected to accurately represent the emissions performance of any specific engine or equipment. The off-road emissions database, and GSE database in particular, is not at this state of development.

Tables 1 through 11 present basic emission rate data for off-road engines by horsepower range as extracted from the ARB off-road model. Tables 1 through 5 present new engine emission rates for HC, CO, NO_x, PM, and CO_2 respectively. All emission rates, except those for CO_2 are in units of grams of emission per brake horsepower-hour of work performed (g/bhp-hr). CO_2 emission rates are in grams per gallon of fuel consumed. Table 6 presents the brake-specific fuel consumption (in units of pounds of fuel per brake horsepower-hour) and fuel density (in pounds per gallon) estimates required to convert the CO_2 emission rates presented in Table 5 into units of g/bhp-hr. Specific estimates for CNG equipment are not included in the ARB model and there is very little data available to construct detailed GSE CNG-specific emission rates. Nevertheless, on the basis of limited data cited in previous GSE studies, CNG emission rates were estimated to be: (1) for HC, 33 percent lower than corresponding LPG HC emissions, (2) for CO_2, 8 percent lower than corresponding LPG CO_2 emissions, and (3) for CO, NO_x, and PM, equivalent to corresponding LPG emissions.

As is the case with all engines, emission rates usually increase with age due to engine and control system deterioration, malperformances, or misadjustment. The ARB model includes estimates of pollutant- and engine-specific emission deterioration rates, but both the magnitude and form of these deterioration data should be viewed as even less developed than other aspects of off-road (and specifically GSE) emission rate data since very little testing on in-use equipment has been performed to date. As already discussed, a structured emissions testing program focused on GSE (both new and in-use) is critical to both the validation and improvement of current emission rate estimates. In the absence of such a test program, Tables 7 through 11 present the current best estimates of pollutant-specific off-road engine emissions deterioration. The presented deterioration data is expressed as the factor by which emissions <u>increase</u> over their full useful life. For example, if an engine has a "when new" emission rate of X grams per brake horsepower-hour and a full life deterioration factor of Y, its emission rate at full useful life (Z) is equal to:

$$Z = X + (X)(Y) = X\ (1 + Y)$$

The emission impact estimates presented in this GSE information series are based on the estimated emission rate at one-half of the applicable equipment's useful life. If this emission rate is defined as $Z_{1/2}$, it is algebraically defined as:

$$Z_{1/2} = X + (X)(0.5Y) + X(1 + 0.5Y)$$

The majority of GSE engines continue to be "uncontrolled" from an emissions perspective and the emission rates presented in this GSE information series reflect such an assumption. Although an increasing number of the larger vehicles used for GSE operations such as water, fuel, lavatory, and aircraft maintenance services are powered by emissions-certified on-road engines, a number of older GSE performing similar services and nearly all specially-designed GSE continue to utilize engines that have not been designed for low emissions. As a result, the emission estimates presented in this series will, in most cases, accurately reflect the potential emission reductions due to control strategy implementation, but will in some cases, where newer GSE is concerned, overstate potential reductions to varying extents. Actual emission reduction potential must be based on data for the specific GSE targeted for control.

Evaporative emission estimates or evaporative emission reduction potential has not been evaluated as part of this GSE information series. Generally, evaporative emissions are significant

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	290.00	26.40	4.25	
(X+1)-15	209.00	7.46	3.96	1.50
16-25	209.00	7.46	3.96	1.84
26-50		5.50	2.00	1.84
51-120		4.00	2.00	1.44
121-175		4.00	2.00	0.88
176-250		4.00		0.88
251-500				0.84
501-750				0.84
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 1. Zero Hour HC Emission Rate (grams/brake horsepower-hour)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	840.0	504.2	248.4	
(X+1)-15	311.0	393.1	240.0	5.0
16-25	311.0	393.1	240.0	5.0
26-50		320.0	150.0	5.0
51-120		240.0	150.0	4.8
121-175		240.0	150.0	4.2
176-250		240.0		4.2
251-500				4.1
501-750				4.1
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 2. Zero Hour CO Emission Rate (grams/brake horsepower-hour)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.36	2.12	1.99	
(X+1)-15	0.90	3.48	1.77	10.00
16-25	0.90	3.48	1.77	6.92
26-50		3.75	3.00	6.92
51-120		4.00	3.00	13.00
121-175		4.00	3.00	11.00
176-250		4.00		11.00
251-500				11.00
501-750				11.00
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 3. Zero Hour NO_x Emission Rate (grams/brake horsepower-hour)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	10.00	0.74	0.49	
(X+1)-15	6.50	0.14	0.09	1.00
16-25	6.50	0.14	0.09	0.76
26-50		0.05	0.03[2]	0.76
51-120		0.04[2]	0.04[2]	0.84
121-175		0.03[2]	0.02[2]	0.55
176-250		0.03[2]		0.55
251-500				0.53
501-750				0.53
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

[2] Values assumed to be zero in these size ranges in the ARB model, tabulated values are based on 95 percent reduction from diesel for gasoline and 96 percent reduction from diesel for LPG.

Table 4. Zero Hour PM Emission Rate (grams/brake horsepower-hour)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	8932.77	8932.77	5768.71	
(X+1)-15	8932.77	8932.77	5768.71	9797.23
16-25	8932.77	8932.77	5768.71	9797.23
26-50		8932.77	5768.71	9797.23
51-120		8932.77	5768.71	9797.23
121-175		8932.77	5768.71	9797.23
176-250		8932.77		9797.23
251-500				9797.23
501-750				9797.23
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 5. Zero Hour CO_2 Emission Rate (grams/gallon)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	1.30	1.09	0.97[2]	
(X+1)-15	1.30	0.90	0.80[2]	0.65
16-25	1.30	0.80	0.71[2]	0.53
26-50		0.70	0.62[2]	0.54
51-120		0.55	0.49[2]	0.49
121-175		0.55	0.49[2]	0.44[2]
176-250		0.55		0.44[2]
251-500				0.42[2]
501-750				0.42
750+				
Fuel Density (lb/gallon)	6.20	6.20	4.25	6.80

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

[2] Values encoded in the ARB model are incorrect. Tabulated LPG values are set to 89 percent of 4-stroke gasoline values; tabulated diesel values are set according to available test data.

Table 6. Brake-Specific Fuel Consumption (pounds/brake horsepower-hour)

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.00	1.09	1.09	
(X+1)-15	0.00	1.59	1.59	0.00
16-25	0.00	1.59	1.59	0.00
26-50		1.38	1.38	0.51
51-120		1.38	1.38	0.28
121-175		0.37	0.37	0.28
176-250		0.37		0.28
251-500				0.44
501-750				0.44
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 7. Full-Life HC Deterioration Factor

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.00	0.32	0.32	
(X+1)-15	0.00	0.09	0.09	0.00
16-25	0.00	0.09	0.09	0.00
26-50		0.83	0.83	0.41
51-120		0.83	0.83	0.16
121-175		0.56	0.56	0.16
176-250		0.56		0.16
251-500				0.25
501-750				0.25
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 8. Full-Life CO Deterioration Factor

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.00	0.04	0.04	
(X+1)-15	0.00	0.38	0.38	0.00
16-25	0.00	0.38	0.38	0.00
26-50		0.06	0.06	0.06
51-120		0.06	0.06	0.14
121-175		0.14	0.14	0.14
176-250		0.14		0.14
251-500				0.21
501-750				0.21
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 9. Full-Life NO_x Deterioration Factor

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.00	1.09	1.09	
(X+1)-15	0.00	1.59	1.59	0.00
16-25	0.00	1.59	1.59	0.00
26-50		0.00	0.00	0.31
51-120		0.00	0.00	0.44
121-175		0.00	0.00	0.44
176-250		0.00		0.44
251-500				0.67
501-750				0.67
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 10. Full-Life PM Deterioration Factor

Horsepower Range	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG	Diesel
0-X[1]	0.00	0.00	0.00	
(X+1)-15	0.00	0.00	0.00	0.00
16-25	0.00	0.00	0.00	0.00
26-50		0.00	0.00	0.00
51-120		0.00	0.00	0.00
121-175		0.00	0.00	0.00
176-250		0.00		0.00
251-500				0.00
501-750				0.00
750+				

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 11. Full-Life CO_2 Deterioration Factor

Horsepower Range	Gasoline (2-Stroke) Split	Gasoline (4-Stroke) Split	Diesel Split	Aggregate Split
0-X[1]	0.00	0.00	0.00	0.00
(X+1)-15	1.00	0.00	0.00	0.02
16-25	0.00	0.00	0.00	0.00
26-50	0.00	0.18	0.15	0.17
51-120	0.00	0.51	0.49	0.49
121-175	0.00	0.26	0.27	0.26
176-250	0.00	0.05	0.00	0.03
251-500	0.00	0.00	0.03	0.01
501-750	0.00	0.00	0.05	0.02
751+	0.00	0.00	0.00	0.00

[1] X equals 2 for gasoline 2-stroke; 5 for gasoline 4-stroke and diesel equipment.

Table 12. GSE Horsepower Distributions

from gasoline powered equipment and associated emission reductions would accrue through the imposition of such control strategies as alternative fueled or electric GSE conversion or replacement. However, the lack of evaporative emissions data for most engines and equipment types used in the GSE sector precludes an accurate assessment of the potential significance of such emission reductions. Experience in the on-road vehicle sector indicates that evaporative emissions can constitute a significant fraction of total HC emissions, but this significance is measured on the basis of over two decades of exhaust emissions control. Evaporative emissions are likely to constitute a much smaller fraction of total HC in the GSE sector. Nevertheless, the quantification of evaporative emission rates is an area of needed research and emission reduction potential should be reassessed once a reasonable GSE- or off-road engine-specific database (including engines of the size used for GSE) has evolved.

GSE Engine Size Classification: As might be expected given the diverse nature of the various tasks required of aircraft GSE, a wide range of equipment of varying engine size and fueling type are encountered. The information series selection entitled *Basis for GSE Population Estimates* provides a detailed breakdown of the various GSE equipment by fueling type. The equipment and fueling type population breakdowns presented in this GSE information series differ from those of the ARB off-road model for two reasons. First, the population data encoded in the ARB model is California-specific. Second, the methodology for estimating GSE populations has been improved since the development of the ARB model as described in the *Basis for GSE Population Estimates* information series selection. Nevertheless, the breakdown of the various engine sizes encountered within a specific equipment type, as required to accurately estimate GSE emissions, is best performed using engine distribution data from the ARB model. While the population of GSE equipment should be expected to vary from that of the ARB model, there is no reason to expect that the distribution of engine sizes encountered within a specific equipment type (regardless of population) will vary. Moreover, since the ARB model engine size distributions incorporate all available data on GSE engine distribution, these data represent the current state of GSE information.

While the ARB model continues to represent the best source of horsepower distribution data, it should be recognized that even the basis for this data is limited, consisting of GSE inventory information collected from several airlines during the California Federal Implementation Plan (FIP) development process of the early-1990's. There is no question that an expanded study of GSE engine classifications is both appropriate and necessary to validate or augment existing data.

Table 12 presents the overall horsepower distribution of GSE engines. As indicated, all two-stroke gasoline equipment is small at 15 horsepower or less. Four-stroke gasoline equipment is found over a wide range of horsepower, ranging from 26 hp to as high as 250 hp. Diesel equipment spans an even larger range, from 26 hp all the way up to 750 hp. Neither LPG or CNG GSE distributions can be derived from data encoded in the ARB model since it assumes zero GSE populations for these fuels, but the range of engine horsepower should be very similar to that of four-stroke gasoline equipment. Table 13 presents average horsepower data for the various GSE equipment types represented in the ARB model. The variation across types is dramatic as is expected from the wide range of horsepower observed in the GSE sector and, as a direct result, emissions performance across GSE types (or even across fuels within a specific GSE type) can varies considerably. Clearly, in cases where emission credits are being

Equipment Type	Gasoline/LPG/CNG	Diesel
Aircraft Pushback Tractor	130	216
Conditioned Air Unit	130	300
Air Start Unit	130	600
Baggage Tug	100	78
Belt Loader	60	45
Bobtail	100	100
Cargo Loader	70	76
Cart	12	12
Deicer	93	93
Forklift	50	52
Fuel Truck	130	180
Ground Power Unit	150	145
Lavatory Cart	12	12
Lavatory Truck	130	130
Lift	100	100
Maintenance Truck	130	130
Other	50	50
Service Truck	180	170
Water Truck	150	150

Table 13. Average Horsepower by Equipment and Fuel Type

determined on the basis of equipment retirements or conversions, emission impacts should be calculated on the basis of actual equipment horsepower.

Conspicuously absent from Table 13 and other GSE emissions-related tables in this GSE information series are estimates for “standard” cars, pickup trucks, vans, and buses that are used as GSE for various general services such as personnel transport. Such vehicles are emissions-certified on-road vehicles that have simply been adapted to GSE use. As such, the emissions performance of these vehicles is equivalent to that of other on-road vehicles and is best determined using the U.S. EPA’s MOBILE series of emission factor models developed specifically for estimating on-road vehicle emissions. This is also the case for some unknown fraction of the trucks used to provide fuel, food, water, and lavatory service. Generally, such service trucks include special adaptations to facilitate use as GSE and many are of overseas manufacture and uncertain emissions certification (since their use is restricted to off-road applications, no specific emissions certification has historically been required). However, many are undoubtedly certified on-road vehicles adapted for GSE use and as such, the emission estimates presented for such vehicles in this GSE information series may be overstated.

Newer on-road certified vehicles already incorporate stringent emission controls and may not be good candidates for additional emission reduction through the imposition of the control strategies discussed in this information series (which are slanted toward the reduction of uncontrolled off-road engine emissions). Nevertheless, emission reduction strategies applicable to the general on-road vehicle fleet (e.g., reformulated gasoline) are equally viable for on-road vehicles used as GSE. Therefore, emission reductions for such vehicles should be evaluated in the same context as that of the larger on-road vehicle fleet. The information series selection entitled *Basis for GSE Population Estimates* does include an estimate of the population of on-road cars, pickup trucks, vans, and buses in use as GSE, indicating that they may constitute as much as 12 percent of the overall GSE fleet. The fraction of service trucks that are on-road emissions certified is less certain and all such trucks are assumed to be uncontrolled from an emissions perspective in this information series. Clearly, actual emissions performance should be assessed before any emission reduction credits are granted for the imposition of emission controls on such vehicles.

GSE Load Factors: As was the case with other GSE attributes, the load factor for the various equipment types used as GSE might be expected to vary considerably in accordance with the range of services encountered in the sector. However, information on specific GSE load factors is perhaps the most uncertain of all the activity indicators required to accurately estimate GSE emissions performance. Very little detailed time-in-mode data exist and, as a result, GSE load factors (like those for other off-road equipment types) have been estimated from actual fuel use records and known brake-specific fuel consumption rates for GSE engines. While such an approach is technically sound, there can be considerable uncertainty involved in associating a specific operating time with recorded fuel use (except when concurrent equipment usage meter readings are also available). As a result, there can also be considerable uncertainty in determining precise load factor estimates from fuel consumption records. This uncertainty generally increases as load factor decreases since fuel consumption rates are small relative to rated consumption and the influence of operating time estimation errors becomes more significant. Potential estimation errors can be reduced by increasing the size of the fuel consumption database used to estimate the load factor, but to date the fuel consumption database for GSE is limited and what data is available is reflected in the load factor data encoded in the ARB off-road model. As a result, the ARB off-road model estimates have been used for the emission estimates presented in this GSE information series. Table 14 presents a summary of the load factor estimates by GSE type.

In reviewing the data presented in Table 14, the paucity of data on which to base GSE load factors is obvious as several equipment types exhibit identical estimates due to the unavailability of equipment-specific data. The 0.50 load factor estimate for small engines (i.e., carts) is generally sufficiently close to the J1088 emissions test load factor of 0.39 so that the estimated emission rates based on J1088 should be sufficiently representative. However, for larger equipment (all other GSE), there are several cases where the estimated load factor is outside the 0.56 ±0.2 load factor range associated with the “8 mode” emissions test. Two (of 17) large engine GSE exhibit estimated load factors above 0.76 and five exhibit estimated load factors below 0.36. If these load factors are in fact accurate, then the use of “8 mode” emission test results to accurately portray emission rates for these GSE is questionable.

Equipment Type	Gasoline/LPG/CNG	Diesel
Aircraft Pushback Tractor	0.80	0.80
Conditioned Air Unit	0.75	0.75
Air Start Unit	0.90	0.90
Baggage Tug	0.55	0.55
Belt Loader	0.50	0.50
Bobtail	0.55	0.55
Cargo Loader	0.50	0.50
Cart	0.50	0.50
Deicer	0.95	0.95
Forklift	0.30	0.30
Fuel Truck	0.25	0.25
Ground Power Unit	0.75	0.75
Lavatory Cart	0.50	0.50
Lavatory Truck	0.25	0.25
Lift	0.50	0.50
Maintenance Truck	0.50	0.50
Other	0.50	0.50
Service Truck	0.20	0.20
Water Truck	0.20	0.20

Table 14. Average Load Factors by Equipment and Fuel Type

Without question, additional research into GSE load factors is both appropriate and necessary. Targeted studies using either detailed fuel consumption records and calibrated operating time meters or automatic on-board dataloggers should be implemented at a number of airports of varying size. These studies should include several units of each type of GSE that contributes significantly to overall GSE emissions.

GSE Hours of Use: As indicated above, the overall emission rates for the various GSE depend not only on emission rates, but the overall amount of time the equipment is used. However, experience has shown that equipment usage varies considerably, not only across the various airlines and airports, but by time-of-day, day-of-week, and season. Temporal variation is of marginal concern in estimating long term (e.g., annual or multi-year) emission impacts, but variation across airports is significant and prohibits the development of any generic usage rates for GSE. For example, an airport with limited passenger service may use baggage tractors for only a few hours per day while large, high traffic airports might use baggage tractors continuously throughout an operating day. Based on this airport dependence, the emission estimates presented in this GSE information series are expressed in terms of grams per operating hour and should be equally applicable to any airport or airline employing GSE. However, due to the uncertainties discussed above, these emission estimates should be used for "screening" purposes only (for example, to estimate the potential emission reduction impacts due to the replacement of conventionally fueled GSE with electrically powered equipment) and supplanted with actual site- and application-specific emission estimates in determining actual accrued emission impacts.

Hourly-Specific GSE Emission Rate Estimates: Tables 15-19 present the various emission rates, in units of grams per operating hour, derived using the various GSE data discussed above. As indicated above, these data should be used only for estimation purposes and supplanted with actual site-specific data in determining actual emission impacts.

References:

1. *Analysis of Techniques to Reduce Air Emissions at Airports*, Draft Final Report, prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency, September 1997.

2. *Air Pollution Mitigation Measures for Airports and Associated Activity*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, May 1994.

3. *Technical Support Document for Civil and Military Aviation;* prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency in support of the Notice of Proposed Rulemaking for the Federal Implementation Plan for California, March 1994.

4. GSE population data sheets submitted by member companies of the Air Transport Association as part of the U.S. Environmental Protection Agency's Federal Implementation Plan development process for California, September 1993.

5. *Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, August 1995.

6. California Off-Road Model (June 7, 1996 version) input files *EMFAC.DAT*, *POP.DAT*, and *ACTIVITY.DAT*.

Equipment Type	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG[1]	Diesel
Aircraft Pushback Tractor	n/a	493.0	246.5	174.6
Conditioned Air Unit	n/a	462.2	231.1	230.6
Air Start Unit	n/a	554.6	277.3	553.4
Baggage Tug	n/a	371.8	185.9	70.4
Belt Loader	n/a	202.8	101.4	52.0
Bobtail	n/a	371.8	185.9	90.3
Cargo Loader	n/a	236.6	118.3	62.4
Cart	1,254.0	80.3	42.6	9.0
Deicer	n/a	597.2	298.6	145.0
Forklift	n/a	139.4	50.7	25.6
Fuel Truck	n/a	154.1	77.0	45.1
Ground Power Unit	n/a	533.3	266.6	109.1
Lavatory Cart	n/a	80.3	42.6	9.0
Lavatory Truck	n/a	154.1	77.0	32.6
Lift	n/a	338.0	169.0	82.1
Maintenance Truck	n/a	308.1	154.1	65.2
Other	n/a	232.4	84.5	57.7
Service Truck	n/a	170.6	85.3	34.1
Water Truck	n/a	142.2	71.1	30.1

[1] CNG emission rate equals 0.67 times LPG emission rate.

Table 15. Equipment-Specific HC Emission Rates (grams/operating hour)

Equipment Type	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG[1]	Diesel
Aircraft Pushback Tractor	n/a	31,949	19,968	788
Conditioned Air Unit	n/a	29,952	18,720	1,038
Air Start Unit	n/a	35,942	22,464	2,491
Baggage Tug	n/a	18,678	11,674	222
Belt Loader	n/a	10,188	6,368	136
Bobtail	n/a	18,678	11,674	285
Cargo Loader	n/a	11,886	7,429	197
Cart	1,866	2,465	1,505	30
Deicer	n/a	30,004	18,752	458
Forklift	n/a	6,792	3,184	81
Fuel Truck	n/a	9,984	6,240	204
Ground Power Unit	n/a	34,560	21,600	493
Lavatory Cart	n/a	2,465	1,505	30
Lavatory Truck	n/a	9,984	6,240	147
Lift	n/a	16,980	10,613	259
Maintenance Truck	n/a	19,968	12,480	295
Other	n/a	11,320	5,306	151
Service Truck	n/a	11,059	6,912	154
Water Truck	n/a	9,216	5,760	136

[1] CNG emission rate equals 1.00 times LPG emission rate.

Table 16. Equipment-Specific CO Emission Rates (grams/operating hour)

Equipment Type	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG[1]	Diesel
Aircraft Pushback Tractor	n/a	445.1	333.8	2,055.2
Conditioned Air Unit	n/a	417.3	313.0	2,734.9
Air Start Unit	n/a	500.8	375.6	6,563.7
Baggage Tug	n/a	226.6	170.0	596.7
Belt Loader	n/a	123.6	92.7	160.4
Bobtail	n/a	226.6	170.0	765.1
Cargo Loader	n/a	144.2	108.2	528.6
Cart	5.4	24.8	12.6	60.0
Deicer	n/a	364.0	273.0	1,228.9
Forklift	n/a	57.9	46.4	217.0
Fuel Truck	n/a	139.1	104.3	529.7
Ground Power Unit	n/a	481.5	361.1	1,280.0
Lavatory Cart	n/a	24.8	12.6	60.0
Lavatory Truck	n/a	139.1	104.3	382.5
Lift	n/a	206.0	154.5	695.5
Maintenance Truck	n/a	278.2	208.7	765.1
Other	n/a	96.6	77.3	178.2
Service Truck	n/a	154.1	115.6	400.2
Water Truck	n/a	128.4	96.3	353.1

[1] CNG emission rate equals 1.00 times LPG emission rate.

Table 17. Equipment-Specific NO$_x$ Emission Rates (grams/operating hour)

Equipment Type	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG[1]	Diesel
Aircraft Pushback Tractor	n/a	3.1	2.1	117.9
Conditioned Air Unit	n/a	2.9	2.0	159.2
Air Start Unit	n/a	3.5	2.3	382.1
Baggage Tug	n/a	2.2	2.2	44.0
Belt Loader	n/a	1.2	1.2	19.8
Bobtail	n/a	2.2	2.2	56.4
Cargo Loader	n/a	1.4	1.4	38.9
Cart	39.0	1.5	1.0	6.0
Deicer	n/a	3.5	3.5	90.5
Forklift	n/a	0.8	0.5	16.0
Fuel Truck	n/a	1.0	0.7	30.2
Ground Power Unit	n/a	3.4	2.3	73.0
Lavatory Cart	n/a	1.5	1.0	6.0
Lavatory Truck	n/a	1.0	0.7	21.8
Lift	n/a	2.0	2.0	51.2
Maintenance Truck	n/a	2.0	1.3	43.6
Other	n/a	1.3	0.8	21.9
Service Truck	n/a	1.1	0.7	22.8
Water Truck	n/a	0.9	0.6	20.1

[1] CNG emission rate equals 1.00 times LPG emission rate.

Table 18. Equipment-Specific PM Emission Rates (grams/operating hour)

Equipment Type	Gasoline (2-Stroke)	Gasoline (4-Stroke)	LPG[1]	Diesel
Aircraft Pushback Tractor	n/a	82,412	69,100	108,183
Conditioned Air Unit	n/a	77,261	64,781	136,153
Air Start Unit	n/a	92,714	77,737	326,766
Baggage Tug	n/a	43,583	36,543	30,286
Belt Loader	n/a	23,773	19,933	17,505
Bobtail	n/a	43,583	36,543	38,829
Cargo Loader	n/a	27,735	23,255	26,827
Cart	11,238	7,780	6,523	5,619
Deicer	n/a	70,011	58,701	62,373
Forklift	n/a	15,128	12,684	11,013
Fuel Truck	n/a	25,754	21,594	28,527
Ground Power Unit	n/a	89,148	74,747	68,941
Lavatory Cart	n/a	7,780	6,523	5,619
Lavatory Truck	n/a	25,754	21,594	20,603
Lift	n/a	39,621	33,221	35,299
Maintenance Truck	n/a	51,508	43,187	41,206
Other	n/a	25,213	21,141	19,450
Service Truck	n/a	28,527	23,919	21,554
Water Truck	n/a	23,773	19,933	19,018

[1] CNG emission rate equals 0.92 times LPG emission rate.

Table 19. Equipment-Specific CO_2 Emission Rates (grams/operating hour)

LPG AND CNG CONTROL STRATEGIES

LPG AND CNG CONTROL STRATEGIES

Basic Control Strategy Summary: The majority of conventionally powered GSE can be converted to either liquefied petroleum gas (LPG) or compressed natural gas (CNG) fueling or replaced with a specially-manufactured LPG- or CNG-powered counterpart. The basic issues surrounding the use of LPG or CNG as a GSE fuel are quite similar and, therefore, both fueling strategies can be treated together. Generally, non-methane hydrocarbon (NMHC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), and carbon dioxide (CO_2) emissions from LPG or CNG GSE are all reduced relative to emissions from gasoline-powered GSE. Relative to diesel GSE, emissions of NO_x and PM are reduced, emissions of HC and CO are increased, and emissions of CO_2 can be either slightly increased or decreased depending on equipment size. Important issues for consideration in determining the viability of either conversion or replacement strategies include: the quality of equipment conversions, the cost of conversion or replacement equipment, and the availability (or cost) of LPG or CNG refueling facilities.

Potential GSE Equipment Affected: Generally, there are no technical limitations to the size or type of GSE that can be converted to LPG/CNG power or replaced with equivalent LPG/CNG equipment. For GSE powered by gasoline engines, both conversion and replacement are technically feasible given the spark-ignition nature of both LPG/CNG and gasoline engine designs. However, the compression-ignition design of diesel powered GSE generally restricts the viability of LPG/CNG conversion strategies (due to the lack of an active ignition source), rendering equipment replacement with specially manufactured LPG or CNG counterparts as the only realistic LPG/CNG fueling strategy for diesel powered GSE. It is recognized that there have been demonstration projects involving the passive ignition of gaseous fuels in compression-ignition engines through such techniques as fumigation, but in general these technologies are not considered to be sufficiently mature for mass market penetration at this time.

LPG/CNG Conversions: Although some aspects of the conversion process for LPG and CNG vary, in general, both involve the same elements. Conversion of a spark-ignition engine (i.e., a gasoline engine) essentially involves the installation of a new fuel tank, a new fuel delivery system, and a new fuel metering system. To ensure low emissions operation, most advanced conversion kits also include closed-loop performance feedback controllers that continuously adjust the charge air/fuel mixture to promote optimum combustion. Previous generation open-loop (i.e., non-feedback) conversion packages were prone to frequent combustion "detuning" and large associated increases in emissions. Complete conversion packages for specific engines are usually sold in kits available through a number of dealers nationwide. While, theoretically, diesel engines can also be converted to LPG or CNG fueling, the extensive nature of the engine modifications required with current mass-market technology to turn these compression-ignition engines into spark-ignition engines are prohibitive.

LPG/CNG Replacements: Most GSE manufacturers now sell either specially designed LPG and CNG versions of their equipment or offer LPG and CNG fueling as an optional feature of their gasoline-powered equipment. There are few, if any, GSE applications for which LPG- or

CNG-powered equipment cannot be purchased.

Emission Impacts: The emission impacts of replacement LPG and CNG equipment and quality LPG and CNG conversions are fairly well characterized. However, there are two issues of consideration relative to any assessment of these characterizations. First, the emission relationships presented in this information series are for unregulated (from an emissions standpoint) GSE engines and assume that replacement or converted LPG and CNG systems do not include any emissions aftertreatment devices (for example, catalytic converters) not found on the GSE before replacement or conversion.

To the extent that any future emissions standards are imposed that impact the engines used in GSE (generally large industrial-type engines), the relationship between emissions from GSE powered by gasoline, diesel, LPG, and CNG will be fundamentally altered (potentially to the point of equivalent emission limitations). Nevertheless, the conversion of GSE to LPG/CNG will continue to be a viable control strategy even after the imposition of emission standards due to the lag time associated with GSE retirement and replacement, but at some point (a decade or so after regulatory effectiveness) the emissions benefits associated with such conversion will be eliminated.

Conversely, should replacement or converted LPG/CNG equipment include emission control aftertreatment equipment not present on the GSE before conversion or replacement, then LPG/CNG emission reduction benefits will be larger than indicated in this information series. The combined emission reduction percentage ($\mathrm{PctRed}_{\mathrm{overall}}$) of the fundamental fueling system replacement (generating percent emission reduction PctRed_1) and the emissions aftertreatment device (generating percent emission reduction PctRed_2) can be estimated as follows:

$$\mathrm{PctRed}_{\mathrm{overall}} = \left[1 - \left(1 - \frac{\mathrm{PctRed}_1}{100}\right)\left(1 - \frac{\mathrm{PctRed}_2}{100}\right)\right] \times 100$$

The second issue for consideration is the quality of LPG and CNG conversions. Given the nature of current gasoline GSE engines, there is no reason that a quality, properly installed conversion kit cannot provide for emission performance similar to factory-produced LPG and CNG equipment. However, experience has shown that conversion kits are not always certified (emission certifications are currently only performed by the California Air Resources Board) or, even if certified, properly installed and calibrated and, as a result, both operating and emissions performance can be greatly affected. Frequent detuning observed with open loop conversion kits indicates that such packages should either be exempted from or carefully monitored to ensure compliance with stated emission reductions. As it stands today, the current “unregulated” state of the aftermarket conversion industry can result in after-conversion equipment that generates emissions (of pollutants that would normally be reduced) at the same or even greater rates than the pre-conversion equipment. Since there is no way to quantify the fraction of conversions that are of poor quality, the emission comparisons presented in this GSE information series assume that a proper conversion has been performed and that emissions from that conversion are equivalent to emissions from a replacement engine. However, in practice it will be necessary to institute some type of certification and in-use compliance procedure to ensure that any emission reductions achieved in practice are both quantifiable and consistent with any ascribed credits.

Examples of possible conversion certification programs can be found in California, where the State Air Resources Board (ARB) certifies aftermarket conversion kits to specific emission standards which become enforceable under the California in-use vehicle compliance program. Jurisdictions such as the South Coast Air Quality management District rely on these certifications before granting emission credits under their Mobile Source Emission Reduction Credit (MSERC) program. However, in practice these certifications are only as effective as the in-use compliance program that ensures that installers not only adhere to kit manufacturer requirements, but actually achieve certification level emissions performance. One possible response is to require credit emission reduction recipients to submit associated vehicles for periodic emission inspections to ensure performance consistent with credit assumptions. There may be other equally effective mechanisms, but clearly an effective program will require significant oversight and enforcement.

Using data developed for the off-road emissions model recently released by the California ARB, detailed emission estimates for LPG, CNG, gasoline, and diesel GSE have been developed as described in the information series selection *GSE Emissions and Activity Estimates*. Data used in this emissions estimation analysis include zero hour emission rates, emissions deterioration rates, equipment horsepower, equipment load factors, and brake-specific fuel consumption. Table 1 presents a comparison of derived emission rates for baggage tractors and belt loaders, which together constitute over a third of all GSE. Emission rates for other GSE types will vary from those presented in Table 1 due to variations in engine size and operating characteristics, but the relative relationships between the various fueling types remain consistent. Therefore, the data in Table 1 can be used to assess the relative degree of emission reduction to be expected by converting or replacing conventionally fueled GSE. Table 2 presents these emission reduction relationships and indicates the variability across different GSE types from those included in Table 1.

Several aspects of the tables stand out. Relative to emissions from gasoline GSE, emissions from both LPG and CNG equipment are reduced for all five emission species examined. Similar relationships exist for LPG and CNG NO_x and PM relative to diesel GSE emissions, where the greatest emission reductions due to equipment conversion or replacement are observed. Although (apparently dramatic) emission increases are observed for both HC and CO relative to diesel GSE emissions, these increases are not nearly as dramatic in absolute terms as the percentage increase estimates imply. The large percentages simply result from the relatively low HC and CO emission rates of diesel GSE engines. For example, while diesel baggage tractors are estimated to emit over 200 grams of CO and about 70 grams of HC per hour, equivalent LPG-powered equipment has estimated emission rates of over 9,000 and nearly 150 grams per hour respectively (both well below the estimated emission rates of about 14,500 grams CO and 300 grams HC per operating hour for equivalently sized gasoline equipment (not shown in Table 1)). Finally, the variation of the estimates of LPG and CNG CO_2 relative to diesel GSE around zero are due to the sensitivity of diesel engine efficiency to engine size. However, the cases in which diesel engine efficiency exceeds (and thus CO_2 emissions are lower) than LPG and CNG far outnumber the alternative. Finally, when considering CO_2 emissions in the context of global warming potential, it is also

Emissions from ICE-Powered Baggage Tractors of Gasoline Engine Size

	HC	CO	NO_x	PM	CO_2
Gasoline (4-Stroke)	371.8	18678.0	226.6	2.2	43583.3
LPG	185.9	11673.8	170.0	2.2	36543.1
CNG	123.9	11673.8	170.0	2.2	33619.6

Emissions from ICE-Powered Baggage Tractors of Diesel Engine Size

	HC	CO	NO_x	PM	CO_2
Gasoline (4-Stroke)	371.8	18678.0	226.6	2.2	43583.3
LPG	185.9	11673.8	170.0	2.2	36543.1
CNG	123.9	11673.8	170.0	2.2	33619.6

Emissions from ICE-Powered Belt Loaders of Gasoline Engine Size

	HC	CO	NO_x	PM	CO_2
Gasoline (4-Stroke)	202.8	10188.0	123.6	1.2	23772.7
LPG	101.4	6367.5	92.7	1.2	19932.6
CNG	67.6	6367.5	92.7	1.2	18338.0

Emissions from ICE-Powered Belt Loaders of Diesel Engine Size

	HC	CO	NO_x	PM	CO_2
Gasoline (4-Stroke)	52.0	135.6	160.4	19.8	17505.3
LPG	101.4	6367.5	92.7	1.2	19932.6
CNG	67.6	6367.5	92.7	1.2	18338.0

Table 1. Estimated Emission Rates for Baggage Tractors

	Emissions Relative to Gasoline GSE		Emissions Relative to Diesel GSE	
	LPG	CNG	LPG	CNG
HC	-50% to -65%	-65% to -75%	+95% to +140%	+30% to +60%
CO	-40% to -50%		+4000% to +5000%	
NO_x	-20% to -25%		-75% to -80%	
PM	-20%		-95%	
CO_2	-15%	-20%	-5% to +15%	-10% to +10%

Table 2. Percent Emissions Reduction Due to LPG/CNG GSE

important to recognize that emission species such as methane which are not estimated here can play a critical role in determining the overall global warming potential associated with a specific fuel. For example, CNG equipment will emit methane at a higher rate than either gasoline, LPG, or diesel equipment.

Costs: The incremental cost of LPG conversions has been estimated to be in the range of $1,500 to $2,000 for systems capable of storing the LPG equivalent of about 20 gallons of gasoline. For larger GSE, costs can range as high as $3,000. High pressure fuel storage requirements push typical conversion costs to $4,000 to $4,500 per unit for CNG, even for systems sized to store the equivalent of only about 15 gallons of gasoline. Locating space for adequate fuel tank storage capacity can be an issue for CNG as well as LPG conversions. Most GSE do not have significant unused cargo volumes in which to locate additional fuel storage tanks. Since safety concerns preclude installation in exposed areas, fuel tanks must generally replace existing conventional fuel tanks. However, the CNG's lower fuel energy per unit volume can severely restrict operating range, and thus conversion viability, in some applications.

For gasoline powered GSE, the incremental costs of specially designed LPG and CNG replacement GSE equipment are similar to incremental conversion costs. However, for replacement diesel equipment, incremental costs can be considerably higher given the generally larger size and expected durability of diesel-type GSE. Cost premiums can be as high as 50 percent of the basic diesel GSE cost.

Some of the increased cost of equipment conversion or replacement can be offset by fuel cost savings. Although fuel prices vary geographically, in general LPG and CNG cost from 30-50 percent less on an equivalent energy basis than retail gasoline or diesel (including the cost of compression for CNG). However, most, and in some cases all, of this potential savings is lost in airport applications since on-highway fuel taxes (that comprise 30-40 percent of retail fuel price) are recouped as tax credits due to the off-road nature of GSE use. Potential fuel cost savings are further eroded through an estimated loss in fuel efficiency of about 5 percent for LPG and 10 percent for CNG relative to gasoline GSE and losses of up to 30 percent relative to diesel GSE. Thus fuel cost savings, if any, will be modest. LPG systems could have fuel costs about $0.10 per gasoline equivalent gallon lower than their gasoline counterparts while CNG equipment fuel costs will be about equal to those of their gasoline counterparts and possibly somewhat higher.

Both LPG and CNG GSE could have lower routine maintenance costs than either gasoline or diesel GSE due to reduced particulate and associated deposit formation. However, several airlines using such equipment have reported much higher non-routine maintenance costs for LPG and CNG equipment. This may, however, be a result of early design problems associated with early generation LPG and CNG systems and could decline as additional experience is gained.

Table 3 presents the results of a life cycle cost comparison for a baggage tractor under a high-use operating scenario (i.e., the GSE is generally used to service aircraft continuously throughout an operating day as typically occurs at high traffic airports). The tabulated costs represent the net present value of the various expenditures required over the sixteen year useful life of the tractor. In all cases, the diesel-powered tractor exhibits the lowest life cycle costs by a substantial margin. This is consistent with an observed movement in the GSE industry towards greater

Fuel Type	Purchase Cost	Rebuild or Replacement Costs	Fuel Costs	Reduced LPG/CNG Maintenance Costs	Total Costs if Reduced LPG/CNG Maintenance	Total Costs if Same LPG/CNG Maintenance
Gasoline	$17,000	$2,568	$59,481	$47,089	$126,139	$126,139
Diesel	$22,000	$1,351	$27,386	$47,089	$97,826	$97,826
LPG	$19,000	$2,568	$49,072	$37,176	$107,816	$117,729
CNG	$21,000	$2,568	$65,058	$37,176	$125,802	$135,715

Assumptions: 16 year equipment life; 6 year engine replacement interval for gasoline, LPG, and CNG; 8 year engine rebuild interval for diesel; $2,500 unit cost for all rebuilds/replacements; equipment used 8 hours per day for 350 days per year; gasoline use is 3.2 gallons per hour at $0.75 (after tax credits) per gallon; diesel use is 1.7 gallons per hour at $0.65 (after tax credits) per gallon; LNG use is 3.3 gallons per hour at $0.60 per gallon; CNG use is 3.5 gallons per hour at $0.75 per gallon (including the cost of refueling facility operation and amortization); maintenance costs are $1.90 per hour for gasoline and diesel; maintenance costs are $1.50 per hour for LPG and CNG under a reduced maintenance scenario or $1.90 per hour under a "same maintenance" scenario.

Table 3. Life Cycle Costs for Baggage Tractors

diesel utilization in large engine applications. Relative to gasoline, both LPG and CNG tractors show reduced or similar life cycle costs if one assumes reduced maintenance requirements for LPG and CNG engines. However, if the assumption of reduced maintenance is eliminated, the full life cycle costs favor gasoline over CNG and the savings associated with LPG are cut in half. Clearly, the maintenance issue is critical to the viability of LPG and CNG engines given the current experience of many LPG- and CNG-powered GSE owners, where maintenance costs are not only not reduced, but actually higher than those of comparable gasoline or diesel equipment.

It is also important to note that since both fuel and maintenance costs are a function of usage, the range of life cycle costs narrows and any cost advantages of LPG and CNG engines are diminished if GSE is used less frequently than assumed in the development of Table 3. For example, if a baggage tractor is operated only half the time assumed (i.e., four hours per day instead of eight), the range between diesel and gasoline life cycle costs narrows to about $12,000; the range between gasoline and LPG narrows to about $8,000 under a reduced maintenance scenario or $3,000 under a constant maintenance scenario; and CNG operation becomes about $2,000 more costly than gasoline under a reduced maintenance scenario or $7,000 more costly under a constant maintenance scenario. Clearly site- and application-specific calculations are necessary before accurate airport and airline-specific cost relations can be determined.

<u>Cost Effectiveness</u>: It is difficult to provide detailed cost effectiveness estimates for either LPG or CNG GSE because the impact of such equipment varies across the pollutants examined and relative to whether gasoline or diesel GSE is being replaced. From the cost table presented above, it is clear that from a simple operation and maintenance standpoint, diesel GSE are more cost effective than gasoline, LPG, or CNG. The inclusion of an emissions valuation can shift this relationship, but the shift is greatly dependent on the pollutants included in the valuation. Diesel HC and CO are generally lower than those of gasoline, LPG, and CNG, so that credits assigned to a reduction in either will continue to favor diesel GSE. Under a scenario in which only NO_x

reductions are assigned a marketable value, LPG becomes cost competitive with diesel at a market value of $1,000-$2,000 per ton; CNG becomes cost competitive with diesel at a market value of $3,000-$4,000 per ton; and gasoline becomes cost competitive with diesel at a market value of about $3,500 per ton. A similar scenario that assigns marketable value to PM reductions would make LPG competitive with diesel when PM is valued at $10,000-$20,000 per ton, CNG competitive with diesel when PM is valued at $30,000-$40,000 per ton, and gasoline competitive with diesel when PM is valued at about $30,000 per ton. The inclusion of CO_2 emissions in an evaluation program is somewhat more complex as the relationship between the various fuels shifts slightly with engine size, but diesel engines generally emit lower CO_2 than either gasoline, LPG, or CNG so that under most scenarios in which value is granted to CO_2 reductions, diesel-powered GSE would be favored over the other three fuels.

Relative to gasoline GSE, emissions of all examined pollutants (HC, CO, NO_x, PM, and CO_2) should decline through replacement with either LPG- or CNG-powered GSE. In fact, from the table above it is clear that under a scenario in which LPG and CNG maintenance costs are reduced relative to gasoline that these emissions reductions are derived for free (the life cycle costs of both LPG and CNG are lower than those of gasoline) and any marketable credits obtained through gasoline GSE replacement are essentially windfalls. (It should be noted that for programs crediting HC, CO, or CO_2, diesel GSE would also reflect a windfall status relative to gasoline.) Even under an assumption of similar maintenance costs, LPG retains its windfall status. However, CNG would lose its competitive edge under such an assumption unless HC reductions are valued at about $2,000 per ton, CO reductions are valued at about $100 per ton, or NO_x reduction are valued at about $5,000 per ton (or some combination of all three).

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ELECTRIC GSE

ELECTRIC GSE

Basic Control Strategy Summary: The majority of conventionally powered GSE can be either converted to electric power or replaced with specially-manufactured electrically powered counterparts. Although there is an increase in offsite power generating station emissions resulting from the increased electrical demand required to recharge electric GSE, conversion to electric power or replacement with electric GSE can be a very effective emission reduction strategy. Even when the increased emissions from power generating stations are considered, electric GSE usually emit[*] significantly less hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), and carbon dioxide (CO_2) emissions than their fossil fueled (i.e., gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG)) counterparts. Important issues for consideration in determining the viability of either conversion or replacement strategies include: the capacity of the electric equipment to handle daily GSE scheduling and load demands, the quality of equipment conversions, the cost of conversion or replacement equipment, the availability (or cost) of electric recharging or battery replacement stations, and the ability to schedule recharging or battery replacement around GSE service demands.

Potential GSE Equipment Affected: Generally, there are no technical limitations to the size or type of GSE that can be converted to or replaced with electrically powered equipment. Electrically powered versions of baggage tugs and belt loaders, which together account for over a third of all GSE, are available and in use (although current usage constitutes only a minor fraction of total activity). Additionally, electric powered versions of aircraft pushback tractors, air start units, conditioned air units, forklifts, ground power units, lifts, general purpose vehicles (cars, trucks, and vans), and other specialty GSE are currently available in the marketplace. Electric carts are already fulfilling about half of overall GSE cart demand.

GSE conversion generally requires the removal of the internal combustion engine and fuel storage tanks to obtain sufficient room to install the necessary electric motor, motor controller, and battery pack and, therefore, is equally viable on diesel, gasoline, CNG, and LPG fueled GSE. However, some equipment types or configurations may not be able to store sufficient battery capacity to fulfill required service demands within existing space limitations. Therefore, the ability to convert a specific GSE to electric power, and the specifications for conversion, require a detailed review of the candidate equipment.

Regardless of the availability of replacement or conversion equipment, a primary issue in evaluating the potential acceptability of electrically powered GSE is the daily usage demand placed on the equipment. Equipment that is in continuous or near-continuous service throughout the day will require quick turnaround battery replacement facilities, quick recharge capability, or

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[*] Technically, electrically powered GSE do not emit any pollutants. The term emit, as used here, ascribes to the electric GSE, the offsite increase in power generating station emissions due to increased airport electrical power to support electric GSE recharging. In essence, the electrically powered GSE are treated as if they “emitted” the increased power generating station emissions associated with their use.

the availability of fully charged backup equipment. Most GSE will require between one and five charging cycles per day. GSE that can operate for a full day on a single charge are candidates for off-peak charging, but most equipment will require all-hours recharging access, at least with current battery technology. Battery storage advances could increase the fraction of GSE that can operate throughout the day on a single charge, but existing technology can only be extended through an increase in battery pack size (thus imposing additional storage space considerations). Clearly, the capability of scheduling GSE recharging within the constraints of aircraft service demands is a key issue for those considering replacement or conversion of fossil fueled GSE.

Electric GSE Conversions: Conversion of fossil fueled GSE to electric power generally involves the removal of the internal combustion engine and fuel tank and installation of an electric motor, motor controller, and battery pack. Although the conversion process is generally well established from a technical standpoint, the sizing of the electric motor, selection of an appropriate controller, integration with (or replacement of) existing drivetrain components, and selection and sizing of the battery pack within the volume constraints established by existing GSE design, result in the need for a case-by-case design review. It is important to recognize that design review and installation quality are important from a performance standpoint alone. Like factory-designed replacement GSE, tailpipe emissions from converted electric GSE are non-existent (unlike fossil fuel conversions such as CNG and LPG, for which emissions performance can be quite dependent on conversion quality). Another limiting factor, in addition to conversion design and packaging, is the location of qualified conversion facilities, which tend to be concentrated in California.

Electric GSE Replacements: Specially designed electrically powered GSE are now available from reputable GSE OEM s (original equipment manufacturers). The range of electric GSE now available spans nearly the full range of aircraft service equipment. In general, the latest generation of such equipment has attained a level of reliability equal to or better than that of equivalent fossil fueled GSE. However, battery recharging capacity and scheduling continue to represent major feasibility considerations given current battery technology.

Emission Impacts: The emission performance of replacement or converted electric GSE is well understood since removal or retirement of the fossil fueled internal combustion engine (ICE) results in zero emissions piece of equipment. Nevertheless, overall emission reduction impacts are dependent on two key factors: (1) the emissions performance of the equipment being replaced or converted, and (2) the specific power generating characteristics of the region in which the airport is located.

Most GSE in operation today are unregulated from an emissions standpoint and, therefore, do not incorporate emission reduction technology in their design. A definitive calculation of displaced emissions due to conversion or replacement of equipment with electric GSE involves the measurement of the average emission rate of the displaced fossil fueled GSE and the application of the activity data associated with the displaced unit. A generalized expression of the necessary calculation of displaced emissions takes the form:

To calculate total displaced emissions, the emission rate per unit time (e.g., pounds per year) should be aggregated over the total time such emissions would have accrued. For example, if a unit had an expected additional service period of four years after displacement, then emissions throughout this four year period would be displaced. Determining the emissions performance of units which are displaced by attrition as part of a normal replacement cycle is more complex in that reductions will only accrue in accordance with the emission rate of the newer-design alternative fossil fueled GSE which could (and presumably would) have been purchased in the absence of electric GSE purchase. In addition to fossil fueled GSE emission reductions due to technology evolution, any future emission standards imposed on GSE will reduce the emission reduction benefits of electric GSE by reducing the emission rate of displaced fossil fueled GSE. Under any emissions control scenario, the emission reduction benefits of switching GSE from fossil fueling to electric power will depend on the specific fossil fuel being displaced since each has its own emissions characteristics.

Airports served by relatively low emitting power generation facilities will produce larger emission reduction benefits than will accrue in areas served by older, higher emitting generating facilities. While HC and CO emission reductions are dramatic (approaching 100 percent) regardless of local power generation characteristics, NO_x, PM, and CO_2 reductions can vary considerably. Tables 1 and 2 demonstrate this sensitivity. Table 1 presents estimated hourly emission rates for both fossil fueled baggage tractors[*] and the incremental electricity generation required to power alternative electric baggage tractors. Table 2 presents the resulting emission reductions associated with replacement of the various fossil fueled baggage tractors under alternative power generation scenarios. Baggage tractors alone account for just under a quarter of all GSE and the emission impacts associated with replacement of fossil fueled baggage tractors are consistent with the impacts associated with replacement of other fossil fueled GSE.

As indicated, the dependence of emission impacts on power generation emissions can be dramatic. For example, NO_x reductions due to the replacement of gasoline baggage tractors can range from 40 to 99+ percent and the potential range of CO_2 reductions is nearly as wide at 40 to 80 percent. PM emissions can, as indicated, increase substantially under the highest emission power generation conditions, but can also decline by as much as 90 percent under other power generation conditions. Both the highest and lowest power generation scenarios are equally unlikely to be applicable to any given electric GSE replacement scenario. The highest emission scenario represents an uncontrolled coal-fired application while the lowest emission scenario represents a maximum controls (regardless of cost effectiveness) natural gas application. There may be a few specific instances (e.g., California airports) where actual power generation emissions approach those of the low emissions scenario, but generally emission reductions are more likely to approximate those of the tabulated average scenario which is based on the average of measured emission rates for six geographically diverse U.S. utilities. Therefore,

$$\frac{emissions}{unit\ time} = \frac{grams}{brake\ hp\text{ - }hr}\ x\ hp\ x\ load\ \ factor\ \ x\ \frac{hours\ of\ use}{unit\ time}$$

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[*] The tabulated emission rate data was developed using data from the off-road emissions model recently released by the California Air Resources Board. Data used for this analysis included zero hour emission rates, emissions deterioration rates, equipment horsepower, equipment load factor, and brake-specific fuel consumption. See the information series selection entitled *GSE Emission Rates and Activity* for additional detail.

Emissions from ICE-Powered Baggage Tractors (grams/operating hour)					
	HC	CO	NO$_x$	PM	CO$_2$
Gasoline (4-Stroke)	371.8	18,678.0	226.6	2.2	43,583.3
LPG	185.9	11,673.8	170.0	2.2	36,543.1
Diesel	70.4	222.4	596.7	44.0	30,286.4
Incremental Utility Emissions from Electric Baggage Tractors Assuming					
Utility Scenario[1]	HC	CO	NO$_x$	PM	CO$_2$
Best Case	0.5	1.9	4.4	0.2	9,645.2
Worst Case	6.8	10.2	139.4	75.4	25,619.9
Average Case	2.0	6.0	22.2	1.3	19,088.7
Incremental Utility Emissions from Electric Baggage Tractors Assuming					
Utility Scenario[1]	HC	CO	NO$_x$	PM	CO$_2$
Best Case	0.4	1.5	3.4	0.2	7,523.2
Worst Case	5.3	7.9	108.7	58.8	19,983.6
Average Case	1.6	4.7	17.3	1.0	14,889.2

[1] Utility (i.e., power generating station) emissions will vary in accordance with local electricity generation practices. Major factors include boiler design, boiler fuel, and emission controls in place. The best case scenario represents potential emissions if GSE electrical demand is satisfied by a generating station firing natural gas and employing maximum controls. Conversely, the worst case scenario represents potential emissions if GSE electrical demand is satisfied by a generating station firing coal under essentially uncontrolled (from an emissions standpoint) conditions. The average case represents a more typical level of utility emissions and is based on actual emission rates for a geographically diverse sample of utilities.

Table 1. Estimated Emission Rates for Baggage Tractors

Percent Reduction[1] from a Gasoline (4-Stroke) Baggage Tractor

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.9	100.0	98.1	88.9	77.9
Worst Case	98.2	99.9	38.5	up 3328.4	41.2
Average Case	99.4	100.0	90.2	42.4	56.2

Percent Reduction[1] from an LPG Baggage Tractor

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.8	100.0	97.4	88.9	73.6
Worst Case	96.3	99.9	18.0	up 3328.4	29.9
Average Case	98.9	99.9	86.9	42.4	47.8

Percent Reduction[1] from a Diesel Baggage Tractor

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.5	99.3	99.4	99.6	75.2
Worst Case	92.4	96.4	81.8	up 33.8	34.0
Average Case	97.7	97.9	97.1	97.8	50.8

[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent)

[2] Utility (i.e., power generating station) emissions will vary in accordance with local electricity generation practices. Major factors include boiler design, boiler fuel, and emission controls in place. The best case scenario represents potential emission reductions if GSE electrical demand is satisfied by a generating station firing natural gas and employing maximum controls. Conversely, the worst case scenario represents potential emission reductions if GSE electrical demand is satisfied by a generating station firing coal under essentially uncontrolled (from an emissions standpoint) conditions. The average case represents a more typical level of emission reductions and is based on actual emission rates for a geographically diverse sample of utilities.

Table 2. Estimated Emission Reductions Due to Baggage Tractor Replacement

replacement of fossil fueled GSE will, as indicated, generate substantial emission reductions at most U.S. airports.

Costs: Initial purchase costs for electric GSE are high relative to their fossil fueled counterparts. The cost premium is almost entirely associated with the required battery pack and recharger. Table 3 presents a comparison of electric baggage tractor first costs relative to those of fossil fueled GSE. As indicated, the cost premium ranges from about $8,000 relative to a diesel powered tractor to about $13,000 relative to a gasoline-powered tractor. These purchase price premiums are augmented by periodic battery replacement requirements (at about $4,500 every 5-6 years) that are 2 to 4 times higher on a life cycle basis than corresponding fossil fuel engine rebuild or replacement costs. However, these cost premiums are counterbalanced by a substantial reduction in fuel costs. Electric GSE use no fuel during idle periods and such periods can comprise as much as 50 percent of typical GSE operation. Using an estimated electricity cost of $0.045 per kilowatt-hour, the overall fuel savings associated with high-use GSE operations such as baggage tractors can range from $2,500 per year relative to diesel equipment to over $6,000 per year relative to gasoline and CNG equipment. While lower-use GSE fuel cost savings will be smaller, it is clear that fuel savings alone can offset the entire electric GSE purchase price premium in 2 to 3 years. Moreover, electric GSE fuel cost savings will increase as more efficient electric motors and motor controllers continue to evolve.

In addition to reduced fuel costs, the latest generation of electric GSE have demonstrated significantly reduced maintenance requirements. Costs have been estimated to be reduced by as much as two-thirds relative to gasoline and diesel powered GSE. Table 3 presents the results of a life cycle cost comparison for a baggage tractor under a high-use operating scenario (i.e., generally used to service aircraft continuously throughout an operating day such as occurs at high traffic airports). The tabulated costs represent the net present value of the various expenditures required over the sixteen year useful life of the tractor. Regardless of whether maintenance costs are assumed to be reduced, the electric-powered tractor consistently exhibits the lowest life cycle costs. Life cycle costs for the electric baggage tractor are estimated to be over 40 percent lower than the next lowest cost diesel option under a reduced maintenance scenario and still 10 percent lower even if maintenance costs are assumed to be identical to conventional gasoline and diesel powered GSE maintenance costs.

Cost Effectiveness: It is difficult to provide precise cost effectiveness estimates for electric GSE because the impact of such equipment varies across the pollutants examined and relative to the fossil fuel equipment being replaced and the emissions performance of local utilities. However, it is clear from the data presented in Table 3 that electric GSE represent the lowest cost option relative to all fossil fuel GSE. Therefore, if an appropriate battery recharging schedule and infrastructure can be established, all derived emission reductions accrue for free. Assuming local utility emissions performance is not too different from average U.S. utility emission levels, electric GSE are cost effective from an economic standpoint alone.

Fuel Type	Purchase Cost	Rebuild or Replacement Costs	Fuel Costs	Reduced Maintenance Costs	Total Costs If Reduced Maintenance	Total Costs If Same Maintenance
Gasoline	$17,000	$2,568	$59,481	$47,089	$126,139	$126,139
Diesel	$22,000	$1,351	$27,386	$47,089	$97,826	$97,826
LPG	$19,000	$2,568	$49,072	$37,176	$107,816	$117,729
CNG	$21,000	$2,568	$65,058	$37,176	$125,802	$135,715
Electric	$30,000	$5,147	$5,574	$15,696	$56,418	$87,810

Assumptions: 16 year equipment life; 6 year engine replacement interval for gasoline, LPG, and CNG; 8 year engine rebuild interval for diesel; 5 year battery life for electric; $2,500 unit cost for all rebuilds; $4,500 unit cost for all battery replacements, equipment used 8 hours per day for 350 days per year; idle is 40 percent of operating day; gasoline use is 3.2 gallons per hour at $0.75 (after tax credits) per gallon; diesel use is 1.7 gallons per hour at $0.65 (after tax credits) per gallon; LNG use is 3.3 gallons per hour at $0.60 per gallon; CNG use is 3.5 gallons per hour at $0.75 per gallon (including the cost of refueling facility operation and amortization); electric use is 8.33 kilowatts per operating hour; maintenance costs are $1.90 per hour for gasoline and diesel; maintenance costs are $1.50 per hour for LPG and CNG under a reduced maintenance scenario or $1.90 per hour under a “same maintenance” scenario; maintenance costs are $0.63 per hour for electric under a reduced maintenance scenario or $1.90 per hour under a “same maintenance” scenario.

Table 3. Life Cycle Costs for Baggage Tractors

References:

1. *Analysis of Techniques to Reduce Air Emissions at Airports*, Draft Final Report, prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency, September 1997.

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EMISSIONS AFTERTREATMENT

EMISSIONS AFTERTREATMENT

Basic Control Strategy Summary: The majority of GSE continue to emit pollutants at essentially uncontrolled rates. Certain emission species such as hydrocarbons (HC), carbon monoxide (CO), and, in some cases, oxides of nitrogen (NO_x) can be substantially reduced by the installation of a catalytic converter in the equipment exhaust system. Exhaust system traps (or filters) can perform similar reduction functions for particulate matter (PM). Catalyst technology has been well proven in on-road vehicle applications and particulate trap technology has advanced considerably over the last several years. Both systems are commercially available for equipment in the off-road sector, but long term reliability and effectiveness have not been proven. Systems designed for application on gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG) engines are available, but important issues for consideration in determining the practical application of these technologies include: installation costs, costs associated with the use of catalyst-compatible (i.e., non-poisoning) fuel blends and lubricating oils, exhaust system space constraints, increased exhaust and exhaust system temperatures, the compatibility of GSE operating cycles with effective conversion temperature requirements, and impacts on equipment reliability.

Potential GSE Equipment Affected: Generally, there are no theoretical limitations to the size or type of GSE that can be equipped with a catalytic converter or particulate trap. Effective converters have been designed for applications as small as lawn mower engines. In terms of practicality, however, both catalytic converters and particulate traps require sufficient exhaust system temperatures for high conversion efficiencies and, in the case of traps, effective regeneration. Therefore, equipment with very low load factors may experience extended periods of comparatively low exhaust temperatures, inhibiting both and catalyst and trap performance. Additionally, equipment that is operated only for brief periods between engine startup and shutdown may accumulate a significant fraction of its operating time in conditions where the catalyst has not yet attained the “light-off” temperature required for significant emissions conversion. However, the lack of actual test data for either catalyst or particulate trap performance on GSE (or other similarly sized and utilized equipment), renders it difficult to accurately assess the potential impacts of GSE operating cycles on exhaust aftertreatment system performance. The effectiveness of both certainly increases with operating temperature (up to the point where thermal degradation of catalyst materials occurs). Given the current data deficiency, the installation of catalyst or trap technology on GSE should be treated as developmental at this time and instances of system installation should be closely monitored until demonstrated performance data has been collected.

Oxidation Catalysts: Oxidation catalysts function by promoting the reaction of exhaust HC and CO with oxygen to form water and carbon dioxide. The required oxygen can be obtained by tuning the engine air/fuel mixture to the lean side of stoichiometry (i.e., the combustion air/fuel mixture is set so that there is excess air relative to that required for complete fuel combustion) or by introducing air into the exhaust system upstream of the catalyst. The latter approach, commonly referred to as secondary air injection, was widely utilized in the on-road vehicle sector during the 1970’s when oxidation catalyst technology was common. Although universally displaced by three-way catalysts in the on-road sector, oxidation catalyst technology is well developed and has been shown to be effective, providing appropriate operational procedures are observed.

In the typical oxidation catalyst, the water and carbon dioxide formation reactions are usually promoted using the noble metal platinum. Platinum effectively lowers the temperature at which the desired reactions take place. However, platinum (as well as other catalyst metals) is easily poisoned if proper precautions are not observed. Fuels, lubricating oils, and additives containing lead or phosphorus compounds should be avoided. Existing regulations should serve to ensure appropriate fuel composition, but phosphorus-containing lubricating oils are still available and should be replaced before any catalyst is installed.

Proper engine maintenance is also important in promoting both high catalytic conversion efficiencies and long catalyst life. Engines tuned to run overly rich, or cylinder misfire, can result in temperatures inside the catalytic converter shell (due to the temperature increases associated with excessive conversion reactions) which exceed the durability tolerances of both the catalyst and the substrate onto which it is coated. Prolonged exposure to excessive temperatures can cause the catalyst and substrate to sinter, increasing exhaust system backpressure, in extreme cases, to the point of engine failure. Proper engine maintenance is a critical aspect of any emission reduction strategy designed around the catalytic conversion of engine exhaust.

As already mentioned, optimum oxidation catalyst conversion efficiency is obtained when there is a high concentration of oxygen in the exhaust entering the catalyst. Maximum engine power, however, is obtained with combustion mixtures that are slightly rich (i.e., that have slightly less air than required for complete combustion) and many off-road engines are set to run in a rich mode to obtain maximum performance. For engines that are overpowered relative to operational demands, enleanment of the air/fuel mixture may be an acceptable means of providing required catalyst air, but enleanment will not be a viable approach for engines requiring full power to fulfill operational demands. For such engines, secondary air injection will be required to achieve high catalyst conversion rates.

Space is at a premium with all types of off-road equipment, including GSE. Equipment configuration and sizing are usually designed around a specific engine and exhaust configuration and, therefore, there is generally not sufficient “free” space to easily accommodate modifications. As a result, installing a catalytic converter even without an accompanying secondary air injection system can be problematic. The requirement for secondary air simply compounds this difficulty. Aftermarket catalyst manufacturers have responded to these space restrictions by combining muffler and catalyst functions into a single package that can be installed in place of the standard exhaust system muffler. Moreover, manufacturers have designed effective air breather valves and venturi nozzles into the upstream end of the catalyst/muffler shell to provide adequate secondary air so that compact, fully complete oxidation catalyst systems are available for most applications. The ability of these passive secondary air systems to provide adequate air for effective conversion on larger engines (six and eight cylinder) with lower amplitude exhaust pressure characteristics is potentially an issue, but no definitive conclusions can be reached as performance test data for such applications is not currently available.

Exhaust system temperatures can also be an issue of concern when considering the installation of a catalytic converter. Catalysts produce substantial increases in exhaust system skin temperatures and must be installed such that these increases are not a potential hazard, either through human contact or proximity to combustible materials. Most catalyst installations require heat shielding to ensure adequate safety, and space for such shielding can be an installation concern. Moreover, to avoid the potential for human contact with hot catalyst surfaces, an under-body or under-chassis installation location is generally preferred. Many currently marketed off-road catalysts are designed to replace conventional mufflers which are already isolated for the same heat-related concerns and, therefore, available installation locations may be acceptable (although heat shielding may still be required given the higher skin temperatures of catalysts relative to the mufflers they replace).

Oxidation catalysts can be purchased for gasoline, LPG, or CNG powered equipment. Specially constructed versions can also be purchased for diesel engine application. Diesel converters are generally larger than the mufflers they are designed to replace and, therefore, must be constructed in recognition of the specific space allowances of the targeted equipment. HC and CO emissions from diesel engines are generally quite low even without a catalyst. The primary diesel catalyst design criteria is the reduction of the soluble organic portion of diesel PM. In some cases, soluble organics can comprise up to 40 percent or more of total diesel PM.

Three-Way Catalysts: Three-way catalysts designed to promote the simultaneous oxidation of HC and CO and reduction of NO_x are also available for application in the off-road engine sector. These catalysts effectively promote reactions which add oxygen to HC and CO to form water and carbon dioxide and remove oxygen from NO_x to form molecular nitrogen and oxygen. Issues relating to such installations are much the same as those for oxidation catalysts, with the added issue of a required feedback system to control engine air/fuel ratio. Three-way catalysts only function effectively over a narrow range of air/fuel ratios (around stoichiometry), and it is critical that an effective air/fuel mixture control system be installed in conjunction with the catalyst if high conversion efficiencies are to be obtained. Such systems, which are commonly known as closed loop systems and are standard equipment on all light-duty on-road vehicles, function by monitoring the amount of oxygen in the exhaust system and adjusting the engine air/fuel mixture to maintain stoichiometry. Off-road engines and equipment generally do not incorporate closed loop feedback and, therefore, effective three-way converter installations must include the installation of such a system. Open loop systems (i.e., systems which do not monitor and adjust engine air/fuel mixtures) are available, but only effective in situations where very frequent engine checks and adjustments are the norm. Advanced aftermarket three-way catalyst systems include all appropriate closed loop hardware (i.e., the exhaust oxygen sensor, electronic control module, and throttle actuator) and detailed installation instructions.

Particulate Traps: The development of traps (or filters) designed to capture and burn the solid particulate commonly emitted by diesel engines has been advancing since the late-1980's, when it appeared as if such devices might be required for on-road heavy duty vehicles to meet stringent particulate standards. Although trap technology has never been required to meet PM standards in the on-road sector (even after the imposition of two rounds of more stringent standards beyond those originally thought to require traps for compliance - providing testament to the ingenuity of diesel engine manufacturers), major technology advancements have continued to occur and effective retrofit traps are available in the aftermarket. Early trap designs required an active element to combust collected particulate and regenerate trap capacity, but current designs function by incorporating a catalyst that effectively lowers particulate combustion temperatures into the filter material, thereby promoting filter regeneration during high load operating periods. As long as equipment duty cycles include periodic high load events, current generation particulate traps can effectively reduce diesel PM emissions without need for an active filter regeneration technology.

The issues surrounding the use of diesel PM traps on GSE are very similar to those associated with the installation and use of catalytic converters as described above. Space limitations are probably the most critical aspect of effective trap design because trap dimensions tend to be substantially larger than those of gaseous catalysts, but operating cycle considerations can be as important for some potential applications. The backpressure associated with particulate trapping increases steadily as more particulate is collected. If equipment operating cycles do not include sufficient periods of high load activity (promoting regeneration), this backpressure increase can influence equipment performance. Ideal GSE applications are those with relatively high load factors such that trap regeneration occurs routinely and backpressure is maintained at a low level. Particulate collection and combustion efficiencies of over 90 percent are attainable in properly designed traps applications.

Emission Impacts: No operational data is available from GSE catalyst or trap installations to assess the actual in-use emissions performance of these devices in the aircraft support environment. Available data is limited to catalyst and trap manufacturer test data on similar equipment such as industrial forklifts, and although there is no reason to expect that this data is flawed, it undoubtedly does not represent data collected under average in-use operating conditions. Moreover, these test data reflect conversion efficiencies immediately after converter or trap installation and do not represent measurements that might be expected after catalyst or trap aging has occurred. Nevertheless, there is sufficient evidence from the on-road sector to indicate that converters can maintain very high efficiencies given adherence to proper engine maintenance routines and vehicle operating procedures. If such procedures are followed, it is not unreasonable to expect emission reduction impacts similar to those presented in Table 1.

Oxidation catalyst HC reduction potential declines for both LPG and CNG engines due to the increasing concentrations of short chain hydrocarbons in the exhaust of such engines. Current catalyst technology is most effective on long chain hydrocarbons and a substantial fraction of compounds such as methane and ethane can pass through a catalyst without undergoing further oxidation. The substantial increase in CO_2 emissions results from an assumed backpressure increase as well as the oxidation of HC and CO, both of which are observed in high concentrations in uncontrolled GSE engines. However, increased backpressure accounts for only about two percentage points of the estimated increase, with CO conversion accounting for nearly all of the remainder.

Until such time as catalyst and trap performance has been consistently demonstrated in GSE applications and sufficient test data on in-use engines is available to confirm generalized emission reduction impacts, exhaust aftertreatment device installation and emission credits resulting therefrom should be treated on a case-by-case basis. Individuals applying for such credits should

Oxidation Catalyst Installation					
GSE Fuel	HC	CO	NO_x	PM	CO_2
Gasoline	90	90	0	10	up 60
Diesel	50	90	0	30	up 3
LPG	70	90	0	10	up 45
CNG	50	90	0	10	up 45
Three-Way Catalyst Installation					
GSE Fuel	HC	CO	NO_x	PM	CO_2
Gasoline	90	90	80	10	up 60
LPG	70	90	80	10	up 45
CNG	50	90	80	10	up 45
Particulate Trap Installation					
GSE Fuel	HC	CO	NO_x	PM	CO_2
Diesel	20	0	0	90	up 2

Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier "up" signify emission increases (in percent). CO_2 emission increases result from increased exhaust system backpressure and the oxidation of HC and CO, with CO oxidation accounting for the bulk of the estimated increase.

Table 1. Potential Emission Reduction due to Aftertreatment Device Installation (percent)

be required to perform standardized emissions testing on a representative sample of target GSE engines, both immediately before and after aftertreatment device installation as well as periodically thereafter. Ideally, additional concurrent emissions testing would be performed on a sample of otherwise identical control equipment which were not targeted for aftertreatment device installation. To defray the costs of such database development testing and encourage early aftertreatment device trials, a limited number of credits based on emission reduction expectations might be offered to airlines undertaking the necessary demonstration efforts to ensure that their pioneering work is recognized. In the interim, more detailed estimates of exhaust aftertreatment-driven emission reductions are speculative at best.

<u>Aftertreatment Device Costs</u>: The current aftertreatment device market for off-road engines such as those used in GSE is based on tailored device design and construction. Each potential application is subjected to equipment-specific design review and evaluation to determine potential device sizing restrictions and operating constraints. Only after such review is catalyst or trap fabrication undertaken. As a result, costs for initial equipment installations can be quite high. Even after initial design and construction, costs remain high relative to on-road aftermarket catalysts for two primary reasons. First, production volumes are limited due to the unique nature of many off-road applications and limited catalyst demand (current demand results primarily from Occupational Safety and Health Administration indoor air quality standards). Second, catalyst loading (i.e., the amount of catalytic material present in the aftertreatment device) is considerably higher than the typical loading for on-road catalysts. Limited catalyst size demands increased catalyst loading for high conversion efficiency. For these reasons, off-road catalysts of the type required in the GSE sector can cost on the order of $1,000 or more per unit (after initial design and fabrication costs).

Cost Effectiveness: Given the current state of the off-road aftertreatment device market, it is not possible to provide emission reduction cost effectiveness estimates. Such estimates will vary in accordance with the pre-installation emission rates of the target equipment, the conversion efficiency of the aftertreatment device, and the pollutants examined. Detailed cost effectiveness calculations should be performed in conjunction with any emissions testing program implemented to evaluate aftertreatment device potential.

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FIXED GATE SUPPORT

FIXED GATE SUPPORT

Basic Control Strategy Summary: While the majority of conventionally powered GSE can be either converted to or replaced by GSE powered by alternative fuels such as liquid petroleum gas (LPG), compressed natural gas (CNG), or electricity, a significant fraction of GSE can be eliminated entirely by incorporating fixed point-of-use support equipment into aircraft gate design. Such design not only eliminates all energy demands associated with moving displaced mobile GSE between aircraft gates and maintenance/storage facilitates, but also facilitates the use of "hard-wired" electrical power connections thereby eliminating the need for a recharging infrastructure and scheduling plan. Although as with electrically powered GSE, there is an increase in offsite power generating station emissions due to the increased demand for electrical power, fixed equipment is likely to consume less power than equivalent mobile GSE due the elimination of the motive aspect of GSE operation. Even when the increased emissions from power generating stations are considered, fixed electrically powered support equipment usually emit[*] significantly less hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), and carbon dioxide (CO_2) emissions than their mobile fossil fueled (i.e., gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG)) counterparts. Important issues for consideration are essentially limited to the capital and operating cost and reliability of fixed gate-based equipment.

Potential GSE Equipment Affected: Generally, the only technical limitations to the replacement of mobile GSE with gate-based fixed support equipment are manifested in those services which, by definition, require the manual movement of objects from one place to another. Cargo and baggage loading operations and, in some cases, passenger and service personnel transport are among the few operations which cannot be easily reduced or eliminated through the use of fixed gate-based equipment. The use of fixed gate-based power and conditioned air services has become quite common both in the U.S. and worldwide. Gate-based electrical connections eliminate not only the emissions associated with ground power units (GPU), but the majority of aircraft-based auxiliary power unit (APU) emissions[**] as well. Similarly, gate-based conditioned air support eliminates the use of equivalent traditional GSE. Other GSE that can be either eliminated or curtailed through the use of fixed gate-based equipment include: lavatory, fuel, water, food, and air start service equipment. In the most advanced cases, even mobile baggage tugs and belt loaders can be eliminated through the installation of a centralized conveyer belt-driven baggage distribution and delivery system that moves baggage directly from check-in counters to the gate. However, these systems are expensive and usually cannot be retrofitted to

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[*] Technically, electrically powered GSE do not emit any pollutants. The term emit, as used here, ascribes to the electric GSE, the offsite increase in power generating station emissions due to increased airport electrical power demands to support electric GSE recharging. In essence, the electrically powered GSE are treated as if they "emitted" the increased power generating station emissions associated with their use.

[**] During the period that aircraft main engines are shut down at the gate, aircraft still require power and often conditioned air to ensure that control system operations as well as passenger and crew comfort and safety are maintained.

existing terminal designs. Application of fixed baggage systems is really limited to new terminal construction and is not usually a viable emission reduction option for existing airport operations.

Fixed Equipment Installation Issues: The installation of fixed airport service equipment at new gates as well as retrofitting such equipment at existing gates is becoming more commonplace. In the U.S., most such installations are limited to an electrical supply (which either displaces a mobile GPU or curtails the use of an onboard aircraft APU) and possibly a conditioned air supply for aircraft use while at the gate (which also curtails the use of an onboard aircraft APU and displaces ground-based conditioned air GSE used in instances of non-functional aircraft APU). However, fixed gate fuel, lavatory, food, water, and air start services are also feasible.

Two general types of systems have been designed (and implemented) to provide fixed gate aircraft power services. Central power systems are based on a large main electrical control center within the airport facility that feeds individual aircraft gates through a distributed network. Conversely, point-of-use systems incorporate essentially independent controllers at each gate, each connected independently to the airport electrical power system. The point-of-use systems, due to easier, less intrusive, and less costly installation, as well as a reduced demand for preventive maintenance (in the centralized system, all gates are dependent on the functionality of the central power unit) have become the dominant choice for fixed gate-based power. Similar approaches have been employed for gate-based conditioned air services. Large centrally located chillers and control units with complex piping distribution systems have been operated, but have generally fallen into disfavor relative to independently powered and operated point-of-use systems.

In most gate-based installations, both aircraft power and conditioned air services are offered. However, in some cases only power services are available and, as a result, situations can arise when aircraft APU must be operated regardless of gate power availability. If conditioned air is demanded by weather conditions, the aircraft APU (or an on-ground, usually diesel fueled, GSE equivalent) must be operated either in conjunction with or in place of the gate-based power supply. Clearly, such a situation is not desirable and most airports opt to install both systems as a package. Airports in colder climates sometimes provide both services at only a fraction of available gates, based on the premise that conditioned air demands will be limited. However, it is not clear whether aircraft gate routing is modified in accordance with conditioned air demands or whether aircraft at non-equipped gates simply rely on APU usage during demanding weather conditions.

The majority of point-of-use fixed power and air systems are installed on the underside of gate passenger ramps and powered through electrical system cables designed to operate reliably in conjunction with the telescoping movement of the ramp. Other systems have been installed as “pop-up” units beneath surface of the gate apron. Either approach provides aircraft service personnel easy access to both aircraft and service connections and allows for quick service connection (and APU shutdown) upon aircraft arrival at the gate. APU use cannot be eliminated completely as APU operation is required during pre-flight checks and main engine startup, but use can be restricted to this period and APU usage for narrow body aircraft can be reduced from 40-45 minutes without fixed gate services to 5-7 minutes with fixed gate services. Wide body aircraft APU usage reductions can be even more dramatic, with APU use declining from 60-90 minutes or more without fixed gate service to 5-7 minutes with gate service.

Fixed-gate fuel, water, and lavatory services are somewhat more complex in that each require the availability of in-ground distribution systems or gate-based supply and storage tanks. Aircraft refueling is already generally accomplished using an in-ground hydrant system in conjunction with truck-mounted “hydrant-to-aircraft” equipment. This traditionally truck-mounted interface equipment can be replaced with equivalent fixed gate equipment, with equipment storage, reliability, and in-ground hydrant proximity being the only major technical concerns. Similar concerns, along with the added issue of water supply connectivity, exist for gate-based potable water service. Gate-based waste disposal concerns must be addressed in any installation of lavatory service equipment at the gate as traditional mobile GSE will continue to be required for any system based on simply installing gate-based transfer tanks.

Gate-based food and cabin supply service facilities can be relatively easily installed as add-on storage rooms at existing gates. While these storage facilities will not eliminate mobile GSE service entirely since supplies must be restocked and waste removed periodically, but gate storage will allow for a substantial reduction in mobile GSE use as multiple aircraft can be serviced through single re-supply and removal activities which can take place during periods of low aircraft activity.

Emission Impacts: The emission impacts due to the installation and operation of fixed gate services depends on three key factors: (1) the emissions performance of the equipment being displaced or curtailed, (2) for curtailed equipment, the reduction in equipment usage, and (3) the specific power generating characteristics of the region in which the airport is located.

Most GSE in operation today are unregulated from an emissions standpoint and, therefore, do not incorporate emission reduction technology in their design. A definitive calculation of displaced emissions due to equipment displacement or curtailment involves the measurement of the average emission rate of the displaced (or curtailed) fossil fueled GSE and the application of the activity data associated with the unit. A generalized expression of the necessary calculation of displaced emissions takes the form:

$$\frac{\text{emissions}}{\text{unit time}} = \frac{\text{grams}}{\text{brake hp - hr}} \times \text{hp} \times \text{load factor} \times \frac{\text{hours of use}}{\text{unit time}}$$

To calculate total displaced emissions, the emission rate per unit time (e.g., pounds per year) should be aggregated over the total time such emissions would have accrued. For example, if a displaced unit had an expected additional service period of four years after displacement, then emissions throughout this four year period would be displaced. Determining the overall longevity of emission reductions is an issue to be addressed since the emissions performance of displaced units may have changed during normal mobile equipment replacement cycles which are discontinued once fixed equipment is in place. In addition to emission reduction influences due to technology evolution, any future emission standards imposed on GSE will reduce the emission reduction benefits of fixed gate services by reducing the emission rate of displaced mobile GSE. Under any emissions control scenario, the emissions reduction benefits of switching from mobile GSE to fixed gate-based (electrically powered) services will depend on the specific fossil fuel being displaced since each has its own emissions characteristics.

Without definitive knowledge of exactly which mobile GSE are being displaced or curtailed for a given application, it is difficult to estimate the overall emission reduction potential of fixed gate services. Moreover, experience has shown that even when fixed gate services such as aircraft power and conditioned air are available, they are not always used. Whether such non-use is a result of airline practice (a recent EPA study found some airlines employing APU in place of fixed gate services about 50 percent of the time) or other factors is unclear, but the overall emissions reduction due to the installation of fixed equipment is certainly affected. Table 1 shows the estimated hourly-specific emission rates[*] for the various types of GSE that can be displaced or curtailed by the installation of fixed gate-based equipment. Operators can estimate the impacts at their specific facilities by selecting those specific equipment affected and applying the number of hours of curtailed use.

Not shown in Table 1 are the emission rates for aircraft APU which can also be displaced through the installation of fixed gate services. In fact, some of the largest emission reductions due to fixed gate services will accrue from curtailed APU usage. APU emission rates vary considerably across aircraft, averaging about 93 grams of HC, 1,055 grams of CO, and 542 grams of NO_x per operating hour but reaching as high as 360 grams per operating hour HC, 1,978 grams per operating hour CO, and 542 grams per operating hour NO_x. As indicated above, APU operating time can be reduced by 85-95 percent, or 35-40 minutes per narrow body gate service and 55-85 minutes per wide body gate service. Once these parameters have been established for a particular airport application, total APU emission reductions can be calculated as:

$$\frac{\text{emissions}}{\text{unit time}} = \frac{\text{grams}}{\text{operating minute}} \times \frac{\text{operating minutes reduced}}{\text{aircraft service event}} \times \frac{\text{aircraft service events}}{\text{unit time}}$$

Since fixed gate equipment uses electricity to power required pumps, compressors, etc., incremental power generation emissions must be subtracted from the emission reductions due to GSE displacement to derive net emission reductions. Therefore, airports served by relatively low emitting power generation facilities will produce larger emission reduction benefits than will accrue in areas served by older, higher emitting generating facilities. In the absence of definitive power consumption estimates for fixed gate-based equipment, the emissions associated with electrically powered GSE can be used to estimate net emission reductions. While fixed electrical equipment will likely consume less electricity per service event than mobile electric GSE due to the elimination of motive power demands, there are likely to be offsetting consumption losses during non-service periods. Therefore, assuming power generation emissions equivalent to those

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[*] The tabulated emission rate data was developed using data from the off-road emissions model recently released by the California Air Resources Board. Data used for this analysis included zero hour emission rates, emissions deterioration rates, equipment horsepower, equipment load factor, and brake-specific fuel consumption. See the information series selection entitled *GSE Emission Rates and Activity* for additional detail.

Gasoline (4-Stroke) Equipment					
Type of GSE	HC	CO	NO$_x$	PM	CO$_2$
Ground Power Units	533	34,560	482	3	89,148
Conditioned Air Units	462	29,952	417	3	77,261
Lavatory Carts	80	2,465	25	2	7,780
Lavatory Service Trucks	154	9,984	139	1	25,754
Fuel Service Trucks	154	9,984	139	1	25,754
Water Service Trucks	142	9,216	128	1	23,773
Food Service Trucks	171	11,059	154	1	28,527
Air Start Units	555	35,942	501	4	92,714
Gasoline (2-Stroke) Equipment					
Type of GSE	HC	CO	NO$_x$	PM	CO$_2$
Lavatory Carts	1,254	1,866	5	39	11,238
LPG Equipment					
Type of GSE	HC	CO	NO$_x$	PM	CO$_2$
Ground Power Units	267	21,600	361	2	74,747
Conditioned Air Units	231	18,720	313	2	64,781
Lavatory Carts	43	1,505	13	1	6,523
Lavatory Service Trucks	77	6,240	104	1	21,594
Fuel Service Trucks	77	6,240	104	1	21,594
Water Service Trucks	71	5,760	96	1	19,933
Food Service Trucks	85	6,912	116	1	23,919
Air Start Units	277	22,464	376	2	77,737
Diesel Equipment					
Type of GSE	HC	CO	NO$_x$	PM	CO$_2$
Ground Power Units	109	493	1,280	73	68,941
Conditioned Air Units	231	1,038	2,735	159	136,153
Lavatory Carts	9	30	60	6	5,619
Lavatory Service Trucks	33	147	383	22	20,603
Fuel Service Trucks	45	204	530	30	28,527
Water Service Trucks	30	136	353	20	19,018
Food Service Trucks	34	154	400	23	21,554
Air Start Units	553	2,491	6,564	382	326,766

Table 1. Emission Rates for Potentially Displaced GSE (grams/operating hour)

associated with mobile electric GSE (see the information series selection entitled *Electric GSE* for more information) should provide a reasonably accurate estimate of incremental utility emissions due to the installation and operation of fixed equipment. These estimates will, of course, need to be replaced with estimates derived from actual fixed gate-based equipment power consumption data once fixed unit models and operating data have been established.

Regardless of the incremental power generation emissions, HC and CO emission reductions will be dramatic (approaching 100 percent). However, NO_x, PM, and CO_2 reductions can vary considerably. Table 2 presents the sensitivity of electrical equipment emission reductions to the range of power generating facilities in operation in the U.S. As indicated, the dependence of emission reductions on power generation practices can be dramatic. For example, NO_x reductions due to the displacement of gasoline GSE can range from 40 to 99+ percent and the potential range of CO_2 reductions is nearly as wide at 40 to 80 percent. PM emissions can, as indicated, increase substantially under the highest emission power generation conditions, but can also decline by as much as 90 percent under other power generation conditions. Both the highest and lowest power generation scenarios are equally unlikely to be applicable to any given GSE displacement scenario. The highest emission scenario represents an uncontrolled coal-fired application while the lowest emission scenario represents a “maximum controls” (regardless of cost effectiveness) natural gas application. There may be a few specific instances (e.g., California airports) where actual power generation emissions approach those of the low emissions scenario, but generally emission reductions are more likely to approximate those of the tabulated “average” scenario which is based on the average of measured emission rates for six geographically diverse U.S. utilities. Therefore, installation of fixed gate-based equipment should generate substantial emission reductions at most U.S. airports.

Costs: Several previous studies of actual fixed gate-based power and conditioned air installations have demonstrated the economic cost effectiveness of such systems. In general, these systems, which carry installation costs ranging from about $50,000 for narrow body aircraft gate service to about $130,000 for wide body aircraft gate service, have been shown to completely pay for themselves in less than one year through savings in APU fuel and maintenance costs. Net savings are estimated to be about $200 per day for narrow body aircraft gate service and $400 per day for wide body aircraft service. Expanding fixed gate-based services to include water, lavatory, fuel, and catering facilities has been estimated to add another $20,000-$50,000 to installation costs (per gate based on a complete 12 gate terminal installation). Based on the operating and maintenance cost savings of GSE displacement alone, these services are not as economically cost effective as gate-based power and air systems. However, additional cost savings may accrue from reduced labor requirements for aircraft service, faster aircraft cycling time allowing more aircraft to be serviced per gate, reduced gate congestion, and less frequent GSE accidents.

Cost Effectiveness: It is difficult to provide precise cost effectiveness estimates for fixed gate-based equipment because the impact of such equipment varies in accordance with the pollutants examined, the scope of fixed services offered, the fueling characteristics of the equipment being displaced, and the emissions performance of local utilities. However, as discussed above, gate-based power and conditioned air systems have been demonstrated to be costs effective on a purely economic basis and, therefore, all derived emission reductions due to the installation of these services accrue for free. The installation of additional services may be cost effective, but a definitive determination will require airport-specific analysis.

Percent Reduction[1] from Gasoline (4-Stroke) GSE

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.9	100.0	98.1	88.9	77.9
Worst Case	98.2	99.9	38.5	up 3328.4	41.2
Average Case	99.4	100.0	90.2	42.4	56.2

Percent Reduction[1] from LPG GSE

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.8	100.0	97.4	88.9	73.6
Worst Case	96.3	99.9	18.0	up 3328.4	29.9
Average Case	98.9	99.9	86.9	42.4	47.8

Percent Reduction[1] from Diesel GSE

Utility Scenario[2]	HC	CO	NO_x	PM	CO_2
Best Case	99.5	99.3	99.4	99.6	75.2
Worst Case	92.4	96.4	81.8	up 33.8	34.0
Average Case	97.7	97.9	97.1	97.8	50.8

[1] Unsigned and unqualified values signify emission reductions (in percent). Values preceded by the qualifier “up” signify emission increases (in percent)

[2] Utility (i.e., power generating station) emissions will vary in accordance with local electricity generation practices. Major factors include boiler design, boiler fuel, and emission controls in place. The best case scenario represents potential emission reductions if GSE electrical demand is satisfied by a generating station firing natural gas and employing maximum controls. Conversely, the worst case scenario represents potential emission reductions if GSE electrical demand is satisfied by a generating station firing coal under essentially uncontrolled (from an emissions standpoint) conditions. The average case represents a more typical level of emission reductions and is based on actual emission rates for a geographically diverse sample of utilities.

Table 2. Estimated Emission Reductions Due to the Use of Electric GSE

References:

1. *Analysis of Techniques to Reduce Air Emissions at Airports*, Draft Final Report, prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency, September 1997.

2. *Air Pollution Mitigation Measures for Airports and Associated Activity,* prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, May 1994.

3. *Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, August 1995.

4. "All the Power You Need," product literature from Hobart Ground Power, 1996.

5. "JETLINK," product literature from FMC/Jetway Systems.

6. "The Vehicle Free Ramp," product literature from FMT.

7. *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources,* Chapter 1 (External Combustion Sources), as downloaded on July 29, 1998 from the U.S. EPA internet website www.epa.gov/ttn/chief/ap42.html.

GSE CONTROL STRATEGY SUMMARY

GSE CONTROL STRATEGY SUMMARY

Background: Aircraft ground support equipment (GSE) represent one of three groups of mobile emission sources at airports. Together with aircraft and ground access vehicles, GSE contribute a small but significant share of the hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulate matter (PM) emitted in metropolitan areas. Today, total emissions from these three source categories comprise on the order of 2-3 percent of total manmade emissions in a typical metropolitan area, but this share is expected to increase as air travel continues to grow while emissions from other, non-airport sources are subject to increasingly stringent controls. An evaluation of GSE and associated service demands indicates that there are several control strategies that offer the potential to reduce emissions over both the long and short terms. Such strategies include both demonstrated and innovative technologies and all have associated issues which must be considered prior to implementation, but a generalized classification includes:

- The development of new engine emission standards for all currently unregulated equipment;
- The replacement or conversion of gasoline or diesel powered GSE to liquid petroleum gas (LPG) or compressed natural gas (CNG) fueling;
- The replacement or conversion of gasoline, diesel, LPG, or CNG powered GSE to electric power;
- The replacement of mobile GSE with electrically powered fixed gate-based equipment;
- The retrofit of existing GSE with catalytic converters or particulate traps; and
- The preferential replacement of existing two-stroke gasoline engines.

As expected, both the feasibility and cost effectiveness of emission reductions vary considerably across the potential control strategies. The following sections provide an overview of the major issues associated with each strategy and, where possible, provide an estimate of associated emissions reduction and cost effectiveness. Because all strategies will involve some application and site specific dependencies, each ultimately needs to be evaluated in the context of the specific conditions in place at the target airport(s). Moreover, to the extent that airlines or airports are encouraged to undertake strategies on a voluntary basis in return for marketable emission credits or alternative incentive rewards, the cost effectiveness of individual controls can be greatly dependent on the (as yet undefined) value of the credit or incentive reward. Nevertheless, a general ranking of the likelihood of implementation is possible, and the discussions below are presented in general order of increasing to decreasing likelihood.

New Engine Emission Standards: The development of new engine emission standards is not a control strategy that can feasibly be implemented on an airport-specific basis. Its inclusion here is simply intended to place the remaining control strategies, which can be implemented locally, in a proper context. Only the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) have the authority to set new engine emission standards and both have established standards, or are currently in the process of doing so, for several categories of off-road engines used in GSE. Spark-ignition engines rated at 25 horsepower or less and produced for California sale beginning in 1995 or national sale beginning in 1997 are subject to CARB and EPA standards respectively. Although such engines are not found in a large fraction of GSE, they do exist in small numbers in such applications as lavatory cart pumps. Of greater impact on GSE are standards for off-road compression-ignition (i.e., diesel) engines. First round standards adopted by EPA and CARB took effect in 1996 and 1995 respectively and a second set of more stringent standards is slated to be phased in beginning in 1999. Ultimately, these standards will affect all diesel GSE engines (currently about one-third of the total GSE engine population), reducing emissions of HC, CO, and especially NO_x and PM by substantial margins.

Currently, no emission standards have been adopted for off-road spark-ignition (e.g., gasoline) engines rated at greater than 25 horsepower. About 60 percent of all GSE engines fall into this category. Many such engines are derived from 1980's-era automobile engines and, in recognition, CARB is currently in the early development stages of regulatory standards for this engine category based on a level-of-control equivalent to that associated with the installation of closed-loop three-way catalyst aftertreatment systems. Initial plans cite a proposed phase-in of such standards beginning in 2001. The EPA has not yet made any formal announcements of a planning process for emission standards applicable to this engine category (CARB standards will only affect engines built for sale in California), but it is likely that such a process will eventually be undertaken.

Most, and probably all, new GSE engines will ultimately be covered by stringent emission standards. Stringent standards affecting diesel GSE engines have been formally proposed and standards affecting larger spark-ignition (i.e., gasoline, LPG, CNG, etc.) GSE engines are probably not far off. However, since even the already-adopted off-road engine standards have only recently taken effect, almost all in-use GSE engines not certified for on-road use (i.e., between 75 and 90 percent of all GSE) are uncontrolled from an emissions standpoint. Considering the rate of GSE engine turnover, it is likely that uncontrolled engines will continue to dominate the GSE fleet at least through 2010. Clearly, new engine emission standards are a longer term approach to reducing GSE emissions. To achieve short term emission reductions, control strategies affecting the GSE engines already in use must be explored. Such short term approaches are the focus of this summary document and the companion GSE Information Series documents.

In considering the emission reduction and cost effectiveness estimates presented in this and companion documents, it is critical that the reader recognize that baseline GSE emission rates are assumed to be uncontrolled. Relative to engines certified to emission standards in effect either now or in the future, the emissions reduction potential and cost effectiveness estimates presented for the short term control strategies will be greatly overstated. These estimates are valid only in the context of targeting reductions from GSE engines not certified to meet the evolving new engine emission standards. Over the short term, this restriction poses few if any concerns. However, over time, controlled engines will enter the GSE fleet and gradually (over the next 10 to 15 years) reduce or even negate the effectiveness estimates presented below. As this occurs, revised estimates of control strategy effectiveness relative to the controlled engine emission levels will be required.

Replacement or Conversion to LPG/CNG Power: Both LPG and CNG offer the opportunity to reduce emissions from conventionally powered GSE. While both gasoline and diesel GSE are candidates for replacement equipment powered by LPG or CNG, the conversion of existing equipment is more suitable to gasoline powered GSE. For the most commonly available LPG and CNG technologies, an active ignition system, as found on gasoline engines, is required to initiate combustion. As a result, the conversion of compression-ignition diesel equipment is more complicated (and expensive) than the similar conversion of gasoline equipment. Technologies such as pilot injection/fumigation systems have demonstrated the ability to combust gaseous fuels in diesel engines without active ignition systems, but these technologies are generally recognized as developmental and do not reflect typical diesel conversion technology, which includes the installation of an active ignition system.

Both CNG and LPG are currently available as factory options for most GSE. These options generally reflect high quality design and installation and carry full manufacturers warranties. However, conversions of existing engines can vary considerably in terms of quality and performance. In principle, the conversion to LPG or CNG power is fairly simple, requiring in the simplest cases only the installation of a new fuel tank and new fuel delivery and metering systems. But achieving good performance and low emissions simultaneously can be quite challenging and, as a result, a large percentage of conversions never achieve the emissions reduction potential of either LPG or CNG. In some cases, emissions performance actually declines relative to pre-conversion emissions. To aid in overcoming such problems, advanced low emissions conversion kits include a closed-loop combustion control system capable of continuously adjusting the combustion charge air-fuel ratio in accordance with exhaust gas characteristics. Even so, the calibration of equipment conversions is as much art as science and should only be performed by qualified, experienced personnel to ensure low emissions while maintaining good engine performance. Such quality conversions can achieve emissions performance equivalent to factory installed replacement equipment.

Under a scenario in which emission reduction credit (either marketable or State Implementation Plan credit) is granted for GSE conversion, it will be necessary to impose certain restrictions to ensure claimed emission reductions are actually achieved. Both the EPA and CARB have established certification procedures for on-road engine conversion kits, but the application of these procedures to off-road GSE engines will be difficult until such time as emission standards for such engines are in place (generally the EPA and CARB procedures demonstrate compliance with an emission standard not quantify a specific emission level). Nevertheless, a variation of the on-road process designed to establish a "maximum warranted emission rate" could be adapted to the certification of off-road engine conversion kits. Warranty requirements for kit manufacturers and installation requirements for kit installers, as well as non-compliance penalties, would add necessary incentives to ensure that claimed reductions are achieved. Periodic emission testing requirements might also be imposed throughout the life of any emission reduction credit. In the absence of a formal certification program, certain conversion kit requirements might be established to provide a minimally acceptable guarantee of low emissions. For example, kits which do not include closed-loop combustion control systems might be excluded from any program assigning emission reduction credits. For purposes of this document, it is assumed that an appropriate low emissions compliance program is in place and that converted equipment emissions performance is similar to that of factory installed replacement equipment. If such performance levels are not achieved in practice, the emission reduction impacts presented below will be overstated.

Table 1 presents an estimate of the emission impacts associated with the replacement or conversion of GSE to LPG or CNG power. Relative to gasoline GSE, emissions of HC, CO, NO_x, and PM as well as carbon dioxide (CO_2) are all expected to decline. Relative to diesel GSE, significant reductions in both NO_x and PM are expected, while minor CO_2 changes and significant increases in both HC and CO occur. These latter increases are a function of the inherently low HC and CO emissions associated with diesel engines. While the overall mass emissions increase of both pollutants is modest relative to the quantity of HC and CO emitted by gasoline GSE (as indicated, both LPG and CNG are expected to emit lower levels of HC and CO than gasoline GSE), the percentage change as measured from a very small baseline is substantial. For example, with new (uncontrolled) engine CO emission rates of about 5 grams per brake horsepower-hour (g/bhp-hr) for diesel GSE, 150 g/bhp-hr for LPG GSE, and 250 g/bhp-hr for gasoline GSE, it is easy to see that while the 145 g/bhp-hr CO increase between LPG and diesel engines represents a 2,900 percent increase, the absolute emissions increase still places the LPG CO emission rate at only about 60 percent of that of gasoline GSE. In-use deterioration further expands the difference between diesel and LPG engines, but does not significantly alter the LPG/gasoline relationship.

Therefore, relative to gasoline, a switch to LPG or CNG power will result in net emission reductions regardless of the particular pollutant of interest. Relative to diesel, LPG and CNG are effective emission reduction strategies for NO_x and PM, but those reductions come at the cost of increases in HC and CO.

	Emissions Relative to Gasoline GSE		Emissions Relative to Diesel GSE	
	LPG	CNG	LPG	CNG
HC	-50% to -65%	-65% to -75%	+95% to +140%	+30% to +60%
CO	-40% to -50%		+4000% to +5000%	
NO_x	-20% to -25%		-75% to -80%	
PM	-20%		-95%	
CO_2	-15%	-20%	-5% to +15%	-10% to +10%

Table 1. Emission Impacts of LPG and CNG GSE

The replacement cost premium for LPG GSE relative to gasoline GSE is estimated to be similar to the cost of conversion at $2,000-$3,000 per unit. For CNG, first cost premiums are higher due to the need for high pressure fuel storage, at $4,000-$4,500 per unit. Because off-road equipment users are provided a one-for-one tax credit against gasoline and diesel fuel taxes, the fuel cost savings associated with LPG and CNG usage in the on-road sector are substantially diminished. In fact, while LPG is estimated to provide a net savings of about $0.10 per gasoline equivalent gallons of fuel used, the cost of CNG is not expected to be significantly different than the cost of an equivalent quantity of gasoline. Over the long term, maintenance costs for both LPG and CNG are expected to be 20-25 percent lower than conventional fuel maintenance costs, but this improvement has yet to be observed in-use due to a high rate of occurrence of LPG/CNG equipment problems. This trend should disappear as experience is gained and equipment becomes more reliable but observational support is lacking at this time.

Table 2 presents an estimate of life cycle costs for baggage tractors (which constitute up to 25 percent of all GSE) powered by the various fuel options. While absolute costs will vary somewhat for other types of GSE, the relative relationships across fuel types will be similar. Regardless of whether maintenance costs are reduced or not, LPG equipment is cost competitive with gasoline GSE. Conversely, CNG is only cost competitive under a reduced maintenance, high equipment usage scenario. In all cases, diesel GSE are estimated to be the least cost alternative when no definitive value is assigned for emissions performance.

Although emissions valuation can alter life cycle cost relations, it is difficult to place a generic value on emissions reduction. Emission reductions of high value in one area can be of marginal or negative value in another. Therefore, a specific emissions valuation strategy must be implemented before a definitive assessment of the impact on life cycle costs can be made. Nevertheless, some

	Gasoline	Diesel	LPG	CNG
High Equipment Usage Scenario (Hub-Type Airport)				
Reduced Maintenance[1]	$126K	$98K	$107K	$126K
Same Maintenance	$126K	$98K	$118K	$136K
Average Equipment Usage Scenario (Non-Hub Airport)				
Reduced Maintenance	$53K	$47K	$49K	$56K
Same Maintenance	$53K	$47K	$52K	$59K

[1] The "reduced maintenance" scenario assumes LPG and CNG maintenance costs are 20 percent lower than gasoline and diesel maintenance costs. The "same maintenance" scenario assumes all four GSE types possess similar maintenance costs.

Table 2. Life Cycle Costs for Baggage Tractors

general observations are possible. First, under any scenario in which a positive value is assigned to either HC or CO reductions, the life cycle cost advantage of diesel GSE will be enhanced due to the inherently low HC and CO emission rates of diesel engines. If NO_x emission reductions alone are valued, a value of $1,000-$2,000 per ton will render LPG life cycle costs competitive with diesel GSE costs. A value of $3,000-$4,000 per ton of NO_x will render CNG GSE cost competitive with diesel. To achieve diesel cost competitiveness on the basis of PM reductions alone requires a substantially higher per ton valuation, on the order of $10,000-$20,000 per ton for LPG and $30,000-$40,000 per ton for CNG. Of course, the PM reductions are derived for free if NO_x is also valued at the rates previously indicated.

In summary, it is apparent that replacement or conversion of both gasoline and diesel GSE to LPG or CNG can provide significant emission reductions relative to current uncontrolled baseline emission rates and be cost competitive under reasonable emissions valuation scenarios. In fact, LPG GSE is cost competitive with gasoline GSE regardless of emissions reduction value. However, in cases where emissions reduction is not assigned a marketable value (as is the case under current market conditions), diesel GSE is overwhelmingly the least cost option relative to gasoline, LPG, and CNG. This is consistent with recent movement in the GSE sector toward a greater utilization of diesel equipment. It is, therefore, likely that some definitive incentive will need to be instituted before large scale shifts in the GSE fleet toward either LPG or CNG will be observed.

<u>Replacement or Conversion to Electric Power</u>: Virtually all GSE, regardless of current fueling option, are candidates for conversion to electric power or replacement with electrically powered equipment. GSE manufacturers currently offer an electric power option on a wide range of equipment types, while several firms (most centered in California) offer aftermarket conversions to electric power. The issues of range and performance which continue to dampen the acceptability of electric vehicles in the on-road sector are largely eliminated or controlled in the operating environment of GSE. Clearly, such operations are restricted to a small geographic area so that proximity to battery recharging or replacement centers (once in place at the airport) is not an issue. Additionally, most GSE duty cycles consist of short periods of high load operation followed by extended periods of idle or engine-off. Since electric GSE consume no power under either mode, both the total time between battery discharge cycles and the amount of time available for opportunity charging can be significant. On-road performance concerns such as top speed and grade handling ability are usually not of concern in airport settings where grade is limited and speed restrictions are present regardless of fuel.

The emission impacts associated with the use of electric GSE can vary with local power generating characteristics. While electric GSE emit no pollutants in the conventional sense, they do place an additional demand on local power generating stations and the emissions associated with this additional demand are a direct result of electric GSE use. Table 3 presents estimates of the emission impacts of electric GSE. To provide an indication of the dependence of emission reductions on local power generating characteristics, Table 3 presents minimum, maximum, and typical emission reduction estimates. The minimum reductions reflect impacts assuming uncontrolled coal-fired power generation, while the maximum reductions reflect impacts assuming a "maximum controls" (regardless of cost) natural gas-fired power generation scenario. Typical

	Relative to Diesel	Relative to Gasoline	Relative to LPG/CNG
HC	-90% to -99% (-98%)	-98% to -99.9% (-99%)	-96% to -99.9% (-99%)
CO	-96% to -99% (-98%)	-99.9% to -99.9% (-99.9%)	-99.9% to -99.9% (-99.9%)
NO_x	-80% to -99% (-97%)	-40% to -98% (-90%)	-20% to -97% (-85%)
PM	+30% to -99% (-98%)	+3500% to -90% (-40%)	+3500% to -90% (-40%)
CO_2	-25% to -70% (-45%)	-40% to -80% (-55%)	-30% to -75% (-50%)

Table 3. Emission Impacts of Electric GSE

emission impacts are based on average emission rates observed across a sample of geographically diverse power generating stations and should reflect a good estimate of the emission impacts expected in most circumstances. Neither the minimum or maximum reductions are reflective of likely impacts in any, except the most atypical, area. Therefore, while actual impacts will require a local analysis for confirmation, the tabulated typical impacts should provide a good indication of the emission reduction potential of electric GSE.

Clearly, the emission reduction potential associated with the use of electric GSE is dramatic compared with all four internal combustion engine (ICE) fuels. Under any scenario, HC and CO emissions are nearly eliminated. The same is typically true for NO_x and PM relative to diesel GSE. The variation in potential NO_x reductions relative to gasoline, LPG, and CNG GSE is a bit wider, but typical reductions approach 90 percent for all three fuels. Because PM emissions from the three fuels are substantially lower than those of diesel GSE, electric vehicle PM reductions are typically smaller than HC, CO, and NO_x, but still significant. In all but the most extreme cases, replacement or conversion of ICE-powered equipment can be expected to generate large emission reductions for all pollutants, including CO_2.

Electric GSE carry a significant purchase or conversion price premium of $10,000-$15,000 relative to gasoline GSE or $8,000-$10,000 relative to diesel GSE. This initial price premium is further compounded by periodic battery replacement requirements (every five years or so) that are twice as expensive as the alternative engine replacement or rebuild requirements associated with ICE-powered GSE. However, electric vehicle fuel savings are significant, not only because of lower unit fuel costs, but because no power is consumed during equipment idle periods. Fuel savings relative to diesel GSE can reach $2,500 per year under a high equipment usage scenario and approach $1,000 per year for average usage. Fuel savings relative to gasoline and CNG can be twice that relative to diesel, with LPG savings between the two extremes. Electric GSE, are expected to have reduced maintenance costs relative to ICE-powered GSE, but like CNG and LPG equipment, first generation electric GSE were prone to high maintenance and were also found to be inefficient and under-powered. Users of second generation electrics have reported significant improvements in all three areas and expectations of long term maintenance cost reductions on the order of 70 percent now appear viable. Nevertheless, electric GSE batteries require frequent and careful maintenance checks to ensure long battery life and keep replacement costs to a minimum.

Life cycle cost estimates for the various ICE-powered GSE were previously presented in Table 2. Table 4 reviews these estimates and adds similarly calculated life cycle cost estimates for electric GSE. Once again, while the tabulated costs are specifically calculated for baggage tractors, the relative relationships across fuels will be similar for other GSE types. Strikingly, electric GSE possess the lowest life cycle costs under all but the same maintenance/average usage scenario and even then electric GSE costs are competitive with the other fueling options. For a highly trafficked airport, electric GSE are clearly the lowest cost option. This is also true for lesser trafficked airports if electric GSE durability expectations are achieved in-use. Moreover, these relations are based on calculations which do not include any valuation for emission reductions. In most cases, electric GSE are cost effective on a purely economic basis alone.

Based on these relationships, a greater utilization of electric GSE is a reasonable future expectation and any such increase will provide significant emission reductions. Nevertheless, there are institutional barriers which must be overcome before large scale penetration can be expected. The poor reputation inspired by inefficient, under-powered, and high maintenance first generation electric GSE must be overcome though a demonstrated service reliability by the new second generation equipment. If the new electric GSE can demonstrate an in-use reliability equivalent to that of conventional GSE, greater penetrations will be observed. Additionally, recharging infrastructure enhancements will be required at airports to support significant electric

	Gasoline	Diesel	LPG	CNG	Electric
High Equipment Usage Scenario (Hub-Type Airport)					
Reduced Maintenance[1]	$126K	$98K	$107K	$126K	$56K
Same Maintenance	$126K	$98K	$118K	$136K	$88K
Average Equipment Usage Scenario (Non-Hub Airport)					
Reduced Maintenance	$53K	$47K	$49K	$56K	$42K
Same Maintenance	$53K	$47K	$52K	$59K	$52K

[1] The "reduced maintenance" scenario assumes LPG and CNG maintenance costs are 20 percent lower and electric GSE maintenance costs are 70 percent lower than gasoline and diesel maintenance costs. The "same maintenance" scenario assumes all five GSE types possess similar maintenance costs. For electric GSE, both maintenance scenarios assume frequent, effective battery maintenance checks to ensure long battery life.

Table 4. Life Cycle Costs for Electric Baggage Tractors

GSE penetrations. Should these barriers be overcome, it is not unreasonable to expect significant movement toward an electric GSE fleet. Providing additional incentive by placing a definitive value on associated emission reductions may be sufficient to accelerate this movement.

Replacement of GSE with Electrically Powered Fixed Gate-Based Equipment: A substantial number of the services currently provided by mobile GSE can be performed by electrically powered equipment installed in a fixed position at each aircraft gate. Initial movements in this direction have already taken place at many U.S. airports where fixed gate-based equipment has been installed to handle the electrical power and conditioned air requirements of aircraft. This equipment displaces not only GSE ground power and conditioned air units, but high emission rate aircraft auxiliary power units (APU) as well. Additional GSE types which are also candidates for replacement include: fuel, water, catering, and compressed air service as well as somewhat more difficult to replace baggage and aircraft pushback tractors.

Many airports have already recognized the cost effective nature of fixed gate-based power and conditioned air systems. Gate-based units capable of providing the 400 Hz electrical service demanded by aircraft are being installed at an increasing number of airports. At gates without such systems, the power necessary to operate critical aircraft systems is usually provided by an on-board APU (a small jet engine) or, when the APU is out-of-service, a mobile GSE ground power unit. Due to the length of time a typical aircraft spends at the gate (relative to the time spent approaching, landing, taxiing, and taking off from an airport), APU emissions can be responsible for 10-30 percent of the HC, 40-80 percent of the CO, and 30-60 percent of the NO_x emitted by aircraft during a typical landing and takeoff (LTO) cycle (which, from an airport emissions standpoint, begins and ends when the aircraft enters and leaves the tropospheric mixing zone). Although APU emissions cannot be completely eliminated due to the need for APU operation during engine startup, overall APU emissions can be reduced by up to 90 percent. As a result, the emission reductions derived from the installation of fixed gate-based electrical power units far exceed those derived from the replacement of ICE-powered GSE ground power units with mobile electric GSE.

In most cases, fixed gate-based conditioned air service is installed in conjunction with gate-based electrical power service. These two services go hand-in-hand, because in the absence of ground service both will be supplied using power generated by the aircraft APU. Therefore, if climatological conditions demand conditioned air service during aircraft gate periods, the aircraft APU (or alternative GSE conditioned air unit) will be operated even if gate-based electrical power is available. In such situations, the emissions reduction effectiveness of gate-based electrical power is completed negated.

As might be expected, gate-based electrical power and conditioned air service have substantial initial costs. Such costs can range from $50,000-$130,000 per gate (for the most popular point-of-service systems[*]) depending on the type of aircraft serviced (i.e., narrow body versus

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[*] Generally, two types of gate-based services are available. Point-of-use systems rely on dedicated equipment installed at each aircraft gate. Centralized systems use large centrally located equipment, supported by a network distribution system to transfer power and conditioned air to individual airport gates. The point-of-service systems

wide body), but because of the very high operating costs of aircraft APU, associated cost savings can reach $30-$50 per hour. At highly trafficked airports, such operating cost savings result in payback periods of less than one year. While the payback period might be several years for less highly trafficked airports, fixed gate-based power and conditioned air systems are cost effective from a purely economic standpoint and as recognition of this cost effectiveness continues to increase, more and more airports are adopting fixed gate-based power and conditioned air service. Placing a marketable value on the associated emission reductions can only serve to accelerate a process that is already underway.

"Vehicle free" gate systems represent a longer term goal. Stationary fuel, water, and lavatory hookups can be installed at airport gates, but each require a fairly complex distribution system to completely eliminate the GSE currently providing these services. The installation of gate-based food and supply storage rooms can greatly reduce GSE catering service demand. Centralized baggage conveyors which distribute baggage from check-in points to aircraft gates can displace GSE baggage tractors (which alone represent up to 25 percent of all GSE), but such systems are very difficult to retrofit into existing airports. Automated aircraft pushback systems offer the potential to displace GSE pushback tractors. All of these services are technically feasible at this time and, in fact, have been installed at a few European airports such as Arlanda in Sweden. However, these systems are much less cost effective than the gate-based power and air systems described above since operating cost savings do not approach those associated with the shutting down of aircraft APU. Nevertheless, actual cost effectiveness must be determined on the basis of local airport conditions and the specific services targeted. Marketable emission credits may accelerate the installation of vehicle free gate demonstration technologies, but are more likely to influence replacement of ICE-powered mobile GSE with mobile electric alternatives due to similar emission reductions and much lower capital cost requirements.

Installation of On-Road Type Emissions Aftertreatment Devices: As discussed above, many current GSE engines are similar to those used in 1980's-era automobiles. In recognition of this, CARB is in the early stages of proposing new engine emission standards equivalent to the level-of-control possible through the use of three-way catalytic converters. Catalysts have been in use in the on-road vehicle sector for 25 years and have demonstrated the capability to maintain high emissions conversion efficiencies throughout the useful lives of passenger cars and light trucks. However, it must be recognized that one reason catalyst effectiveness and durability have advanced to their current state in the on-road sector is that vehicle manufacturers have designed complete combustion control systems around the aftertreatment equipment. Unleaded gasoline, highly effective stoichiometric air-fuel mixture control systems, and current discussions to limit fuel sulfur content are but examples of the advances made (or proposed) to accommodate emissions aftertreatment. Notwithstanding the fact that current GSE engines and engine controls are not manufactured to support today's sophisticated automotive aftertreatment devices, retrofit of devices such devices or their less sophisticated predecessors is possible. For gasoline, LPG, and CNG GSE, potential aftertreatment devices include both three-way and oxidation catalysts while diesel aftertreatment, due to excess air combustion characteristics, are limited to oxidation catalysts and particulate traps

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generally have lower capital costs and can be installed with less service disruption.

While there are no theoretical limitations to the retrofit of catalyst or particulate trap technology on GSE, there are several practical issues regarding both installation and operation. Off-road engine powered GSE are open-loop systems in that they do not have combustion control feedback systems to adjust combustion air-fuel mixture as necessary to promote aftretreatment efficiency. Therefore, the simplest catalyst installations will be limited to oxidation-only catalysts which do not require near-stoichiometric combustion for effective operation. However, most spark-ignition GSE are tuned rich, at least under high load conditions, necessitating the use of secondary air injection to promote effective oxidation. Closed-loop combustion control systems could be included as an integral component of the retrofit, thereby opening the possibility for the use of three-way oxidation/reduction catalysts, but a switch to stoichiometric operation may limit critical maximum power for some GSE. Perhaps most importantly, most GSE have operating cycles that consist of short engine-on periods interrupted by extended engine-off periods. Therefore, a substantial portion of GSE operation may occur before exhaust catalysts have reached effective conversion temperatures (i.e., light-off) or particulate traps have reached effective regeneration temperatures. Finally, installation location and space will be restricted on most GSE so that aftertreatment packages designed to replace stock mufflers are likely to be the most feasible approach. Neither the durability or effectiveness of such units have yet been demonstrated over extended usage periods.

Table 5 presents the potential emission reduction effectiveness of exhaust aftertreatment devices. It is critical to recognize that these estimates are not based on any demonstrated experience in the GSE sector, but instead rely on performance observed for on-road vehicles. Until such time as the appropriate demonstrations have been made on off-road equipment such as GSE, the reduction estimates presented in Table 5 should be interpreted as upper-bound reduction potentials. Catalytic HC reduction potential declines for both LPG and CNG engines due to the increasing concentrations of short chain hydrocarbons in the exhaust of such engines. Current catalyst technology is most effective on long chain hydrocarbons and a substantial fraction of compounds such as methane and ethane can pass through a catalyst without undergoing oxidation. The substantial increase in CO_2 emissions results from an assumed backpressure increase as well as the oxidation of HC and CO, both of which are observed in high concentrations in uncontrolled GSE engines. Increased backpressure accounts for only about two percentage points of the estimated increase, with CO conversion accounting for nearly all of the remainder.

Until such time as catalyst and particulate trap performance has been consistently demonstrated in GSE applications and sufficient test data on in-use engines is available to confirm generalized emission reduction impacts, exhaust aftertreatment device installation and any emission credits granted for such installation should be treated on a case-by-case basis, supported by on-going emissions testing. Given catalyst and trap sizing and design limitations, costs for aftertreatment device installation will be substantially higher than the cost of similar devices for on-road equipment. Initial catalyst costs of $1,000 or more per unit are likely. Given the lack of practical experience, it is not possible to accurately estimate cost effectiveness at this time, but clearly emissions reduction potential is significant and the institution of marketable emission credits may be sufficient incentive to undertake at least the necessary demonstration programs.

<table>
<tr><th colspan="6">Oxidation Catalyst Installation</th></tr>
<tr><th>GSE Fuel</th><th>HC</th><th>CO</th><th>NO_x</th><th>PM</th><th>CO_2[1]</th></tr>
<tr><td>Gasoline</td><td>-90%</td><td>-90%</td><td>0%</td><td>-10%</td><td>+60%</td></tr>
<tr><td>Diesel</td><td>-50%</td><td>-90%</td><td>0%</td><td>-30%</td><td>+3%</td></tr>
<tr><td>LPG</td><td>-70%</td><td>-90%</td><td>0%</td><td>-10%</td><td>+45%</td></tr>
<tr><td>CNG</td><td>-50%</td><td>-90%</td><td>0%</td><td>-10%</td><td>+45%</td></tr>
<tr><th colspan="6">Three-Way Catalyst Installation</th></tr>
<tr><th>GSE Fuel</th><th>HC</th><th>CO</th><th>NO_x</th><th>PM</th><th>CO_2</th></tr>
<tr><td>Gasoline</td><td>-90%</td><td>-90%</td><td>-80%</td><td>-10%</td><td>+60%</td></tr>
<tr><td>LPG</td><td>-70%</td><td>-90%</td><td>-80%</td><td>-10%</td><td>+45%</td></tr>
<tr><td>CNG</td><td>-50%</td><td>-90%</td><td>-80%</td><td>-10%</td><td>+45%</td></tr>
<tr><th colspan="6">Particulate Trap Installation</th></tr>
<tr><th>GSE Fuel</th><th>HC</th><th>CO</th><th>NO_x</th><th>PM</th><th>CO_2</th></tr>
<tr><td>Diesel</td><td>-20%</td><td>0%</td><td>0%</td><td>-90%</td><td>+2%</td></tr>
</table>

[1] CO_2 emission increases result from increased exhaust system backpressure and the oxidation of HC and CO, with CO oxidation accounting for the bulk of the estimated increase.

Table 5. Potential Emission Impacts of Exhaust Aftertreatment

<u>Preferential Replacement of Two-Stroke Gasoline Engines</u>: Uncontrolled two-stroke gasoline engines emit about 7 times the HC, 1.5 times the CO, and 10 times the PM of similarly sized uncontrolled four-stroke engines, while two-stroke NO_x is only about 20 percent of that of four-stroke engines. While the population of two-stroke GSE is declining, there remains a number of such units in use in applications such as pumps on lavatory carts. In general, all such equipment is rated at less than 25 horsepower and, therefore, subject to recent new engine emission standards established by both the EPA and CARB. Since both two-stroke and four-stroke engine standards are identical under the EPA and CARB programs, high emission rate two-stroke engines will disappear from the GSE fleet over time. Nevertheless, near term preferential replacement of existing two-stroke engines can generate significant reductions in HC and PM. While, because of relative low two-stroke engine populations, these reductions are not of the magnitude possible through the previously discussed control strategies, they can be cost effective as the cost and reliability of small four-stroke engines become competitive with similarly sized two-strokes.

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ESTIMATING GSE ACTIVITY

ESTIMATING GSE ACTIVITY

Knowledge of the activity levels of airport ground support equipment (GSE) is critical to accurately determining emissions performance. This is true regardless of whether one considers the baseline emissions performance of today's GSE fleet or the potential emission reductions that can be derived through the implementation of various control measures. Either assessment requires the detailed characterization of equipment population and/or usage rates to derive accurate emission or emission reduction estimates.

The basic GSE emissions calculation methodology for a particular piece of equipment can be summarized algebraically as:

$$\frac{\text{unit GSE emissions}}{\text{time period of interest}} = \frac{\text{g}}{\text{bhp - hr}} \times \text{rated hp} \times \frac{\text{hours of operation}}{\text{time period of interest}} \times \text{load factor}$$

where: *g/bhp-hr" represents an equipment-specific emission factor expressed in grams of emissions per brake horsepower-hour of work,*

"rated hp" indicates the maximum power output of the equipment expressed in horsepower,

"hours of operation/time period of interest" indicates the total accumulated time (expressed in hours) the equipment's engine is in operation during any particular period of interest, and

"load factor" indicates the ratio of actual expended work to maximum possible work during the same time period.

Both the "g/bhp-hr" and "rated hp" parameters are elements of engine design. However, the former is generally dependent on the latter (at least across discrete power ranges) and, therefore, the specific horsepower demands of a given airline's or airport's support services can influence the emission rates of its GSE. In this context, the horsepower distribution of GSE can be viewed as an indicator of GSE activity (i.e., is the activity being conducted by large, high-powered GSE or smaller, lower-powered counterparts). The remaining two parameters, "hours of operation/time period of interest," and "load factor" are obviously indicators of GSE activity and can vary with both GSE application and airport design.

While the four parameters defined above are sufficient to determine emission rates for a particular equipment type, total GSE emissions can only be determined once the overall distribution and population of GSE is known. Expressed algebraically, aggregate GSE emissions are calculated as:

$$\frac{\text{aggregate GSE emissions}}{\text{time period of interest}} = \sum_{i=1}^{\text{GSE types}} \left[\left(\frac{\text{unit GSE emissions}}{\text{time period of interest}} \right)_i \times \text{GSE population}_i \right]$$

where: "unit GSE emissions/time period of interest" are calculated as above,

"GSE population" indicates the number of individual units of a particular equipment type in operation, and

"GSE types" indicates the total number of different types of equipment in operation.

Both the population of individual equipment and the number of equipment types in service will vary across airlines and airports. Therefore, even given a detailed database of GSE-specific emission factors, it is still necessary to accurately define at least five specific GSE activity parameters (rated horsepower, load factor, usage rate, equipment-specific population, and number of specific GSE types in use) to estimate overall GSE emissions. Unfortunately, detailed knowledge of each of these parameters is complicated by several factors. First, GSE includes a diverse range of vehicles and equipment of differing sizes, usage rates, and load factors. Second, usage rates and load factors can vary substantially across time so that GSE activity, and therefore emissions, can be temporally dependent. Third, GSE demands can vary substantially across airports in accordance with (among other factors) airport design and aircraft activity. For example, a busy airport may require dedicated GSE for each gate to meet service demands while a low volume airport may be able to use the same equipment to service multiple gates. Fourth, and perhaps most importantly, very little information has been collected on any of these parameters so that databases sufficient to distinguish temporal and airport- or airline-specific influences remain to be developed.

Given this situation, GSE emissions estimation must be considered as a developing exercise at this time. Initial estimates for all the parameters required to calculate emissions have been developed, but the uncertainties inherent in these parameter estimates are unknown as the robust databases necessary to evaluate such uncertainty are non-existent. An overview of current GSE emissions estimation parameter values as well as important associated background information is presented in the GSE Information Series 1 and 2 selections, entitled *Basis for GSE Population Estimates* and *GSE Emissions and Activity Estimates* respectively. This abbreviated document serves to both bring together these parametric values in a single document and provide an initial assessment of some of the uncertainty inherent in key GSE emissions estimation parameters.

Before presenting current "best estimates" for each of the required GSE activity parameters, it is important to place the limitations imposed by the relative infancy of the GSE emissions estimation field in a proper perspective. Basically, such perspective involves the recognition that the majority of emissions estimation uncertainty comes into play only when aggregated estimates are required, be they across equipment types, airlines, or airports. Emissions estimation parameters for specific GSE units can be readily determined from site-specific analysis. Population estimation methods become irrelevant when treating individual units and equipment horsepower, usage rates, and load factors can be readily determined either through direct observation or analysis of associated data such as fuel use records. Therefore, in instances where emission reduction estimates due to such control measures as fueling system conversion are required, most of the emissions estimation uncertainty can be controlled simply by replacing the “average” parametric estimates used for aggregate GSE emissions estimation with site-specific equivalent estimates derived specifically for the affected equipment.

GSE Population Estimates: Ideally, GSE population data by equipment type would be compiled and maintained through a national database so that accurate population estimates for any given airport, airline, or equipment type could be readily developed. However, no such database exists and no standard GSE tracking procedures have been developed across airports. Therefore, alternative mechanisms for estimating GSE population must be derived. Two possible approaches involve so-called “top-down” and “bottom-up” estimation. Under the top-down approach, aggregate (i.e., national or state-specific) GSE populations are estimated and allocated to individual airports on the basis of some activity indicator. For example, scrappage algorithms can be applied to annual GSE sales data to estimate aggregate GSE populations. These GSE can then allocated to individual airports through the use of an activity indicator such as the number of aircraft landing and take-off (LTO) cycles. Such an approach was employed in the U.S. Environmental Protection Agency’s (EPA’s) 1991 Nonroad Engine and Vehicle Emissions Study (NEVES). Alternatively, under a bottom-up approach, GSE populations are estimated for individual airports and aggregated as necessary. In the absence of comprehensive airport-specific data, such an approach typically involves the statistical analysis of known GSE population data for a given sample of airports in order to relate observed GSE populations to one or more explanatory parameters that are readily available for all airports (e.g., LTO cycles). Once such a relationship has been defined, it is a relatively simple matter to apply the regression equation to other airports and develop airport-specific GSE population estimates.

Both approaches are theoretically sound, but both also have inherent weakness and potentially large uncertainties. Generally, however, the bottom-up approach tends to more readily incorporate airport-specific information into the derived population estimates. Moreover, uncertainties with potential top-down approach sources of error, such as the use of standard scrappage algorithms, are inherently addressed in the derived bottom-up regression relations. For these reasons and given that a small sample of airport-specific GSE population data are available to undertake the necessary regression analysis, the bottom-up approach generally reflects a more robust GSE population estimation approach. The current best estimate bottom-up regression equation approach is presented in GSE Information Series 1 selection entitled *Basis for GSE Population Estimates*. Basically, the approach is based on aircraft LTO cycles as the predictive GSE population parameter and the resulting regression equation is expressed algebraically as follows:

$$\text{GSE} = 0.0226\,(\text{LTO}_{\text{nswwb}}) + 0.0054\,(\text{LTO}_{\text{nswnb}}) + 0.0022\,(\text{LTO}_{\text{sw}}) + 0.0008\,(\text{LTO}_{\text{prop}})$$

where: *"GSE" represents the calculated GSE population,*

"LTO_{nswwb}" indicates the number airport LTO cycles accumulated by wide-body jets, exclusive of those operated by Southwest Airlines,

"LTO_{nswnb}" indicates the number airport LTO cycles accumulated by narrow-body jets, exclusive of those operated by Southwest Airlines,

"LTO_{sw}" indicates the number airport LTO cycles accumulated by all jets operated by Southwest Airlines, and

"LTO_{prop}" indicates the number airport LTO cycles accumulated by non-jet aircraft.

As described in GSE Information Series 1, the regression equation yields a national GSE population estimate of about 45,000 units. This estimate is consistent with several estimates derived over the last several years using alternative approaches, but considerably lower than the estimate derived using the top-down approach employed for the NEVES (about 85,000 units).

Although the regression equation is based on a significant sample of observed GSE population[*] and the relationships with the selected predictive parameters (i.e., the various LTO cycle parameters) are significant at over 99 percent confidence, the variability observed across airlines and airports is, nevertheless, significant (correlation coefficients for component regressions are generally around 0.80). Therefore, a review of the ability of the regression equation to accurately forecast individual airport GSE populations is important in assessing the absolute utility of the population predictions.

Airlines at several airports were contacted directly to obtain comparative GSE inventory information, but unfortunately this survey was not successful as airline and airport managers at airports including Atlanta's Hartsfield International, Indianapolis International, Norfolk Regional, Albuquerque International, and Portland (Oregon) International declined to provide the requested information. Of the airports surveyed, only Sacramento Metropolitan and Madison County Airport in Huntsville, Alabama provided comprehensive GSE population data which can be compared with regression predictions. As a alternative source of comparative data, survey responses included in Appendix A of the Gas Research Institute's (GRI's) 1998*"Survey of Airport Vehicle Fleets: Final Report"* were examined and those that included sufficient data to estimate airport GSE populations were identified. Of the 38 survey responses included in the GRI report, the 12 airports presented in Table 1 included sufficient information to estimate airport GSE populations (note, Table 1 also includes statistics for the Huntsville and Sacramento airports which provided GSE population data in response to direct requests).

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[*] In total, GSE populations for 35 individual airlines at 10 airports, comprising nearly 2,500 GSE, are incorporated in the regression analysis. Together, these airline/airport combinations account for about 9 percent of national LTO cycles.

Airport	1996 LTO's	NSWWB LTO's	NSWNB LTO's	SW LTO's	PROP LTO's	Observed GSE	Predicted GSE	Percent Error
Huntsville	5,792	0	5,792	0	0	37	31	-16%
Orange County	40,628	709	34,964	4,955	0	66	216	227%
Sacramento	42,778	437	20,349	18,366	3,626	128	163	28%
San Antonio	45,301	317	27,410	15,142	2,432	112	191	70%
Kansas City	66,243	78	48,152	17,082	931	169	300	78%
Baltimore	73,917	161	56,092	10,873	6,791	325	336	3%
San Diego	77,447	1,511	43,835	27,069	5,032	356	335	-6%
Salt Lake City	100,029	9,527	72,969	15,408	2,125	554	645	16%
Miami	127,880	27,265	92,336	1	8,278	2,819	1,121	-60%
Detroit Metro	170,980	9,767	151,640	6,163	3,410	661	1,055	60%
St. Louis	229,259	6,221	142,626	31,022	49,390	1,196	1,019	-15%
Los Angeles	247,388	40,005	139,292	38,047	30,044	2,200	1,764	-20%
Dallas/Ft. Worth	373,263	14,070	262,531	1	96,661	600	1,812	202%
O'Hare	377,096	22,825	300,658	1	53,612	2,894	2,181	-25%
Aggregate Data								
	1,978,001	132,893	1,398,646	184,130	262,332	12,117	11,169	-8%
Aggregate Data Exclusive of Miami and Dallas/Ft. Worth								
	1,476,858	91,558	1,043,779	184,128	157,393	8,698	8,236	-5%

Table 1. Predicted Versus Observed GSE Populations

LTO cycle data, as required to evaluate the GSE population regression equation, was extracted from the U.S. Department of Transportation, Bureau of Transportation Statistics' (BTS') report entitled *"Airport Activity Statistics of Certificated Air Carriers"* for the calendar year 1996. LTO cycle data for each airport was disaggregated into the four required predictive parameters (i.e., wide-body jet LTO's exclusive of Southwest Airlines, narrow-body jet LTO's exclusive of Southwest Airlines, Southwest Airlines LTO's, and non-jet LTO's) using the aircraft type- and airline-specific LTO data published in the BTS report. The single limitation associated with the use of the BTS report data is that it does not include LTO cycles accumulated by foreign air carriers. As a result, airports at which foreign carrier LTO's comprise a significant fraction of total LTO cycles can be expected to exhibit some under-prediction of GSE population.

Foreign carrier LTO data can be requested from the FAA, but requires special processing by agency staff and, therefore, such data were not requested for this basic analysis. Previous analyses of aircraft operations have, however, demonstrated that foreign carriers can comprise as much as 15 percent of LTO cycles at high traffic international airports such as Los Angeles International, with smaller contributions of 0-5 percent at non-hub international airports such as

Boston Logan and Baltimore/Washington International. Since foreign carrier LTO's tend to be more heavily weighted toward wide-body aircraft, which (as indicated by regression coefficients) carry about 2.5 times the GSE demand of narrow-body aircraft, GSE under-prediction due to non-consideration of foreign carrier LTO's can reach 25 percent or more at foreign hub airports such as Los Angeles International, Chicago O'Hare, and Miami International. Lesser under-predictions of 0-10 percent would be expected at foreign carrier non-hubs such as St. Louis Lambert, Detroit Wayne, and Kansas City International.

Table 1 indicates observed (domestic carrier) LTO cycles, observed GSE population, the regression-predicted GSE population, and the percent error of prediction for each of the 14 airports at which observed GSE population data was available for comparison. Figure 1 presents a corresponding graphical illustration of the observed and predicted GSE populations. As indicated, the error of prediction ranges from -60 to +227 percent, with an aggregate error over all 14 airports (representing about 25 percent of all domestic carrier LTO's) of about -8 percent. Unfortunately, due to the third-party nature of 12 of the 14 observed GSE populations, it is not possible be certain that all of the indicated error is, in fact, associated with the regression predictions. For example, as shown in Figure 1, Miami and Dallas/Ft. Worth exhibit observed GSE populations that are vastly out-of-line with other airports of similar LTO activity. Miami exhibits an "observed" GSE population as large as airports with three times as many LTO cycles, whereas Dallas/Ft. Worth exhibits a population that is as small as airports with two to three times less LTO activity. Clearly, it is possible that the GSE populations reported in the GRI survey for these airports are not correct. In fact, if these two airports are eliminated from the analysis, the regression predictions are within about ±25 percent of observed for eight of the twelve airports investigated, with an aggregate error of -5 percent.

The largest band of prediction error appears to fall in the 40,000-70,000 LTO range, where the regression equation appears to over-predict GSE populations by a substantial margin. Three of the four airports with errors of prediction outside the ±25 percent range (excluding Miami and Dallas/Ft. Worth) fall within this LTO region. Conversely, for those seven airports with greater than 70,000 LTO cycles (again, excluding Miami and Dallas/Ft. Worth), four: San Diego, St. Louis, Los Angeles, and O'Hare, all exhibit under-predictions right-in-line with expectations given the exclusion of foreign carrier LTO's and two: Salt Lake City and Baltimore, are only slightly over-predicted. Only Detroit's Wayne County Airport shows evidence of substantial over-prediction.

Given the estimated prediction errors, several conclusions can be drawn regarding the use of the GSE population regression[*]. First, additional regression development may improve predictions.

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[*] Although the reliability of "observed" GSE populations (on which the regression prediction error is based) is not assured given the simple extraction of such populations from published surveys of uncertain consistency and quality, the general magnitude of most such "observations" appears reasonable. Therefore, while additional efforts to collect and validate accurate GSE population data will be beneficial, it is quite probable that the extracted observations provide a good assessment of regression accuracy, especially in terms of differences across airports.

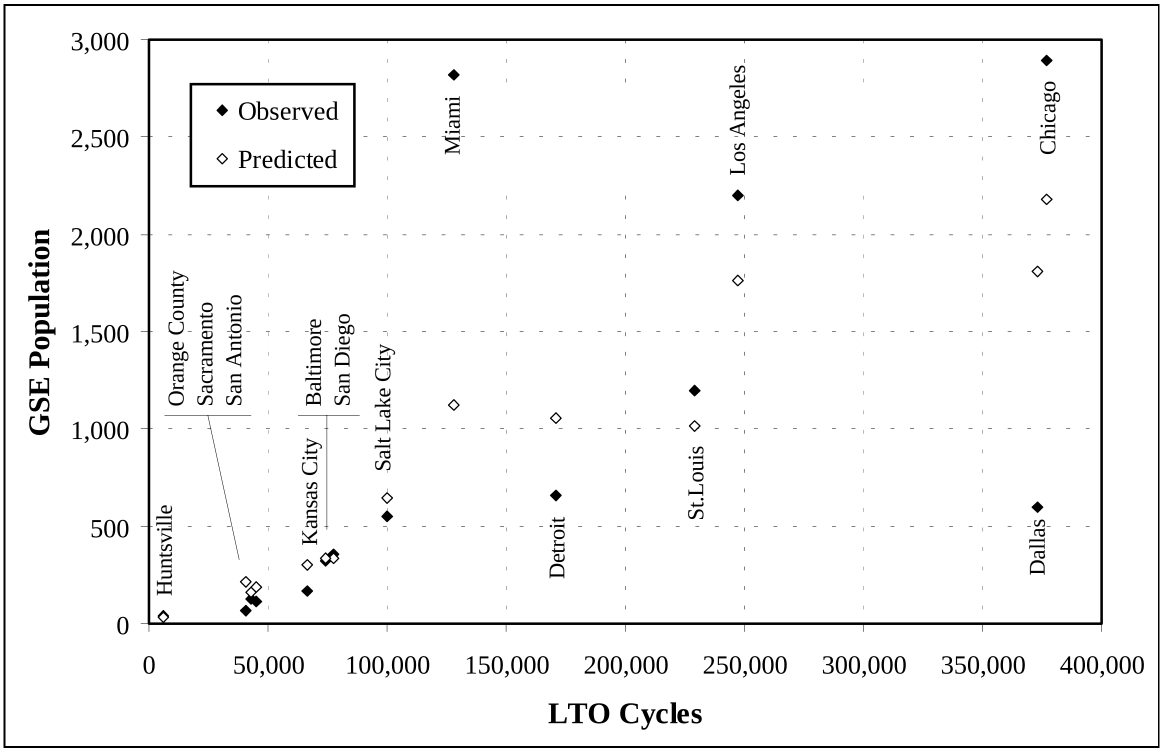

Figure 1. Predicted Versus Observed GSE Populations

For example, the current regression already includes a distinct treatment of Southwest Airlines. Perhaps, a singular treatment of other airlines might reveal additional unique characteristics across carriers. Given the over-prediction observed for Detroit, investigation of Northwest Airlines GSE practices might provide a good initial focus. Additionally, some characterization of airport layout and aircraft traffic intensity may be beneficial. Parameters indicating the degree of simultaneous (multi-gate) aircraft service demand and inter-gate GSE impedances may help to define otherwise unconsidered differences between airports.

Second, despite uncertainty in the observed GSE populations, it is clear that the regression predicts GSE population fairly well across an aggregate grouping of airports with differing characteristics. Estimated national and regional GSE population predictions are likely to be quite reasonable. Third, given the significant error observed for individual airports, especially those with less than 70,000 or so annual LTO cycles, regression predictions should be used only for emissions estimation screening purposes at individual airports. Such predictions can provide a reasonable first estimate of potential emission loads associated with GSE or potential emission reductions due to GSE controls, but detailed emission estimates should be reserved until actual GSE counts are available or until enhanced regression parameters have been developed.

<u>Equipment Type-Specific GSE Population Estimates</u>: The problems inherent in estimating the total GSE population in-use at airports are magnified when one considers the individual types of equipment which are used for aircraft ground support. Various types of equipment can be used to support various service demands and not all airlines address the same service requirements with the same equipment. Certain units such as aircraft pushback tractors, baggage tugs, and belt loaders are fairly common across carriers and airports, but others such as forklifts, carts, and ground power units vary considerably in usage rates and population, depending on both airline and airport practices. Even developing a specific list of GSE types that apply at all airports is not straight-forward. However, over the last several years, a somewhat "standard" list of 23 GSE types has been in-use in the airport analysis community and, in the absence of alternatives or obvious deficiencies, this list represents a convenient GSE categorization scheme. These 23 equipment types, as listed in Table 2, provide an adequate level-of-detail to characterize the important differences in design and usage of component GSE.

Given the current paucity of detailed GSE population data, there is little alternative at this time but to base estimates of specific equipment type populations on the aggregate equipment distributions for those carriers which have provided detailed GSE data. As described in GSE Information Series 1, such data consist of detailed population distributions for 35 airlines at 10 U.S. airports. Table 2 presents the equipment type distributions derived from this data, at both the level-of-classification associated with the overall GSE population regression parameters (i.e., jet aircraft exclusive of Southwest Airlines, Southwest Airlines, and non-jet aircraft) and at an aggregate level for all observed sample distributions.

At this point in the development of GSE databases, the equipment type-specific distributions presented in Table 2 reflect the "best methodology" for estimating specific equipment populations at airports for which site-specific data is unavailable. GSE population estimates for any selected airport can be developed by applying tabulated distribution data to aggregate population estimates predicted using the GSE population regression described above. While this approach inherently incorporates all of the uncertainty already described for regression-predicted aggregate GSE populations, as well as any additional uncertainty inherent in the equipment type-specific distributions, it nevertheless incorporates the most complete data currently available.

Figures 2 and 3 present a comparison of equipment type distributions estimated using the "best methodology" regression/disaggregation approach to distributions derived from data for GSE at two airports not reflected in the database used to develop the underlying estimation statistics. The data for St. Louis was extracted from the GRI airport fleet vehicle survey already described, while that for Sacramento was provided directly by airport personnel. Note, the comparisons presented focus solely on error in the equipment type-specific distributions and ignore any aggregate GSE population prediction error (due to the use of the GSE/LTO regression equation) which has already been discussed above. Also, the default (or predicted) GSE distributions were developed by applying the aircraft-specific GSE distributions presented in Tables 2a-2c to airport-specific LTO data for 1996. The aggregate GSE distributions presented in Table 2d are not considered in these comparisons, but would deviate substantially from those indicated. As expected, the "best methodology" approach to determining individual equipment subpopulations includes substantial error when applied to any given airport. Nevertheless, in the absence of alternative site-specific data, the default (i.e., predicted) equipment type-specific distributions do provide a reasonably accurate means of estimating of equipment populations. In most cases, the

Equipment Type	Population Fraction	Diesel Share	Gasoline Share	Electric Share	LPG/CNG Share	Turbine Share
Aircraft Pushback Tractor	0.0590	0.7577	0.1801	0.0372	0.0249	0.0000
Conditioning Air Unit	0.0109	0.8017	0.0661	0.0661	0.0661	0.0000
Air Start Unit	0.0198	0.8701	0.0744	0.0189	0.0000	0.0366
Baggage Tug	0.2281	0.4093	0.4655	0.0257	0.0996	0.0000
Belt Loader	0.1120	0.4608	0.4542	0.0196	0.0654	0.0000
Bobtail	0.0227	0.1614	0.8222	0.0000	0.0164	0.0000
Cargo Loader	0.0341	0.7738	0.1508	0.0000	0.0754	0.0000
Cart	0.0469	0.0154	0.5314	0.4532	0.0000	0.0000
Deicer	0.0113	0.0638	0.9362	0.0000	0.0000	0.0000
Forklift	0.0773	0.0426	0.2607	0.2227	0.4740	0.0000
Fuel Truck	0.0113	0.1605	0.8066	0.0000	0.0329	0.0000
Ground Power Unit	0.0652	0.8034	0.0337	0.1630	0.0000	0.0000
Lavatory Cart	0.0004	0.0000	1.0000	0.0000	0.0000	0.0000
Lavatory Truck	0.0158	0.0000	1.0000	0.0000	0.0000	0.0000
Lift	0.0377	0.0291	0.5823	0.1943	0.1943	0.0000
Maintenance Truck	0.0297	0.0126	0.9748	0.0000	0.0126	0.0000
Other GSE	0.0399	0.2200	0.6793	0.0181	0.0825	0.0000
Service Truck	0.0476	0.1383	0.7464	0.0000	0.1153	0.0000
Bus	0.0066	0.3887	0.6113	0.0000	0.0000	0.0000
Car	0.0132	0.0000	1.0000	0.0000	0.0000	0.0000
Pickup Truck	0.0633	0.0114	0.9366	0.0000	0.0520	0.0000
Van	0.0429	0.0000	0.9657	0.0000	0.0343	0.0000
Water Truck	0.0044	0.0000	1.0000	0.0000	0.0000	0.0000
All Equipment	1.0000	0.3247	0.5127	0.0685	0.0934	0.0007

Table 2a. Jet Aircraft GSE Distribution, Exclusive of Southwest Airlines

Equipment Type	Population Fraction	Diesel Share	Gasoline Share	Electric Share	LPG/CNG Share	Turbine Share
Aircraft Pushback Tractor	0.0324	1.0000	0.0000	0.0000	0.0000	0.0000
Conditioning Air Unit	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Air Start Unit	0.0000	n/a	n/a	n/a	n/a	n/a
Baggage Tug	0.3222	0.4329	0.5671	0.0000	0.0000	0.0000
Belt Loader	0.0541	0.0000	1.0000	0.0000	0.0000	0.0000
Bobtail	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Cargo Loader	0.0000	n/a	n/a	n/a	n/a	n/a
Cart	0.0541	0.0000	1.0000	0.0000	0.0000	0.0000
Deicer	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Forklift	0.0000	n/a	n/a	n/a	n/a	n/a
Fuel Truck	0.0108	1.0000	0.0000	0.0000	0.0000	0.0000
Ground Power Unit	0.2249	1.0000	0.0000	0.0000	0.0000	0.0000
Lavatory Cart	0.0541	0.0000	1.0000	0.0000	0.0000	0.0000
Lavatory Truck	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Lift	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Maintenance Truck	0.0216	0.0000	1.0000	0.0000	0.0000	0.0000
Other GSE	0.0000	n/a	n/a	n/a	n/a	n/a
Service Truck	0.0432	0.0000	1.0000	0.0000	0.0000	0.0000
Bus	0.0000	n/a	n/a	n/a	n/a	n/a
Car	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
Pickup Truck	0.0324	0.0000	1.0000	0.0000	0.0000	0.0000
Van	0.0746	0.0000	1.0000	0.0000	0.0000	0.0000
Water Truck	0.0108	0.0000	1.0000	0.0000	0.0000	0.0000
All Equipment	1.0000	0.4076	0.5924	0.0000	0.0000	0.0000

Table 2b. Southwest Airlines GSE Distribution

Equipment Type	Population Fraction	Diesel Share	Gasoline Share	Electric Share	LPG/CNG Share	Turbine Share
Aircraft Pushback Tractor	0.1554	0.8325	0.1675	0.0000	0.0000	0.0000
Conditioning Air Unit	0.0000	n/a	n/a	n/a	n/a	n/a
Air Start Unit	0.0260	1.0000	0.0000	0.0000	0.0000	0.0000
Baggage Tug	0.3323	0.6221	0.3341	0.0438	0.0000	0.0000
Belt Loader	0.2328	0.7138	0.2862	0.0000	0.0000	0.0000
Bobtail	0.0038	0.0000	1.0000	0.0000	0.0000	0.0000
Cargo Loader	0.0000	n/a	n/a	n/a	n/a	n/a
Cart	0.0077	0.0000	1.0000	0.0000	0.0000	0.0000
Deicer	0.0077	0.0000	1.0000	0.0000	0.0000	0.0000
Forklift	0.0222	0.1724	0.3448	0.0000	0.4828	0.0000
Fuel Truck	0.0000	n/a	n/a	n/a	n/a	n/a
Ground Power Unit	0.0406	1.0000	0.0000	0.0000	0.0000	0.0000
Lavatory Cart	0.0222	0.0000	1.0000	0.0000	0.0000	0.0000
Lavatory Truck	0.0184	0.0000	1.0000	0.0000	0.0000	0.0000
Lift	0.0077	0.0000	0.0000	0.0000	1.0000	0.0000
Maintenance Truck	0.0000	n/a	n/a	n/a	n/a	n/a
Other GSE	0.0260	0.0000	1.0000	0.0000	0.0000	0.0000
Service Truck	0.0597	0.5000	0.5000	0.0000	0.0000	0.0000
Bus	0.0038	1.0000	0.0000	0.0000	0.0000	0.0000
Car	0.0038	0.0000	1.0000	0.0000	0.0000	0.0000
Pickup Truck	0.0260	0.2941	0.7059	0.0000	0.0000	0.0000
Van	0.0000	n/a	n/a	n/a	n/a	n/a
Water Truck	0.0038	0.0000	1.0000	0.0000	0.0000	0.0000
All Equipment	1.0000	0.6141	0.3530	0.0145	0.0184	0.0000

Table 2c. Non-Jet Aircraft GSE Distribution

Equipment Type	Population Fraction	Diesel Share	Gasoline Share	Electric Share	LPG/CNG Share	Turbine Share
Aircraft Pushback Tractor	0.0612	0.7659	0.1772	0.0341	0.0228	0.0000
Conditioning Air Unit	0.0106	0.7850	0.0856	0.0647	0.0647	0.0000
Air Start Unit	0.0195	0.8751	0.0715	0.0182	0.0000	0.0352
Baggage Tug	0.2331	0.4188	0.4629	0.0257	0.0926	0.0000
Belt Loader	0.1144	0.4713	0.4496	0.0182	0.0609	0.0000
Bobtail	0.0219	0.1589	0.8249	0.0000	0.0162	0.0000
Cargo Loader	0.0324	0.7738	0.1508	0.0000	0.0754	0.0000
Cart	0.0459	0.0150	0.5450	0.4400	0.0000	0.0000
Deicer	0.0112	0.0613	0.9387	0.0000	0.0000	0.0000
Forklift	0.0741	0.0437	0.2615	0.2207	0.4741	0.0000
Fuel Truck	0.0110	0.1774	0.7903	0.0000	0.0323	0.0000
Ground Power Unit	0.0677	0.8202	0.0308	0.1490	0.0000	0.0000
Lavatory Cart	0.0021	0.0000	1.0000	0.0000	0.0000	0.0000
Lavatory Truck	0.0157	0.0000	1.0000	0.0000	0.0000	0.0000
Lift	0.0363	0.0287	0.5813	0.1919	0.1980	0.0000
Maintenance Truck	0.0286	0.0124	0.9752	0.0000	0.0124	0.0000
Other GSE	0.0387	0.2157	0.6856	0.0178	0.0809	0.0000
Service Truck	0.0479	0.1488	0.7422	0.0000	0.1089	0.0000
Bus	0.0064	0.3993	0.6007	0.0000	0.0000	0.0000
Car	0.0129	0.0000	1.0000	0.0000	0.0000	0.0000
Pickup Truck	0.0616	0.0148	0.9345	0.0000	0.0508	0.0000
Van	0.0423	0.0000	0.9669	0.0000	0.0331	0.0000
Water Truck	0.0045	0.0000	1.0000	0.0000	0.0000	0.0000
All Equipment	1.0000	0.3348	0.5097	0.0655	0.0893	0.0007

Table 2d. Sample Aggregate GSE Distribution

default distributions are able to identify both the type and relative presence of the various equipment types in-use at each airport. Most importantly, estimates for aircraft tugs (pushback tractors), baggage tugs, belt loaders, and on-road vehicles, which together comprise 60-75 percent of observed equipment populations, are generally accurate. While the comparative data used to generate Figures 2 and 3 does not include the fuel-type statistics, one can reasonably expect substantial error in fuel-specific equipment population predictions given individual air carrier and airport practices regarding alternative fuel use, etc.

Given airline- and airport-specific influences on equipment type distributions, error in the use of default GSE distributional data is not unexpected. As indicated above in the discussion of aggregate population predictions, the default distributional data should only be used for screening purposes only. Default distributions can provide a reasonable first estimate of potential emission loads associated with GSE or potential emission reductions due to GSE controls, but detailed “official” emission estimates should be reserved until actual site-specific GSE counts are available. For determining the emission reduction associated with control measures which focus on one or several specific pieces of equipment, all default distribution uncertainty becomes irrelevant as data specific to the targeted equipment must be known and can easily displace default statistics.

GSE Horsepower Classification: As described in the GSE Information Series 2 selection entitled *GSE Emissions and Activity Estimates*, the basis for current “best estimates” of GSE horsepower, load factor, and usage rates all derive from data developed for the California Air Resources Boards’ (ARB’s) off-road emission factor model. The aggregate data presented below differs somewhat from that of the ARB model only because the California-specific equipment population data included in the ARB model has been replaced with more robust national data to develop aggregate individual equipment data. Extractions from the ARB model remains the “best estimate” methodology for determining GSE horsepower for several reasons. The model continues to incorporate all GSE horsepower data currently available. Moreover, the model treats the horsepower data in very disaggregated format so that subsequent aggregations using alternative population data are quite easy. However, while the ARB model continues to represent the best source of horsepower distribution data, it should be recognized that the basis for this data continues to be limited, consisting of GSE inventory information collected from only a handful of airlines during the California Federal Implementation Plan (FIP) development process of the early-1990’s. There is no question that an expanded study of GSE engine horsepower distribution is both appropriate and necessary to validate and augment existing data.

Table 3 presents average horsepower data for the various GSE equipment types. As expected, the variation across equipment types is dramatic, in accordance with the wide range of engine power demands in the GSE sector. As a result, the emissions performance of specific GSE types (or even across fuels within a specific GSE type) can vary considerably. As described above for GSE population estimation, these data should only be used for emissions screening purposes and should be displaced with actual equipment horsepower in all instances of emission reduction estimates for specific equipment controls. Note also that Table 3 does not include estimates for on-road vehicles used in GSE applications since emission estimates for such equipment should be derived using the appropriate on-road emission factor model (i.e., MOBILEx, PARTx, or EMFACx). It should similarly be recognized that an unknown fraction of the trucks used to

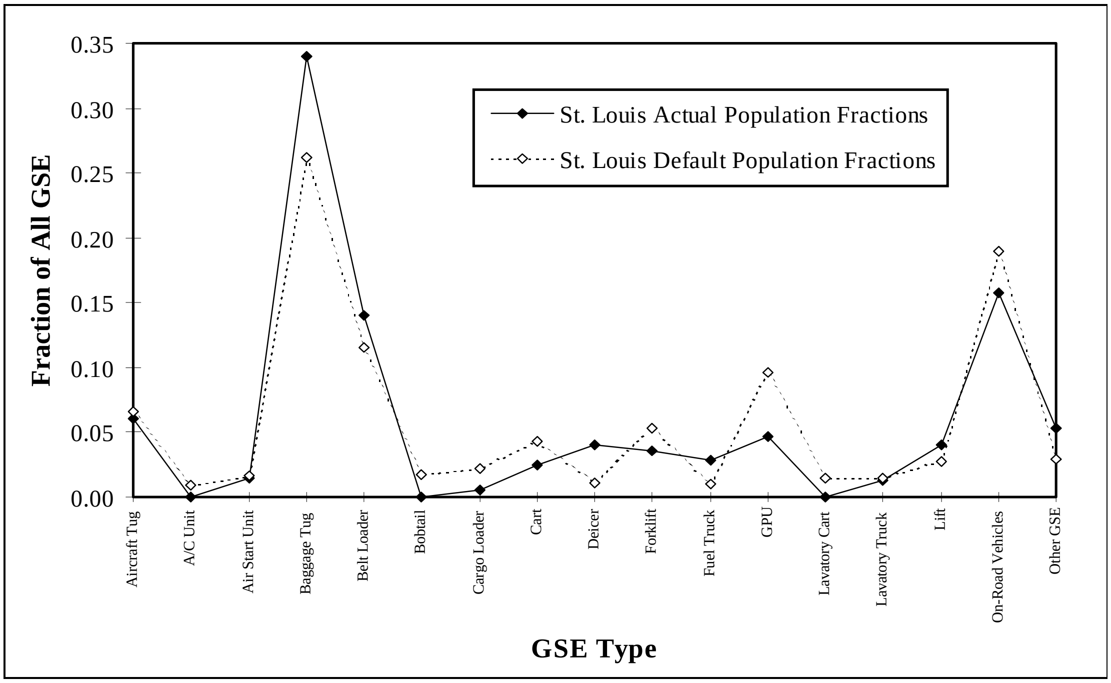

Figure 2. Comparative Equipment Type Distributions for St. Louis

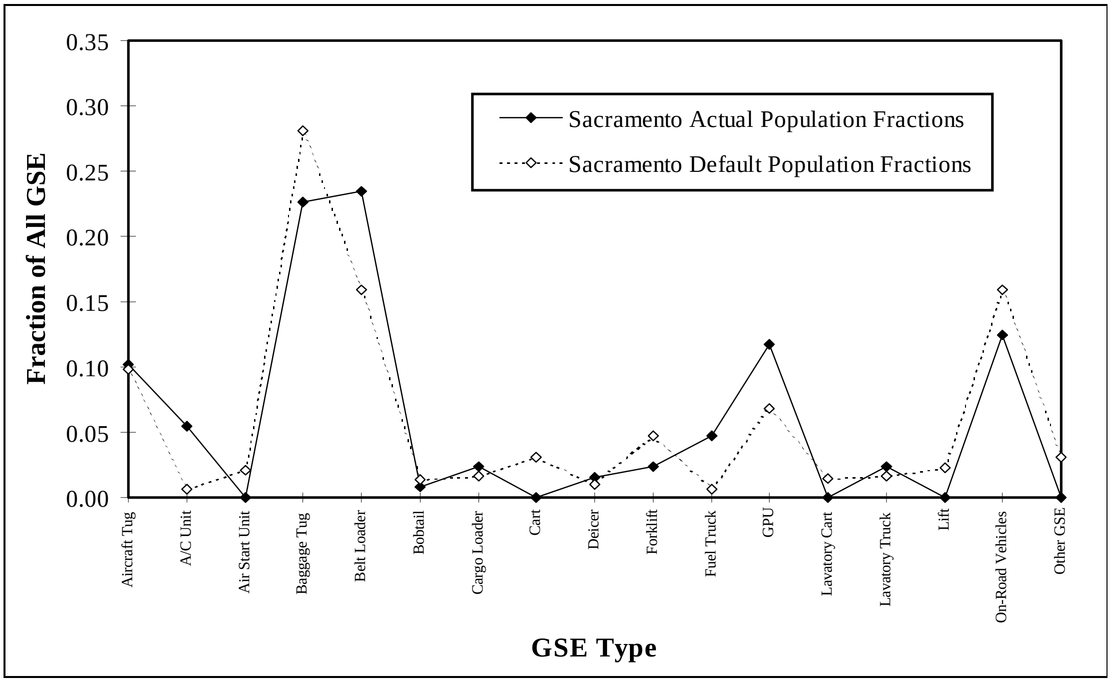

Figure 3. Comparative Equipment Type Distributions for Sacramento

Equipment Type	Gasoline/LPG/CNG	Diesel
Aircraft Pushback Tractor	130	216
Conditioned Air Unit	130	300
Air Start Unit	130	600
Baggage Tug	100	78
Belt Loader	60	45
Bobtail	100	100
Cargo Loader	70	76
Cart	12	12
Deicer	93	93
Forklift	50	52
Fuel Truck	130	180
Ground Power Unit	150	145
Lavatory Cart	12	12
Lavatory Truck	130	130
Lift	100	100
Maintenance Truck	130	130
Other	50	50
Service Truck	180	170
Water Truck	150	150

Table 3. Average Horsepower by Equipment and Fuel Type

provide fuel, food, water, and lavatory service are also on-road certified vehicles. Generally, such service trucks do include special adaptations to facilitate use as GSE and many are of overseas manufacture and uncertain emissions certification (since their use is restricted to off-road applications, no specific emissions certification has historically been required). However, many are undoubtedly certified on-road vehicles adapted for GSE use and as such, associated emission estimates should also be determined using on-road emission factor models.

<u>GSE Load Factors.</u> As described above for GSE horsepower, the basis for current "best estimates" of GSE load factors derives from data developed for the ARB's off-road emission factor model. As was the case for GSE horsepower data, the aggregate data presented below differs somewhat from that of the ARB model because California-specific equipment population data has been replaced with more robust national data to aggregate individual equipment estimates. Nevertheless, extractions from the ARB model continue to incorporate all GSE load factor data currently available. Like horsepower, the model treats load factor data in a very disaggregated format so that subsequent aggregations using alternative population data are quite easy to accomplish. However, it must be recognized that the basic data used to develop the ARB model continues to be limited in scope, consisting primarily of GSE inventory information collected from only a handful of airlines during the California Federal Implementation Plan (FIP) development process of the early-1990's. An expanded study of GSE load factors is both appropriate and necessary to validate and augment existing data.

Table 4 presents a summary of current "best estimate" GSE load factors by equipment type. As was the case with GSE horsepower, on-road equipment types have been excluded from Table 4 as associated emissions estimation should be conducted using the appropriate on-road emission factor models. Again, some fraction of service trucks will also be on-road certified vehicles and should also be modeled as such.

Equipment Type	Gasoline/LPG/CNG	Diesel
Aircraft Pushback Tractor	0.80	0.80
Conditioned Air Unit	0.75	0.75
Air Start Unit	0.90	0.90
Baggage Tug	0.55	0.55
Belt Loader	0.50	0.50
Bobtail	0.55	0.55
Cargo Loader	0.50	0.50
Cart	0.50	0.50
Deicer	0.95	0.95
Forklift	0.30	0.30
Fuel Truck	0.25	0.25
Ground Power Unit	0.75	0.75
Lavatory Cart	0.50	0.50
Lavatory Truck	0.25	0.25
Lift	0.50	0.50
Maintenance Truck	0.50	0.50
Other	0.50	0.50
Service Truck	0.20	0.20
Water Truck	0.20	0.20

Table 4. Average Load Factors by Equipment and Fuel Type

GSE Hours of Use: Like all GSE emissions estimation parameters, equipment usage rates vary considerably from airport to airport. Moreover, use hours even at a single airport can vary considerably by time-of-day, day-of-week, and season. Little investigation into such variation has been undertaken for GSE and, therefore, usage rates have generally focused on long term (e.g., annual) activity. Even so, variation across airports (e.g., due to variations in aircraft LTO cycles) is significant and limits the utility of generic usage rates for GSE. Nevertheless, estimates of annual equipment usage have been developed for such applications as the ARB off-road model. Like other estimates extracted from the ARB model, usage rates are based on limited data, consisting primarily of GSE information collected from only a handful of airlines during the California Federal Implementation Plan (FIP) development process of the early-1990's. An expanded study of GSE activity (and its variability across airports) is both appropriate and necessary to validate and augment existing data.

Table 5 presents the average annual GSE usage rates derived from the ARB off-road model. As with all other GSE activity parameters, the use hour estimates should be supplanted with actual site-specific data whenever possible. For use hours, this caution is amplified. Large, highly-trafficked airports may experience GSE usage rates much higher than those presented. For example, baggage tugs might operate as much as eight hours per day for 350 days or more per year, yielding an annual usage rate of 2,800 hours or more. This is over three times the usage rate indicated in Table 5. Similar, but opposite, errors can be evidenced at very low-traffic airports. Since emission estimates are directly proportional to usage rate and airport-specific differences can be large, substantial emissions estimation errors can accrue due to a failure to account for airport-specific usage rates. As with all other GSE activity estimation parameters, "default" usage rates should be limited to emissions screening analysis only.

Equipment Type	Use Hours/Year
Aircraft Pushback Tractor	551
Conditioned Air Unit	22
Air Start Unit	135
Baggage Tug	876
Belt Loader	810
Bobtail	876
Cargo Loader	719
Cart	150
Deicer	22
Forklift	726
Fuel Truck	22
Ground Power Unit	796
Lavatory Cart	183
Lavatory Truck	1212

Lift	376
Maintenance Truck	449
Other	183
Service Truck	1299
Water Truck	310

Table 5. Average Annual Hours-of-Use by Equipment Type

References:

1. *Survey of Airport Vehicle Fleets*, Final Report, prepared by Edwards and Kelsey, Inc. for the Gas Research Institute, April 1998.

2. *Airport Activity Statistics of Certificated Air Carriers for twelve months ending December 31, 1996*, U.S. Department of Transportation, Bureau of Transportation Statistics.

3. Breakdown of GSE Equipment for Sacramento Metropolitan Airport, provided by Jim Humphries to Bob Dulla of Sierra Research via fax, August, 1998.

4. *Analysis of Techniques to Reduce Air Emissions at Airports*, Draft Final Report, prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency, September 1997.

5. *Air Pollution Mitigation Measures for Airports and Associated Activity*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, May 1994.

6. *Technical Support Document for Civil and Military Aviation;* prepared by Energy and Environmental Analysis, Inc. for the U.S. Environmental Protection Agency in support of the Notice of Proposed Rulemaking for the Federal Implementation Plan for California, March 1994.

7. GSE population data sheets submitted by member companies of the Air Transport Association as part of the U.S. Environmental Protection Agency's Federal Implementation Plan development process for California, September 1993.

8. *Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model*, prepared by Energy and Environmental Analysis, Inc. for the California Air Resources Board, August 1995.

9. California Off-Road Model (June 7, 1996 version) input files *EMFAC.DAT*, *POP.DAT*, and *ACTIVITY.DAT*.

APPENDIX A

GSE MODEL INSTRUCTIONS

GSEMODEL OPERATING INSTRUCTIONS

Introduction

GSEModel is a personal computer spreadsheet-based analysis tool that has been developed to quantify emission benefits and calculate the cost-effectiveness of converting existing airport ground support equipment (GSE) to cleaner-burning fuels and engine technologies. The model has been developed as a planning tool for use by metropolitan planning organizations (MPOs), airports, and other agencies interested in evaluating potential emission benefits and cost savings resulting from available GSE emission control technologies. It has been designed with a mouse-enabled graphical user interface to make it simple and easy to use.

The GSEModel tool is based upon the "best practice" methodologies and information presented earlier in the body of this report. It has been designed to utilize local (i.e., airport-specific) GSE usage and cost information coupled with best-available emission factor data to perform the following functions using a consistent methodology:

- Estimate current and alternative technology GSE emissions by individual equipment category (e.g., aircraft pushback tractors, baggage tugs, cargo loaders, etc.);

- Compute the emission benefits of the available alternative technologies;

- Quantify the incremental capital, operating, and life-cycle costs of converting GSE units to these alternative technologies; and

- Calculate and compare the cost-effectiveness (cost per unit emissions reduced, e.g., $/ton) of these alternative technologies for each equipment category under airport-specific operating and usage conditions.

Nevertheless, as with any analysis tool, the results computed by the model retain the inherent uncertainties of the data and estimates upon which they are based. As described in the operating instructions that follow, the model provides "default" values for a number of inputs to enable the user to quickly develop GSE emission reduction and cost-effectiveness estimates associated with alternative technologies. Where actual local data are available, the user is encouraged to utilize them to provide more accurate results.

Following this introduction, the remaining sections of the GSEModel documentation are organized as follows:

- Required Operating Environment - describes the software and hardware needed to run the GSEModel application;

- Quick-Start Installation and Instructions - provides an overview on installing and executing GSEModel to get started quickly; and

- Detailed Operating Instructions and Guidance - contains step-by-step instructions for operating the application and basic guidance for inputting data and interpreting the results.

Required Operating Environment

Software Requirements - GSEModel is a spreadsheet-based application that runs on personal computers using Microsoft's Windows 95 or Windows 98 operating systems.[*] The model was written in Microsoft Excel Visual Basic for Applications (VBA), an extension of the Visual Basic programming language that allows applications to be designed with a user-friendly interface around a series of Excel spreadsheet calculations. As a result, users must have Microsoft Excel 95 (i.e., Excel 7.0) or Excel 97 installed on their computer in order for the GSEModel application to run.

Hardware Requirements - The minimum hardware requirements listed by Microsoft to run Windows 95 and Excel 7.0 are sufficient to use the GSEModel program. The application has been satisfactorily tested at 640 x 480, 800 x 600, and 1,024 x 768 display resolutions, at both 256-color and 16-bit (HiColor) depths, and should run at any available video display setting.

The GSEModel program requires 500 KB of disk capacity. Each saved scenario file (described later) occupies 14 KB of disk space.

"Quick-Start" Installation and Operating Instructions

Installation of the application simply consists of downloading or copying the **GSEMODEL.XLS** file to any valid directory chosen by the user. However, it is suggested that a separate, initially empty directory be created for the GSEModel application (e.g., C:\GSEMODEL) and the GSEMODEL.XLS file copied into it. As explained later in more detail, a key ease-of-use feature of the application is its ability to save and re-load "input scenario" files. Thus, it is recommended that a new directory be created to store the GSEMODEL.XLS application and the

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[*] The GSEModel application should theoretically also be able to run under Windows NT 4.0, but it has not been tested under that operating system.

user-created scenario files (suffixed ".gse") that it uses in order to separate them from other files on your computer.

Running the Program - From Windows 95 or Windows 98, the GSEModel application can be executed in several ways familiar to Windows users:

- Create and launch a shortcut to the application (creating a shortcut is discussed in the next section);
- Double-click* the GSEMODEL.XLS file from within the Windows Explorer or Internet Explorer window (assuming Excel has been installed and associated with .XLS file types);
- Right-click the GSEMODEL.XLS file, then click "Open" from the pop-up menu; or
- Click the Start button at the bottom left of Windows 95 and Windows 98 desktop, select "Documents" from the pop-up menu, and then click the GSEMODEL.XLS file from the pop-up list of documents.

(Note that this latter method works only when the GSEMODEL.XLS file has been recently opened and appears in the "Recent Documents" list.)

Inputting Data - Once the program finishes loading (signaled by a "Ready" indicator at the bottom left of the application window), the user is placed at the top of the first of three data input screens, the SCENARIO INPUTS screen. Using the graphical "point-and-click" interface, much of the input data required by the application can be easily entered by clicking drop-down lists and selecting specific items or clicking various check-boxes to utilize default information supplied by the model. Table A-1 provides a brief summary of the data inputs required by the application.

The buttons near the bottom of each input screen allow the user to navigate from screen to screen.

Viewing Results - After entering all required inputs (or selecting default values), GSEModel automatically performs the alternative technology emission reduction and cost-effectiveness calculations. To view the results, simply click the "View Results" button (the right button at the bottom of each input screen). The user can scroll down the tabular summary to examine the calculated results.

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* If the Windows Explorer has been replaced by Internet Explorer (e.g., in Windows 98), Internet Explorer can be configured to launch programs with a single mouse click instead of a double-click.

Table A-1
Summary of GSEModel Data Inputs

Scenario Inputs	IC Technology Activity & Costs Inputs	Electric Technology Inputs
• A scenario title (optional) • The GSE equipment category being evaluated • The "base" or current technology used in that type of equipment • The number of units of that type and technology being considered for conversion • The alternative technologies to be assessed	• Annual hours of operation (of the selected equipment type) • Expected equipment and engine life • Purchase, replacement, operating and maintenance costs • Discount rate assumed (for Net Present Value cost analysis) • The weighting scheme (optional) used to combine pollutant emission reductions in calculating cost-effectiveness	• The amount of time (in %) that the current technology GSE equipment being evaluated is operated at idle • Expected electric GSE equipment life and battery life • Electric GSE purchase, replacement, operating and maintenance costs • Power-generation utility emission rates reflective of local conditions

(Note that if complete input data have not been entered, when the View Results button is clicked an "Incomplete Input" message box is displayed that indicates which data must still be entered.)

To return to the input screen after viewing the results calculated by GSEModel, click the "Edit" item on the main menu near the top of the application window. Then click either of the three "Return to ..." items to go back to one of the input entry screens.

> ***IMPORTANT* - Other than exiting the program, this is the only way to navigate out of the Results screen!**

Printing Inputs and Results - To print both the input data and the tabulated emission reductions and cost-effectiveness results for the current scenario being evaluated, click the "Print" item on the main menu bar, then click the "Print Scenario" item on the drop-down menu. A two-page report is then printed on the current "default" printer selected from Windows. The first page shows a summary of the data inputs; results are displayed on the second page.

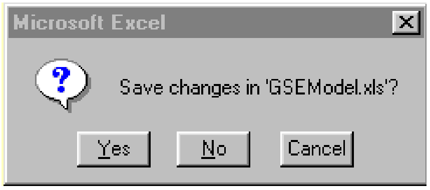
Saving and Loading Scenario Files - To make repeated use of the GSEModel tool quicker and easier, the application includes the capability to save a complete set of analysis inputs and re-use them later as a modifiable template for evaluating other GSE scenarios. (This avoids having to type in complete data from scratch for each analysis.) After inputting data for a specific analysis case, the information can be saved to a “scenario file” (indicated by a “.gse” file extension) by clicking “File” on the main menu and then clicking “Save Scenario.” A dialog box is then displayed, allowing the file to be saved to disk for later use. Click the arrow to the right of the “Save in” box to select the destination directory, then type a file name for the scenario to be saved in the “File name”box, using the .GSE suffix. (It is suggested that the “.gse” scenario files be saved to the same directory where the application program was stored, e.g., C:\GSEMODEL.)

Similarly, to load and re-use a saved scenario file, click “File” on the main menu, then click “Load Scenario.” Select the directory and file to be loaded into the application.

Exiting the Program - To exit the GSEModel application, click “File” on the main menu, then click “Exit GSEModel.” The application will then close and exit. Remember to save the current inputs in a scenario file as described above if you plan to re-use them later.

> ***IMPORTANT* - Do not close the GSEModel application using the Close Box in the upper right-hand corner of the application window such as the one shown.** ☒
>
> ***If this happens inadvertently, you may be prompted as shown below in Figure 1 to save changes to the GSEMODEL.XLS file.***

Figure 1



Microsoft Excel

Save changes in 'GSEModel.xls'?

> ***ANSWER “NO” TO THIS PROMPT, OR ELSE YOU MAY CORRUPT THE PROGRAM!***

Detailed Operating Instructions and Guidance

This section of the documentation provides step-by-step descriptions and guidance for operating and inputting data to the GSEModel application and understanding the calculated results.

Creating a Shortcut to Launch GSEModel - Prior to running the application for the first time, the user may want to create a shortcut to the application, enabling it to be launched directly from the Windows desktop with a single mouse click. To do so, perform the following steps:

- Open the Windows Explorer and locate the GSEMODEL.XLS file in the folder/directory it was installed into;

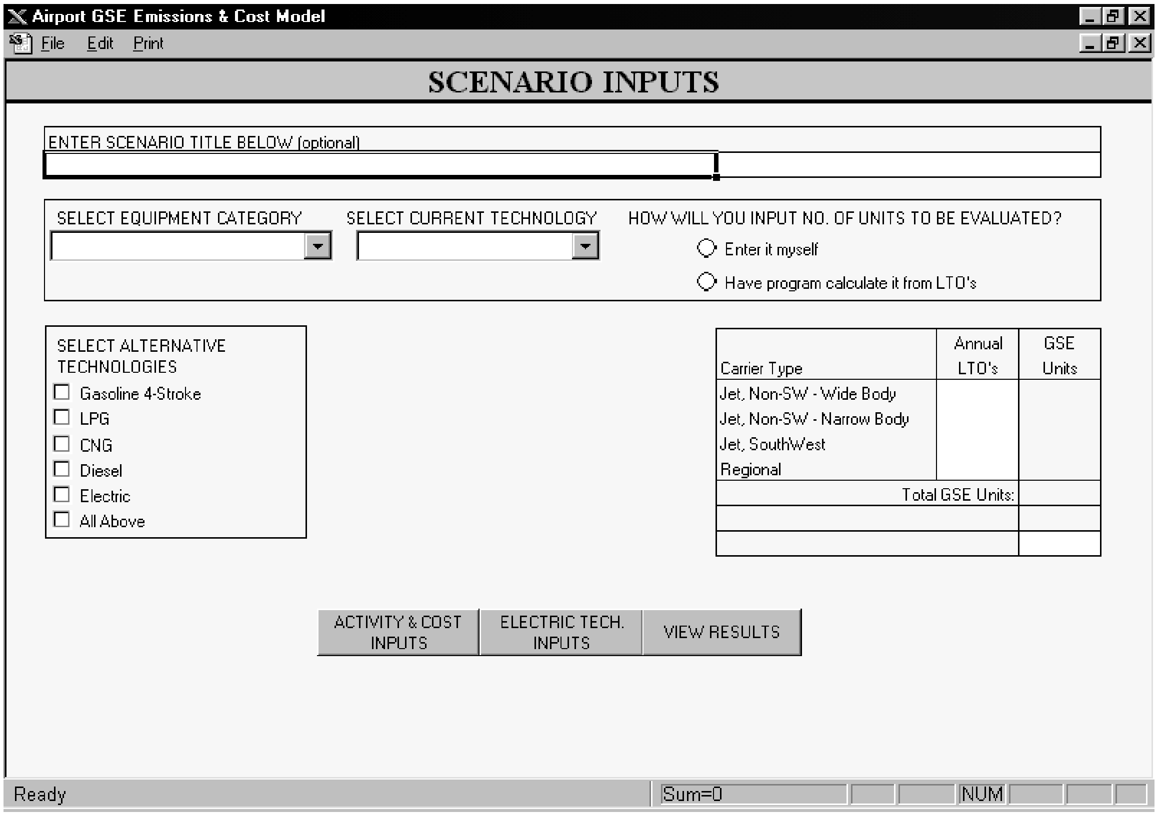
- Right-click the GSEMODEL.XLS file and click “Copy”on the pop-up menu;

- If necessary, size the Explorer window so that part of the desktop is visible, then right-click the mouse on any visible portion of the desktop and click “Paste Shortcut” from the pop-up menu.

Windows then places a shortcut to the application on the desktop called “Shortcut to GSEMODEL.XLS.” To rename the shortcut (e.g., to simply “GSEModel”), select the shortcut icon, right-click and select “Rename” from the pop-up menu. Type in the new name and hit the Enter key on the keyboard when finished.

Inputting Data - Scenario Inputs Screen - After being launched, the GSEModel program takes several seconds to load. When loading is finishing (denoted by a “Ready” indicator in the lower left corner of the application window), the user is placed at the first of three inputs screens, the Scenario screen, shown in Figure 2. The user can navigate from screen to screen using the buttons located toward the bottom of each input screen.

Figure 2
Scenario Inputs Screen



Carrier Type	Annual LTO's	GSE Units
Jet, Non-SW - Wide Body		
Jet, Non-SW - Narrow Body		
Jet, SouthWest		
Regional		
Total GSE Units:		

On the Scenario screen, basic information about the analysis case being evaluated are entered, including the GSE equipment category and the current and alternative emission control technologies being considered. White-colored areas indicate where user inputs are provided. Each of the inputs on this screen is discussed below.

Scenario Title (optional) - If desired, the user can enter a specific title for the scenario being evaluated.

Equipment Category - Using a drop-down list, accessed by clicking the down arrow to the right of this input box, one of 19 available GSE equipment categories must be selected for analysis. (As stated earlier, the GSEModel application is set up to analyze emission reductions and cost-effectiveness for one category at a time.) Table 2 lists the available GSE equipment categories.

Table 2 **GSE Equipment Categories**
Aircraft Pushback Tractor
Air Conditioning Unit
Air Start Unit
Baggage Tug
Belt Loader
Bobtail
Cargo Loader
Cart
Deicer
Forklift
Fuel Truck
Ground Power Unit
Lavatory Cart
Lavatory Truck
Lift
Maintenance Truck
Other GSE
Service Truck
Water Truck

Current Technology - A similar drop-down list feature is used to select the technology currently used in the GSE equipment being evaluated. The following choices are available:

- Gas-2 - Two-stroke gasoline engines;

- Gas-4 - Four-stroke gasoline engines;
- LPG - Liquid Petroleum gas-fueled engines;
- CNG - Compressed natural gas-fueled engines;
- Diesel - Diesel-designed and fueled engines; and
- Electric - Electrically powered equipment.

Note that for a given GSE equipment category, any one of these options can be selected. The GSEModel program does not include logic to identify "valid" choices for each individual equipment category. That responsibility is left up to the user.

Input Units Method/Number of Units - By clicking either of the two radio buttons, the user indicates which of two methods will be used to input the number of GSE units (for the selected category and current technology) to be evaluated:

1. Direct Entry - The user simply enters the number of units being considered in the cell below (e.g., 30 baggage tractors); or

2. Calculate from LTOs - If the number of units of a particular equipment category is unknown, annual LTO (landing and takeoff operation) information can be entered and the GSEModel program will estimate the number of units of the equipment type and current technology selected.

If option 2 is selected, annual LTO data for four commercial air carrier categories are required:[*]

- Wide-body jets from all carriers except Southwest Airlines;
- Narrow-body jets from all carriers except Southwest Airlines;
- Southwest Airlines jets; and
- Non-jet regional/commuter aircraft (e.g., turboprops).

Alternative Technologies - Using a group of check-boxes, the user can select alternative technology categories to be evaluated by the program as indicated. (Depending upon the current technology selected earlier, one of the alternative technology check-boxes may be disabled and shaded out.) The "All Above" check-box can be used to select or de-select all available technologies.

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[*] The GSE Information Series 1 (Basis for GSE Population Estimates) document also prepared under this EPA Work Assignment provides a detailed discussion of how GSE equipment unit counts can be derived from air carrier LTO data.

<u>Inputting Data - I-C Technology Activity & Cost Inputs Screen</u> - Figure 3 shows the layout of the I-C Technology Activity & Cost Inputs screen.

This screen is used to enter activity and cost data for the current and alternative technologies for the GSE equipment category selected earlier. (Information for all internal combustion (I-C) technologies is entered on this screen. Electric technology-specific data are entered on the next screen.) Each input area is discussed below.

Activity Inputs - Three “activity”-related data elements are entered in this table for both the current and alternative technologies being modeled:

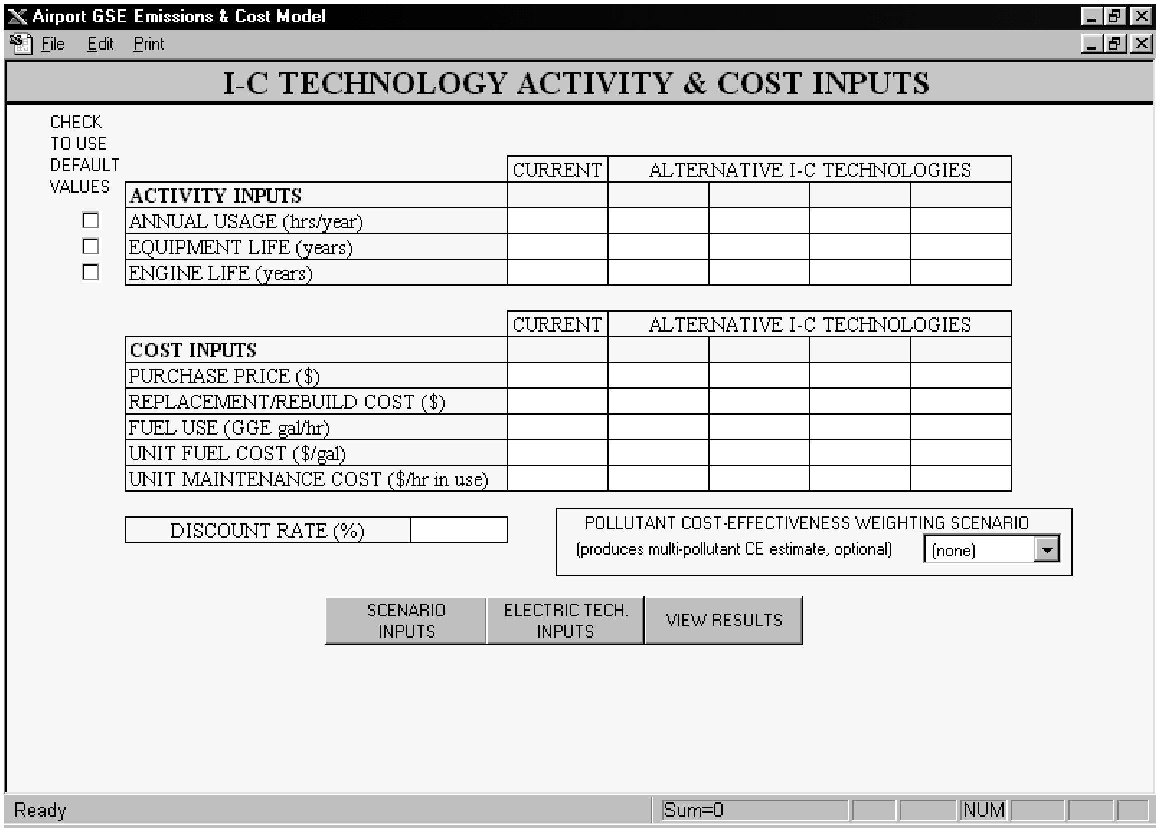
- Annual Usage - the number of hours per year that the equipment is operated (for I-C engines, this consists of the entire time the engine is on and running, including idling);

- Equipment Life - the expected useful life, in years, of the GSE equipment (typically 16 years); and

- Engine Life - the estimated interval, in years, before an engine replacement or rebuild is needed.

As Figure 3 shows, check-boxes at the left of each of these activity data inputs can be clicked to

Figure 3
I-C Technology Activity & Cost Inputs Screen



I-C TECHNOLOGY ACTIVITY & COST INPUTS

CHECK TO USE DEFAULT VALUES		CURRENT	ALTERNATIVE I-C TECHNOLOGIES			
	ACTIVITY INPUTS					
☐	ANNUAL USAGE (hrs/year)					
☐	EQUIPMENT LIFE (years)					
☐	ENGINE LIFE (years)					

	CURRENT	ALTERNATIVE I-C TECHNOLOGIES			
COST INPUTS					
PURCHASE PRICE ($)					
REPLACEMENT/REBUILD COST ($)					
FUEL USE (GGE gal/hr)					
UNIT FUEL COST ($/gal)					
UNIT MAINTENANCE COST ($/hr in use)					

DISCOUNT RATE (%)

POLLUTANT COST-EFFECTIVENESS WEIGHTING SCENARIO
(produces multi-pollutant CE estimate, optional) (none)

have the program supply default values for each element. However, the user is encouraged to utilize actual data for the specific airport being modeled, especially for the annual usage inputs.

Also note that depending upon which current and alternative technologies have been selected earlier, one or more of the columns in this table (and the Cost Inputs table discussed below) will be disabled and shaded out.[*]

Cost Inputs - A similarly displayed table is used to enter required cost information as follows:

- Purchase Price - the initial purchase cost of that equipment category and technology, in dollars;
- Replacement/Rebuild Cost - the cost of rebuilding or replacing the engine of the equipment category and technology being evaluated at <u>each</u> interval specified above in the Engine Life inputs, in dollars;
- Fuel Use - the estimated amount of fuel used for each specific technology, in Gasoline Gallon Equivalent (GGE) gallons <u>per hour of operation</u>;
- Unit Fuel Cost - the cost of each technology-specific fuel, in dollars per gallon; and
- Unit Maintenance Cost - the maintenance-related costs of each equipment/technology combination, in dollars per hour of equipment use.[**]

Reliable, <u>verified</u> data for these costs are not currently available. Therefore, no defaults have been set up within GSEModel for these inputs. The GSE Information Series documents[1][2][3][4][5][6] also compiled under this Work Assignment provide rough estimates for these inputs.

Discount Rate - Below these tables is a cell to enter the discount rate (in percent) to be used in the Net Present Value (NPV) cost calculations (discussed in detail later). A typical discount rate used in NPV analysis is 6%.

Pollutant Cost-Effectiveness Weighting Scenario (optional) - Finally, using a drop-down

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[*] This is normal. The GSEModel program uses logic that fixes the columns in these tables to specific technologies. Depending on which technology has been selected as the current technology and the alternative technologies chosen, the columns in these tables corresponding to non-selected technologies will be deactivated.

[**] Most maintenance cost data are reported in these units. If only annual costs are available for a number of GSE units, simply divide these costs by the product of the number of units and their annual usage level, i.e., Unit Maint. Cost ($/hr) = Annual Maint. Cost for Multiple GSE Units / [# Units x Usage (hrs/year)].

list, the user can optionally select a weighting scheme to calculate combined-pollutant cost-effectiveness in addition to the simple, individual pollutant cost-effectiveness estimates always produced by the program. For example, for ozone-related control-strategy analysis, planning agencies often calculate cost-effectiveness by combining HC, NOx, and CO reductions, where CO is discounted relative to the ozone-formation potential of HC and NOx.[*] In addition to ozone, default weighting schemes have been set up for PM_{10} and CO-only control strategy cost-effectiveness calculations. (To bypass this option, simply leave the "(none)" item selected in the drop-down list.)

<u>Inputting Data - Electric Technology Inputs Screen</u> - If the electrically powered GSE alternative technology was selected for evaluation in the Scenario Screen described earlier, additional electric technology-specific inputs must be entered on this screen, shown in Figure 4. The inputs required in this screen are defined below.

Activity Inputs - The activity-related data required for electric technology is similar but not identical to IC engine inputs. These input distinctions are as follows:

- Base Tech. Operation at Idle - the frequency at which the "base" or current technology engine being modeled operates at idle when turned on[**], in percent;

- Battery Life - the expected life of the battery as regularly charged and used to power electric GSE, in years.

The model provides default battery life estimates by GSE category if the check-box to the left of the table is clicked.

Cost Inputs - As with the activity data, electric GSE cost inputs required by the model are similar to their IC engine counterparts, with the following differences:

- Electric Use - the power consumption rate of the electric GSE equipment, in kilowatts per operating hour; and

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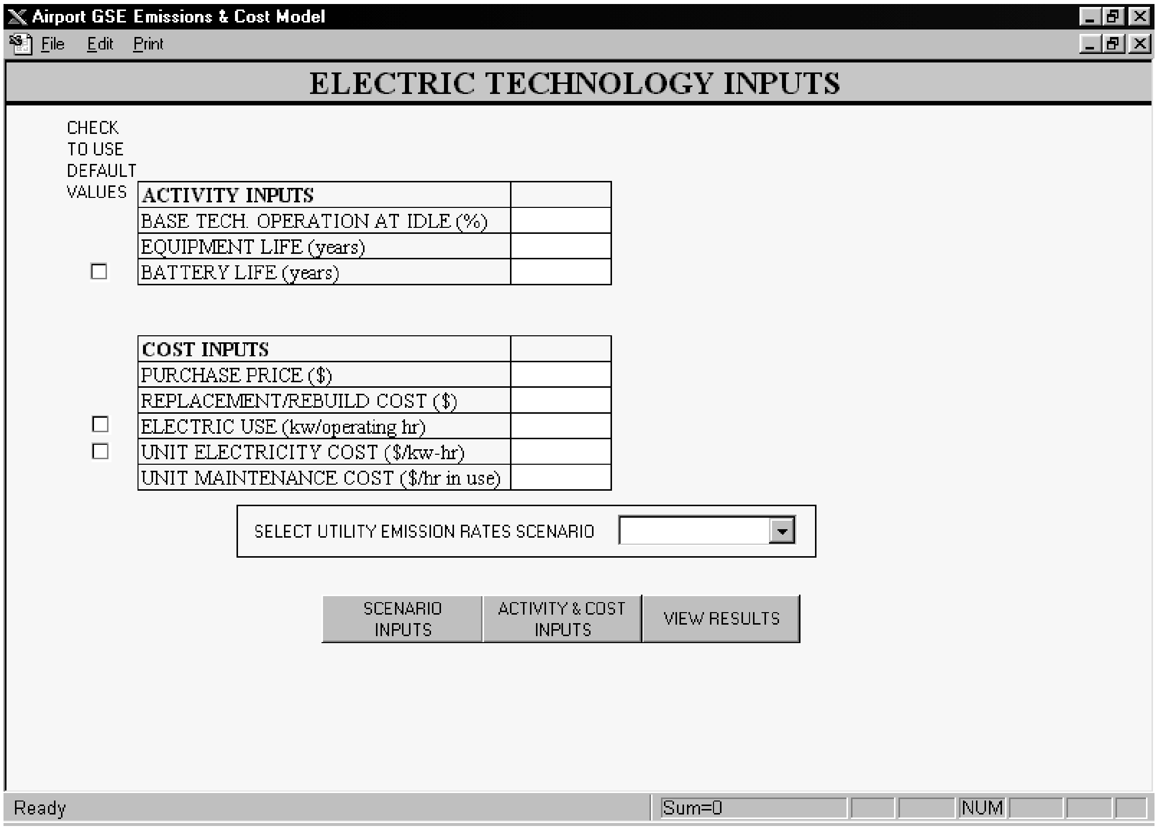
[*] The California Air Resources Board typically uses a HC-NOx-CO weighting scheme of 1-1-$^{1}/_{7}$, respectively to assess ozone-related control strategies for which multi-pollutant reductions are anticipated.

[**] This input is used by the model to account for the fact that many I-C engine-powered GSE are left on for prolonged periods and continue to idle without being used. Conversely, it assumes that electric GSE are shut off when not actually in use.

Figure 4
Electric Technology Inputs Screen



ELECTRIC TECHNOLOGY INPUTS

CHECK TO USE DEFAULT VALUES	ACTIVITY INPUTS	
	BASE TECH. OPERATION AT IDLE (%)	
	EQUIPMENT LIFE (years)	
☐	BATTERY LIFE (years)	

	COST INPUTS	
	PURCHASE PRICE ($)	
	REPLACEMENT/REBUILD COST ($)	
☐	ELECTRIC USE (kw/operating hr)	
☐	UNIT ELECTRICITY COST ($/kw-hr)	
	UNIT MAINTENANCE COST ($/hr in use)	

- Unit Electricity Cost - the energy rate charged by the local electric utility, in dollars per kilowatt-hour (airports are typically charged an industrial rate that is cheaper than residential rates).

The program contains default values for both of these inputs based on data contained in the GSE Information Series 4 - Electric GSE guidance cited earlier. That guidance also includes estimates for the other electric technology cost data required by the program for selected equipment categories.

Utility Emission Rates Scenario - Finally, using a drop-down list, the user must select one of three utility emission rate scenarios contained in the program. This input is used to account for the emissions generated at the utility power plant due to the incremental power demand that results from converting IC engine GSE to electric technology. Table 3 lists these scenarios and shows the utility emission rates assumed by the model.

Table 3
Electric Utility Emission Rate Scenarios and
Power Plant Emission Factors (g/hp-hr)

Scenario	HC	CO	NOx	PM
Minimum	0.008	0.035	0.080	0.004
Typical	0.037	0.109	0.403	0.023
Maximum	0.124	0.185	2.534	1.371

Once <u>all</u> of the inputs required in each of the screens described above are entered (or default values are selected), the GSEModel program automatically performs emission reductions and cost-effectiveness calculations. The "View Results" button located at the bottom of each of these screen can then be clicked to examine the results, or the "<u>P</u>rint" item on the main menu can be clicked to print them.

<u>Output Results - Emissions and Cost-Effectiveness Calculations</u> - This final sub-section of the GSEModel documentation briefly discusses how the emission reduction and cost calculations are performed and presents results from a sample calculation. The methodologies (and default data) used by the program are based entirely upon the GSE Information Series guidance that is summarized in the body of the report to which this documentation is appended.

Using equipment category-specific "average life" emission factors contained in that guidance multiplied by the annual usage inputs described in the preceding sub-sections, GSE emissions (in tons/day) are estimated for current and alternative technologies selected.

Emission reductions (from the current technology emission levels) are then computed on both an absolute (tons/day) and relative (%) basis.

Lifetime costs (based on the equipment useful life, not the engine replacement interval) are then forecasted for engine/battery replacement, operation (i.e., fuel or electricity use), and maintenance by combining the various cost inputs with the equipment usage inputs, and the initial capital cost.

A Net Present Value (NPV) calculation is then performed on these cash flows, using the input discount rate, to compute NPV life-cycle costs for each cost component (initial, replacement, operating and maintenance), and in total under each technology evaluated. The NPV methodology provides a basis to compare a series of uneven future cash flows for difference scenarios (i.e., GSE technologies as used in this application) on an equivalent present value basis, given an assumed discount rate.

Once the NPV costs are computed, <u>individual</u> pollutant cost-effectiveness ($/ton) is computed by dividing <u>incremental</u> NPV costs (alternative technology costs relative to the current technology) by incremental emission reductions for each alternative technology, where the emission reductions are also expressed on an NPV basis. If selected by the user, combined pollutant cost-effectiveness is similarly calculated by dividing incremental NPV costs by the summed weighted-pollutant reductions.

A sample GSEModel Results report showing these outputs is provided in Figure 5.

Figure 5
Sample GSEModel Results Report

GSE MODEL RESULTS

SCENARIO TITLE: Cost-Effectiveness Calculation Example (Baggage Tug)
EQUIPMENT CATEGORY: Baggage Tug
CURRENT TECHNOLOGY: Gas-4
NUMBER OF UNITS: 1

Emissions (tons/year)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	1.148	-	0.574	0.382	0.217	0.006
CO	57.648	-	36.030	36.030	0.686	0.019
NOx	0.699	-	0.525	0.525	1.842	0.068
PM	0.007	-	0.006	0.006	0.136	0.004

Emission Reductions (tons/year)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	n/a	-	0.57	0.77	0.93	1.14
CO	n/a	-	21.62	21.62	56.96	57.63
NOx	n/a	-	0.17	0.17	-1.14	0.63
PM	n/a	-	0.00	0.00	-0.13	0.00

Emission Reductions (%)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	n/a	-	50.0%	66.7%	81.1%	99.4%
CO	n/a	-	37.5%	37.5%	98.8%	100.0%
NOx	n/a	-	25.0%	25.0%	-163.3%	90.2%
PM	n/a	-	16.3%	16.3%	-1758.9%	46.5%

NPV Lifetime Costs ($)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
Purchase Cost	$17,000	-	$19,000	$21,000	$22,000	$30,000
Replacement Cost	$2,568	-	$2,568	$2,568	$2,568	$6,566
Fuel Cost	$59,481	-	$49,072	$65,058	$27,386	$5,576
Maintenance Cost	$47,089	-	$37,176	$37,176	$47,089	$15,614
Total Cost	$126,139	-	$107,816	$125,802	$99,044	$57,756

NPV Lifetime Emissions (tons)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	10.157	-	5.079	3.381	1.924	0.056
CO	510.265	-	318.916	318.916	6.076	0.164
NOx	6.190	-	4.643	4.643	16.302	0.606
PM	0.065	-	0.054	0.054	1.201	0.035
Weighted Total: Ozone	89.243		55.281	53.584	19.094	0.685

NPV Incremental Cost Savings ($)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
Purchase Cost	n/a	-	-$2,000	-$4,000	-$5,000	-$13,000
Replacement Cost	n/a	-	$0	$0	$0	-$3,997
Fuel Cost	n/a	-	$10,409	-$5,576	$32,095	$53,905
Maintenance Cost	n/a	-	$9,914	$9,914	$0	$31,475
Total Cost	n/a	-	$18,323	$337	$27,095	$68,383

NPV Emission Reductions (tons)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	n/a	-	5.079	6.776	8.233	10.101
CO	n/a	-	191.349	191.349	504.189	510.101
NOx	n/a	-	1.548	1.548	-10.112	5.584
PM	n/a	-	0.011	0.011	-1.136	0.030
Weighted Total: Ozone	n/a		33.962	35.659	70.149	88.557

Incremental Cost-Effectiveness ($/ton)	Current		Alternative Technologies			
	Gas-4		LPG	CNG	Diesel	Electric
HC	n/a	-	$3,608	$50	$3,291	$6,770
CO	n/a	-	$96	$2	$54	$134
NOx	n/a	-	$11,839	$218	-$2,680	$12,245
PM	n/a	-	$1,742,065	$32,057	-$23,842	$2,278,120
Weighted Total: Ozone	n/a		$540	$9	$386	$772

4. REFERENCES

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   B. "Estimating GSE Activity," Energy and Environmental Analysis, Inc., September 1998.

5. GSE Information Series 5, "Emissions Aftertreatment," Energy and Environmental Analysis, Inc., September 1998.

6. GSE Information Series 6, "Fixed Gate Support," Energy and Environmental Analysis, Inc., September 1998.